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technology on your time

Build This Cigar Box Guitar!
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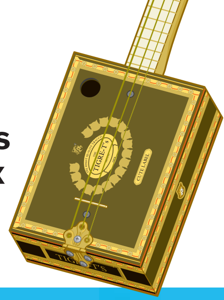

YOUR DESKTOP FACTORY

3D Manufacturing at Home

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21 PROJECTS YOU CAN DO

» PUSH-BUTTON SPEED GAME, PADDED SWORDS, MAGIC PHOTO CUBE, SNOW GUN & MORE

Bre Pettis & the MakerBot CupCake CNC 3D Printer
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BY DALE DOUGHERTY

Much More to Do

Five years in, MAKE is just getting started.

This issue marks the start of the sixth year of MAKE. It's been a wonderful five years, full of surprises and challenges. I'm grateful to each of you who support our efforts by subscribing or buying the magazine on the newsstand. We've gotten to know so many of you and your incredible work through makezine.com and Maker Faire. Five years have gone by very fast, and yet it feels like we're only just beginning to see the possibilities.

Making spans generations and inspires people of all ages. One of our great surprises is that MAKE appeals to kids and adults, and serves to bring them together around projects. Learning to make something is stimulating and satisfying, whether you prefer LPs or MP3s. I hope this new partnership thrives.

Makers go pro, and more pros think of themselves as makers. Makers are enthusiasts who are doing what they love, which is the definition of amateurs. But we're seeing some makers develop a following, and begin to go "pro." They're making kits, developing products, providing services, or marketing their expertise. This "grassroots innovation" deserves recognition as a valuable source of new product ideas. MakerBot Industries, the cover subject of our desktop manufacturing issue, is a good example of makers who developed a product that enables others to create new things. The maker spirit is gaining recognition in the workplace as a catalyst for design thinking. This is good news for the maker community, and remarkable in such a challenging economy. I hope our new Makers Market (makersmarket.com) will foster new opportunities for makers with new products or services to sell.

Even in a digital age, this magazine offers a unique hands-on experience. (And a complete set looks great on the shelf in your work area.) I'm proud of MAKE magazine and the editorial and creative teams who produce it. I am so appreciative of our readers who've told us how much this magazine means to them. Let's keep a good thing going.

Tinkering is getting a good name again in education. There is greater recognition that tinkering is a practical and productive way to learn almost anything and a viable alternative to textbook learning. It's a shift away from proving what you know to demonstrating what you can do. It's also a way of thinking with many levels of complexity. The most important thing in education is to engage the student both physically and mentally. Hands-on projects do just that, especially when students are given the ability to explore their own ideas, develop them, and then share them with others. I hope we can turn more students into creative makers.

DIY doesn't mean doing it by yourself. It's the paradox of DIY. A huge benefit of making things yourself is that you discover there are other people a lot like you. There are people who want to collaborate (in person or across the web), or those who just appreciate what you do and offer tips and encouragement. Getting together to make things and learn new skills at hackerspaces or maker labs is fun and productive. I hope to see the growth of local communities for makers in cities around the world.

Maker Faire comes to Detroit and New York City. Maker Faire will expand to two new cities this year, in addition to the Bay Area. We want to be part of the rebirth of Detroit. We're working with The Henry Ford Museum in Dearborn, Mich., which captures the heart and soul of American manufacturing. Detroit is also home to some of the best American music ever made.

And we're excited to organize a Maker Faire on the East Coast, at the New York Hall of Science. With a large number of makers, New York City offers a chance to explore creativity, innovation, and education on a world stage. I hope you'll get involved.

As you can see, there's a lot to look forward to in the years ahead. And a whole lot more we hope to do together.

Dale Dougherty is the editor and publisher of MAKE.


Let your geek shine.
Meet Steven Kennedy, SparkFun customer and Orchard Park High School teacher. In one of his classes, Steven helps his students discover the world of physical computing by encouraging them to explore all the facets of engineering – whether it is electrical, mechanical, or aeronautical. Using SparkFun products, Steven's class has created projects ranging from a homemade pick-and-place machine to a robotic arm.
Whether you're looking for tutorials to get started in electronics, or a way to inspire your students, the tools are out there. Create an environment of invention, and let your geek shine too.
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For more information about Steven's class and projects, please visit www.youtube.com/user/OPHSTech or www.opschools.org.

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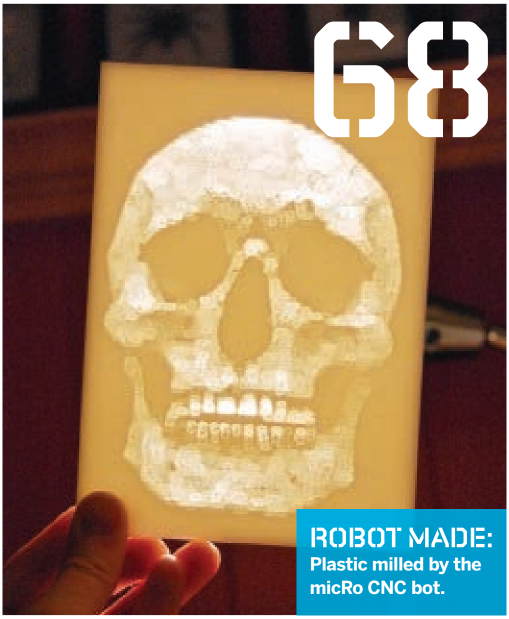
Make: DESKTOP MANUFACTURING



ROBOT MADE: Plastic milled by the micRo CNC bot.

ON THE COVER: MakerBot co-founder Bre Pettis in the Bot Cave, Brooklyn, N.Y., with the CupCake CNC. Photographed by Kate Lacey. Styled by Sam Murphy. Read about how MakerBot Industries started and get specs on the CupCake on page 46.

Columns

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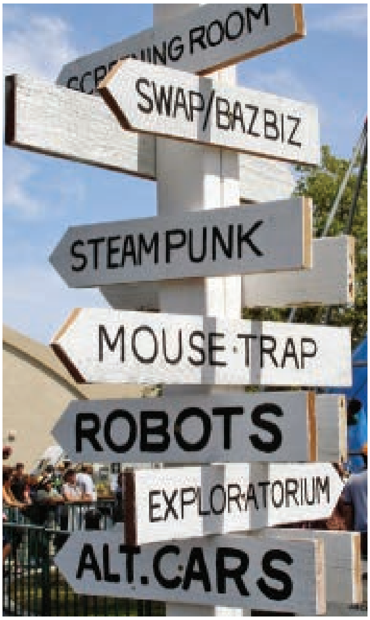

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- and so much more!

Maker Faire Bay Area
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San Mateo, California

Maker Faire Detroit
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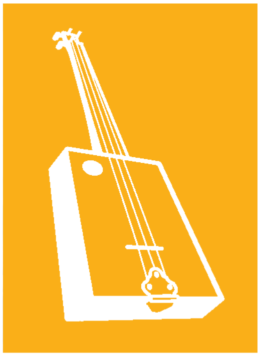
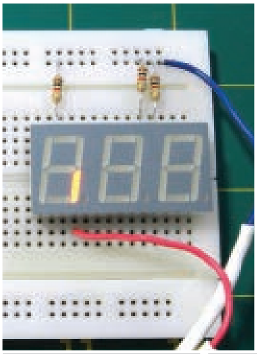
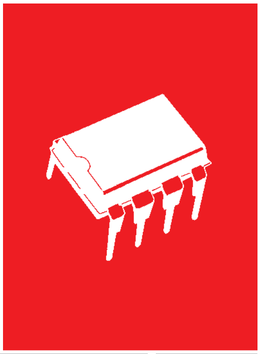
Make: Projects







"Without our ShopBot and the great community of other ShopBotters, we would have never made it this far. Thanks to ShopBot and my fellow ShopBotters for helping us to live our dream of creating new and exciting designs."
Angus Hines, Hines Design Labs
www.AngusHines.com

Angus Hines' life as a Maker began at the age of two when he took his first toy apart to see what made it work. From that point on, if it had screws or could be taken apart and dissected, nothing was safe. He was bound and determined to see what made things work and find ways to make them work better.

After he retired from his career as a project manager and spent some time cruising the Chesapeake Bay, Angus began to get bored and restless. He turned to his first love of creating new things and purchased a laser engraver. Angus started Classic Marine Co. and began making instrument panels, indestructible LEDs and other marine Items, but, as business grew, he decided he needed a larger, more versatile platform. Angus purchased a ShopBot and expanded into larger design projects like furniture, small buildings and larger marine items. Not content to make things that already exist, he started another company, Hines Design Labs, and has now ventured into prototyping, design assistance and helping people take their ideas from a napkin sketch to a finished product. Angus' love of making has taken his company from a small marine manufacturing facility to a full-blown design prototype shop, and his ShopBot helped make it all possible.

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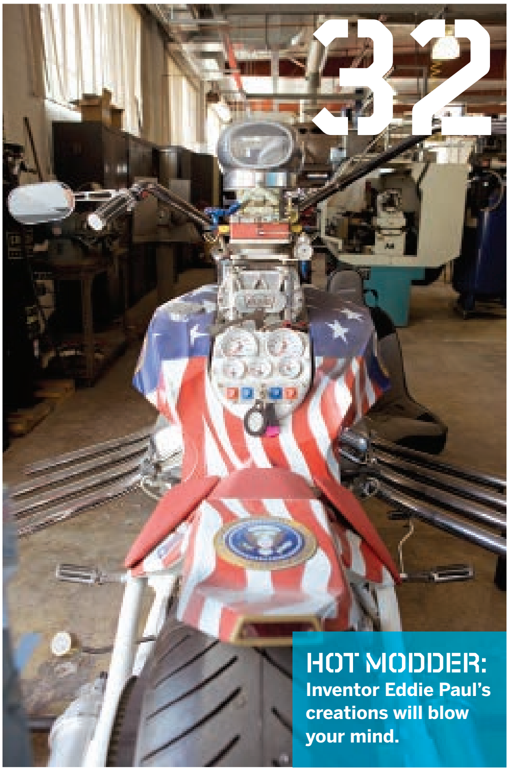
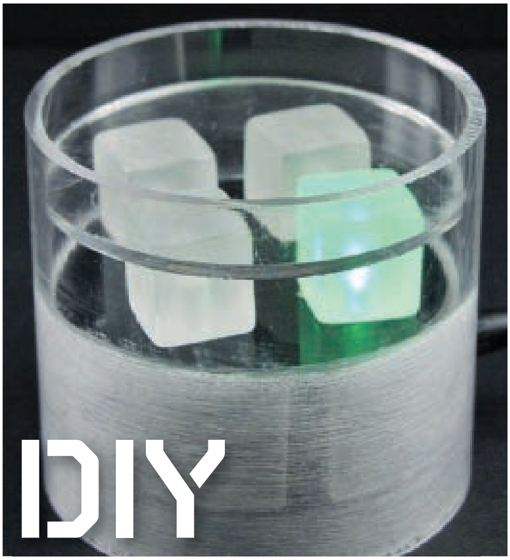
Maker



HOT MODDER: Inventor Eddie Paul's creations will blow your mind.

READ ME: Always check the URL associated with a project before you get started. There may be important updates or corrections.



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"As we benefit from the inventions of others, we should be glad to share our own ... freely and gladly."
—*Benjamin Franklin*

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Contributors

Ken Murphy (*DIY Time-lapse Video*) is a musician, programmer, artist, and tinkerer living in San Francisco. He started programming at age 9, but then took "a long hiatus and focused mainly on playing music until 25, when I reconnected with my inner nerd." By day, he helps keep the website for his local public broadcasting station humming along. Ken is also the creator of Blinkybugs, and he's currently working on a children's comic book and kit featuring these simple little electronic insects. When he's not working on Blinkybugs or his time-lapse project (murphlab.com/hsky), he likes backpacking, winter camping, and motorcycle rides along the California coast.

Laura Cochrane (MAKE's editorial assistant) is a Northern California native who enjoys wordplay. In college, she was able to write an A+ paper on the Greek philosophers Heraclitus and Parmenides, even though her head almost exploded. She respects creativity and genuine enthusiasm, and loves working with the MAKE and CRAFT crew because there is an endless supply of both. She lives with a brother-and-sister pair of cats named Cotswold and Trudy. When she's not hard at work fact-checking stories about amazing and accomplished makers, she dabbles in Andean panpipes, yoga, biking, photography, blowing bubbles, and knitting.

Brooklyn photographer **Kate Lacey** (cover photography) just remodeled her apartment, and all of a sudden she would love to have you over for dinner. Kate was thrilled to shoot this month's cover, the MakerBot CupCake CNC 3D printer, and she can't wait to use one to print out a sweet new Canon EOS 5D Mark II. Her book, *Show Dogs: A Photographic Field Guide*, is coming this fall from Evil Twin Publications/DAP.

Jeremy Kerfs (*DIY Scratch Programming*) is a high school sophomore living in the San Francisco Bay Area. He started programming with Lego NXT and BASIC and moved to Python and Java for creating video games, where he makes his own graphics and sounds as well. When not hacking, he likes juggling, and he hopes one day to merge his love of robotics with the aforementioned juggling. His science fair project takes up vast amounts of his time, but he also enjoys running track and cross-country.

Wendy Tremayne (*DIY Bow Drill*) is an event producer, conceptual artist, builder, and teacher. She founded Swap-O-Rama-Rama (swaporamarama.org), a now international event that's a hybrid of clothing swap and skill-sharing, in an effort to transform consumers into makers. She frequently can be found giving presentations on the subject "The Maker Is the Revolutionary." Wendy writes regular features for CRAFT (craftzine.com) about innovators of reuse and natural materials. She lives off-grid in Truth or Consequences, N.M., where she develops sustainable building techniques. Check her out online at blog.holyscraphotsprings.com and gaiatreehouse.com.

Louis M. Brill aka "Louie Lights" and **Steve Boverie** aka "Dr. Glowire" (*Electroluminescent Wire Primer*) are co-founders of Light 'N Wire Productions. Dr. Glowire (pictured) has designed and built a multitude of maverick and miscellaneous EL wire projects for costumes, props, and Burning Man theme camps. Known for his deft technique with a soldering iron and intuitive grasp of building custom devices, he's created many an electronic gizmo. Louie Lights began his quest for an intimate knowledge of light in New York City's SoHo district in the early 1970s. He has co-designed many LED and lightwire devices for Burning Man events, and operates *The Theater of Performing Lights*.

BY SAUL GRIFFITH

Mad for 3D CAD

I love the third dimension. I'm glad I'm not flat. I love figuring out how to pack the most luggage into the smallest trunk, and I love optimizing the stacking of the dishwasher to fit the most plates and glasses. It should come as no surprise to you that I love — nay, I'm addicted to — 3D CAD programs.

My current large-scale project is to design and build the things I need to make my lifestyle as low in energy use as possible, while improving or retaining my quality of life.

Yes, I'm doing it for environmental reasons: we are heading toward disastrous climate change, and we need to make huge changes to the way we live. More than half the problem is figuring out how to live well with less energy. There are innumerable things to do in this domain — efficient devices and retrofits to invent — and if all makers out there take up a similar call, the world has a shot at survival.

How does this relate to my love of CAD? Well,right now I'm building a hybrid human-electric, tilt-steering, front-loading tricycle, code-named Flying Nun.

Design projects of this kind hugely benefit from 3D CAD programs: doing a lot of the prototyping work in virtual space prevents wasting material resources and energy in the development stage. I love the parametric design engines that let me push the assemblies of components around to make sure the dynamics of the bike and the quality of the ride are solved for, before I ever cut metal.

I also find 3D CAD to be the ultimate video game. For me, it's like the best possible combination of *Tetris*, jigsaw puzzles, sudoku, and *Grand Theft Auto*. The meditation of spinning the objects in 3D until you have the pieces just right is one of the most pleasurable activities I can think of. It takes me straight to that place of "flow" that Mihaly Csikszentmihalyi talks about.

I've used pretty much every CAD package, from SolidWorks, to Autodesk, to Pro/E, to Rhino, to SketchUp, to Alibre. They're all powerful and useful for different purposes. Occasionally I've resorted to writing my own CAD programs when the existing set couldn't do the job.

One great thing about 3D CAD today is that there are more and more CAD models in online libraries, so you can get many of the pieces you need without having to draw them yourself. All of the nuts and bolts in my trike came straight from McMaster Carr's 3D model drawings at mcmaster.com. I was also able to build upon other peoples' models of various bike components that they had posted online.

Another great thing is how well 3D CAD plays with the CAM (computer-aided machining) technologies that have grown up and evolved with CAD. Now that I've finished the design of my trike, it's only a matter of days to have all the components made and ready for assembly into the final product. After I farm out the CAM to various skilled fabricators, every gleaming piece of machined aluminum and welded steel that returns is a thrill.

It takes a village to build a prototype. I could do it all myself, but I've learned that for every fabrication process out there, there's someone who does it far better than I do. I may know how to make a strong weld, but I venerate those people who can make a perfect bead every time. I know how to use a Bridgeport mill, but love working with people who mesh years of hands-on machining experience with the new digital, hands-off CNC. There's still art there; it's just different now.

Throughout this project, though, I've been lamenting one thing. I've become lazy with these amazing new 3D design tools. I can't even remember what a title block or correctly dimensioned drawing looks like. My high school taught a lot of engineering trade skills, and as a 16-year-old I could do fully specified technical drawings by hand, appropriate for any machinist to build. We laboriously drew sheet metal patterns from first principles. Everything was done in 2D. Now I just make ten drawings with lots of redundancy instead, and liberally use the "auto-dimension" function.

I remember the smudged pencil erasings, the T squares and isometric circle templates. I don't miss them, but I lament the passing of their arcane beauty. I'm constantly reminded that having constraints is good for design, so I wonder whether I don't have enough constraints with 3D design tools. Not that it stops me from yearning for every new release of the latest video game. Ahem, CAD program.

Saul Griffith is a new father and entrepreneur. otherlab.com


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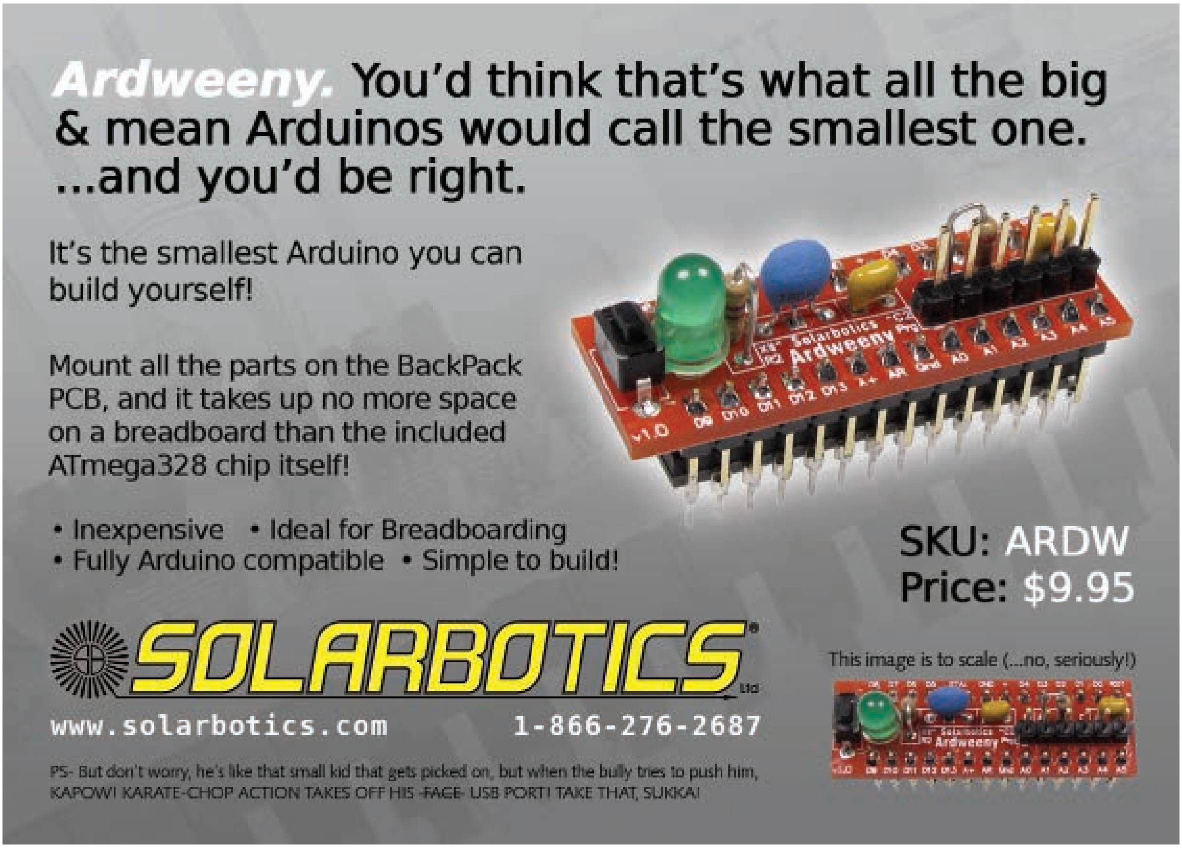
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BY CORY DOCTOROW

Who You Calling Unoriginal?

I don't know if you've noticed it, but holy awesome, there is a lot of *stuff* lying around. If you want some high-density memory, you can just go get it off the shelf — no need to shut yourself up in the basement for a year winding cores.

Componentized pieces like Arduino boards are likewise wonderfully convenient, getting a lot of the finicky stuff out of the way so that you can focus on creating. We've got highly polished text editors, web servers, operating systems; whole libraries of preconfigured virtual machines; mountains of cheap electronic toys to raid for parts.

The proliferation of stuff isn't without its problems (there's a patch of plastic garbage bigger than Texas floating in the middle of the Pacific Ocean), but there's a lot of good news for makers in the stuff explosion.

For starters, just consider the opportunities that arise from standardized packaging ("To make your cantenna, first drill a hole in the cholesterol count on the back of the Pringles can; then puncture the Pringles mascot's left eye, nose, and left lapel.")

Having a lot of stuff lying around opens the door for a different kind of innovation than was characteristic of previous generations. You can buy a whole, fully assembled radio and innovate by changing its firmware so that it does something the inventor never considered. You can innovate by developing Chumby widgets, or by modifying standardized knitting patterns to make them more mathematically interesting.

You can even innovate by doing less (as Brian Eno's aphorism goes, "Not doing the thing that nobody had ever thought of not doing.") Think of the iPod, which succeeded in part by having fewer features and doing less than the confusing, cluttered first-wave MP3 players that preceded it.

Or you can innovate by finding a way to overcome social problems that prevented a technical fix. Cipla, an Indian pharmaceutical company, took advantage of India's compulsory license on anti-AIDS drugs (a compulsory license requires pharma companies to sell their drugs to all comers at a set fee) in order to create an anti-AIDS cocktail that combined drugs from rival manufacturers. Before Cipla's innovation, people living with AIDS had to take these pills separately, which is error-prone and difficult (especially for kids). Because of Cipla's legal innovation, they were able to technically innovate and produce an AIDS pill that saves lives.

There's a strain of thinking that says it's *cheating* to innovate by remixing or reconfiguring other people's existing inventions.

And yet ... there's a strain of thinking that says it's somehow cheating to innovate by remixing or reconfiguring other people's existing inventions — that it's not really yours unless you design it from the ground up. But everything was invented once — wheels, pencils, math, light bulbs. It's literally impossible to create without standing on the shoulders of giants (this sentence was created with raw material provided by Mr. Isaac Newton, whose contribution is gratefully acknowledged herein).

There's nothing wrong with etching your own circuit boards instead of using an Arduino if that's what floats your boat. There's nothing wrong with inventing exciting new compounds instead of mixing up stuff from a chem supply house if it makes you happy.

But there's no virtue in eschewing existing tools simply to be more "original." You'd fire an accountant who announced that he couldn't do your taxes until he finished reinventing double-entry bookkeeping. You'd get out of a taxi whose driver was testing out octagonal wheels just to be different from the pack.

Great ideas may involve reinventing the wheel, but they may not. If you've got a wonderful idea that you can try out more quickly with off-the-shelf parts, give your imagination its due and let it get right to the good part, without having to boringly invent stuff that already exists.

Cory Doctorow's latest novel is *Makers* (Tor Books U.S., HarperVoyager U.K.). He lives in London and co-edits the website Boing Boing.

TALES FROM MAKE: ONLINE | BY GARETH BRANWYN

Get Your DIY On(line)

If you're an avid reader of MAKE and can't wait for the next issue to arrive, don't! Get thee to Make: Online (makezine.com) and CRAFT (craftzine.com). They're two of the most trafficked websites for all things DIY, from making robots to baking cookies, from citizen science in your basement to soft circuit sewing in your attic. At both sites you'll find tons of original content: weekly projects, how-to videos, regular columns, guest authors, fun contests with serious prizes, and plenty more. Here's a sampling of recent highlights.

M: How-To: Make a Star Trek Bluetooth Communicator Guest contributor Diana Eng (*Project Runway, Fashion Geek*) shows you how to turn a classic *Star Trek* Communicator toy into a Bluetooth device that pairs with your cellphone to make and receive calls. makezine.com/go/trekbluetooth

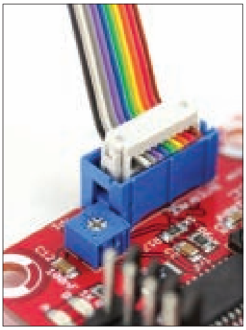
M: MAKE Presents: The Inductor In the latest installment of Collin Cunningham's infectiously quirky, highly informative videos, he examines a deceptively simple and often overlooked electronic component, the inductor, and the electromagnetic forces behind it. makezine.com/go/inductor

M: Make: Projects — Bottle Cutting Make: Online author Sean Ragan shows you how to cut bottles — to use as drinking glasses, flower vases, candleholders, whatever — with a glass cutting wheel and a blowtorch. makezine.com/go/bottlecut

M: MakerBot CupCake CNC Build In this ongoing series, Marc de Vinck meticulously documents his CupCake CNC kit build, from excitedly plucking the box from his doorstep to putting it all together to creating 3D objects with it (see page 46 for related story). makezine.com/go/cupcakecnc

M: Maker Events Calendar Did you know Make: Online has an updated calendar of maker-friendly events, hackerspace meetups, Dorkbots, craft fairs, and all sorts of DIY gathering goodness? Check it out, and add your own! makezine.com/events

M: Make: Newsletter Our free newsletter is a great way to keep up with goings-on at Maker Media, take advantage of special offers and Maker Shed deals, and get original content, such as Gareth Branwyn's new Maker's Dictionary column and Quick n' Dirty Projects, projects you can do in a few minutes. makezine.com/newsletter/subscribe



M: CRAFT: All New and Swanky Our sister site CRAFT (craftzine.com) has a fresh new look and feel! At the heart of CRAFT are great projects with clear instructions and helpful photos, written by some of the most respected names in crafting, as well as by everyday crafters. The site covers the gamut, from knitting and crochet to cooking, home décor, crafts for kids, pet projects, sewing, photography, paper crafts, electronic arts, and more. And now it all comes in a lovely new wrapper!

M: How-To: Sew a Ruffled Scarf CRAFT author Brookelynn Morris shows you how to create a warm and stylish ruffled scarf out of an old sweater. Part of CRAFT's "Me, My Scarf, and I" contest. craftzine.com/go/ruffledscarf

READER INPUT

Love of lashing, kids who solder, hope, and Scout skills.

Let me come straight to the point. While my 10-year-old daughter and I love every issue of your fine periodical, Volume 20 ("Try This At Home!") is spectacular. The theme is spot on, and the article on lashing by Gever Tulley is, without question, one of the most incredibly useful, approachable, and entertaining that I have come across.

The kid and I are always fascinated by at least a couple of things that your tome presents, and while we look forward to each issue, we are not highly technical people. We bought the Blinkybugs and had marvelous success. We bought the pocket theremin and had far less (read: no) success. Some of the articles and projects are simply above our current level of Geekwareness. The article on lashing simply made our week. I believe we have a fully lashed fort on the agenda for the weekend.

Regards to your team, and many thanks for the continued high-quality publication. We look forward to many years more.

—Rustin Sparks, Norman, Okla.

Ahem. While the general population may have forgotten about lashing, it is a required skill for Boy Scouts to achieve the rank of First Class. And they are required to demonstrate its use. The most common one of which is the tripod shown in your article.

—Roland B. Roberts, Ph.D., Brooklyn, N.Y.

EDITOR'S NOTE: Good point, Roland. Here's hoping it becomes a requirement in lots of other clubs and schools as well..

My son Isaac (aka Kidrocket) and I are delighted to be runners-up in the Teach Your Family to Solder challenge [Make: Online, "Summer MAKEcations"]. I'm particularly grateful to MAKE for prompting me to trust Isaac with a soldering iron. It was a great experience for both of us.

Thanks again, so much! Isaac and I are big MAKE fans. Watching MAKE podcasts on my iPhone is one of the ways we chill out together. Y'all are doing a Great Thing with that magazine.

—Thomas Beckett, Hendersonville, N.C.

I address this to all of those behind your marvelous magazine. There is hope. Hope for an inventive culture, for a sense that solutions are more important than problems. For statements of excellence (Adam Savage mentions this in his Welcome to Volume 20). The truly valuable human capability to create something new from what others have discarded.

I was blessed to grow up in just such a home. Today, my father's collection of items from projects over the past 50 years is in the basement of his home. Ironically, he is unable to enjoy the pleasures described in this issue, of discovery and meditative creation. It has been hard. But the joy lives on in my shop, at my computer, and in my son's skills both inherited and learned.

MAKE magazine represents the core of what makes us human. The willingness, enthusiasm, and pure joy of discovery, pursuit, and execution of whatever is next. Best of luck!

—Peter Blacksberg, Wayne, N.J.

P.S. Oh yes, I built a panoramic camera head in 1972 — just a bit ahead of the current pano craze. You can see some of my panoramic photography at flickr.com/photos/peteblac/sets.

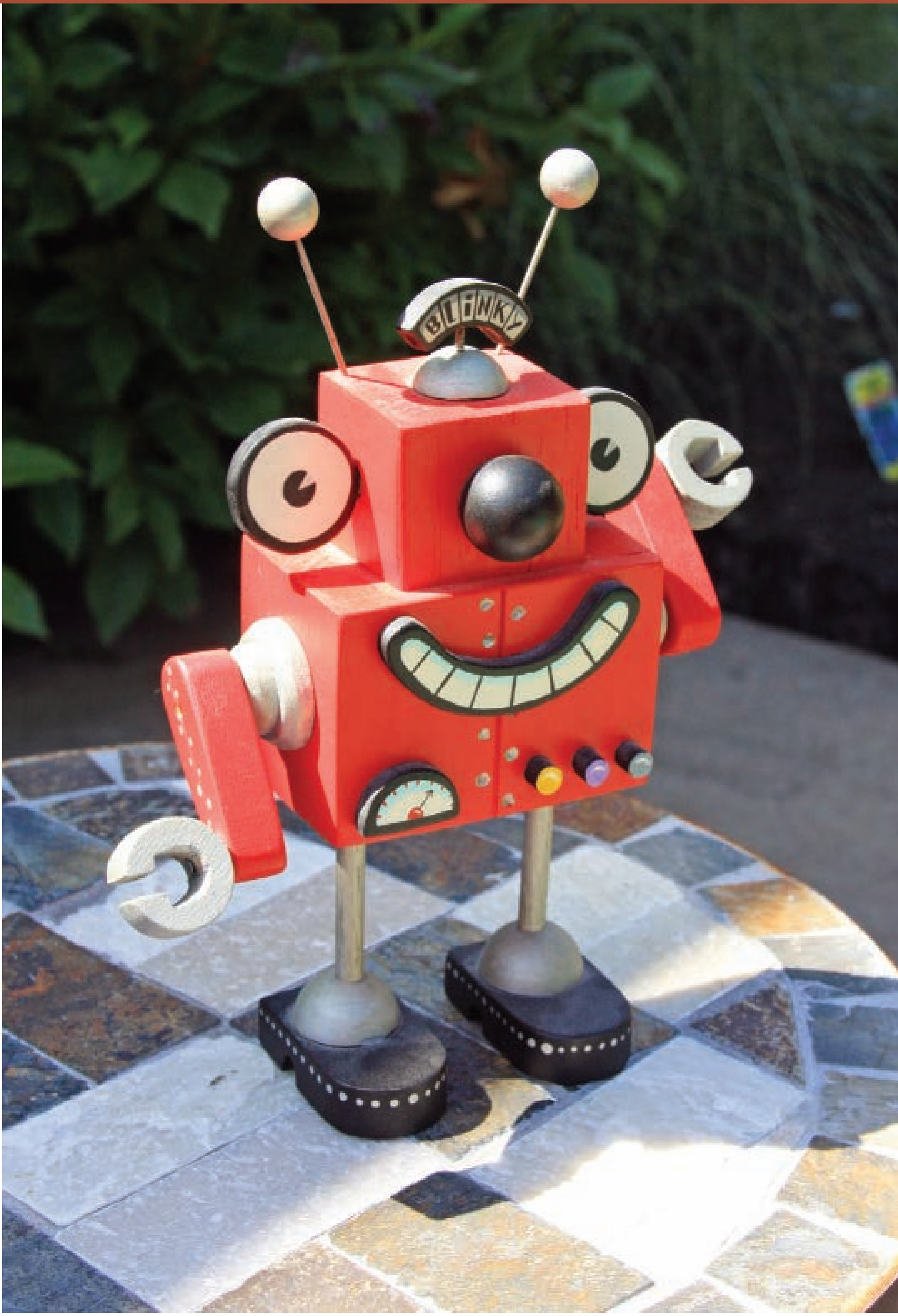
MAKE AMENDS

In the Toolbox section of Volume 20, the Topobo 50- and 100-piece sets are universally available at $149 and $249, respectively, which is half the price they used to be. Therefore the MAKE promo code is no longer necessary or active.

Upon examining the bus in "Bus Tag," which ran in Volume 19, on page 24, sharp-eyed reader Heather R. noticed that the vehicle is covered in a combination of both knit and crocheted yarn.

MADEONEARTH

Report from the world of backyard technology



Photography by Mike Adair

Cranked-Up Creativity

Mike Adair's wife reports that he sleepwalks more when he's in the middle of designing a toy. Adair, a 44-year-old artist from Overland Park, Kan., works at Hallmark. In his spare time, he builds brightly colored wooden crank toys in his basement workshop.

Most of his toys employ a hand crank that powers pulley wheels that create animation. The first crank toy he made, "The Debate," depicts the visceral nature of human disagreement with humor and elegance.

The busts of two men face each other; the one smoking a pipe nods his head slowly, while the other, with a cigarette, shakes his head more vigorously. Using different sizes and shapes of pulley wheels and arm lengths, Adair can generate multiple speeds of action using a single crank.

Growing up in Southern California, Adair loved Disneyland's animatronic attractions, counting America Sings and Country Bear Jamboree among his favorites: "Great examples of animatronic genius!" His family made a pilgrimage to the park every other year, and his parents raised money for the visits by participating in neighborhood craft shows.

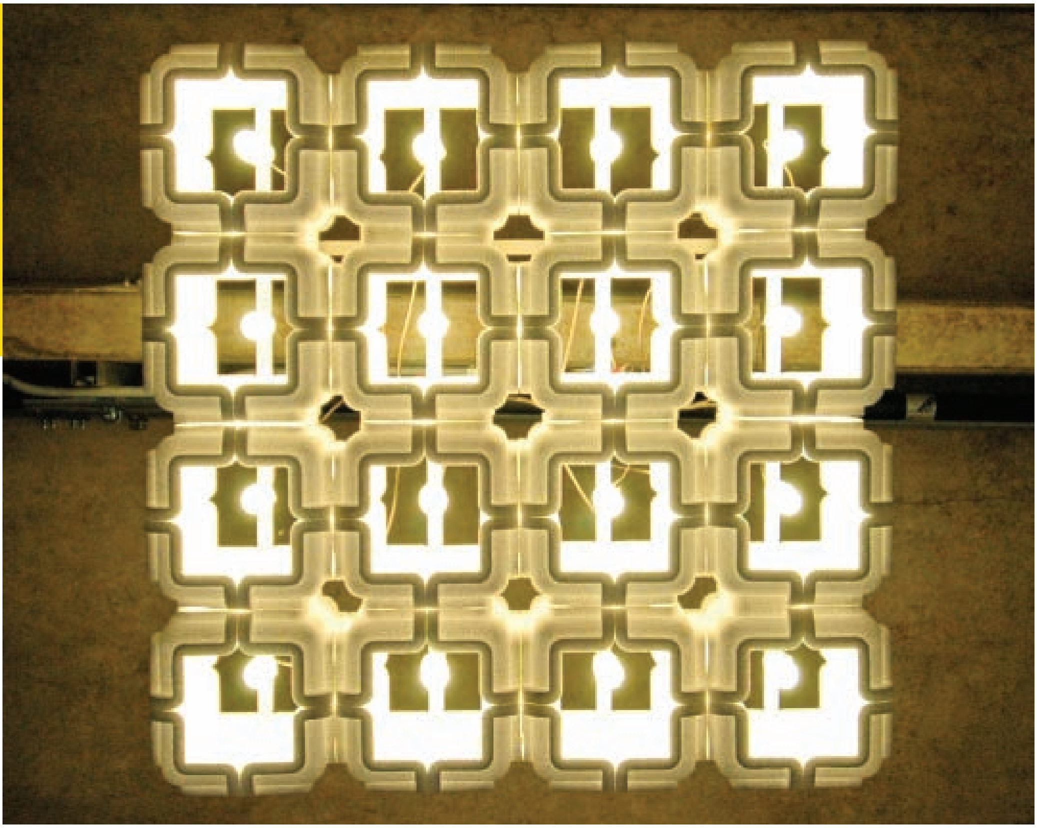
"They worked all year making things to sell," Adair remembers. "My dad cut out wood shapes and my mom did tole painting." With his crafty parents and fascination with animatronics, Adair's artistic inclinations were fed from a young age. As an adult, he visited London's Cabaret Mechanical Theatre, which inspired him to begin building crank-animated toys.

His approach to coming up with toy ideas varies; he's found it easiest to begin with the mechanics and build the concept afterward, but he's learning to work both ways. "As my mental mechanism library increases, I'm able to come at it from the concept side and find the mechanism to carry it out," he says.

In addition to building toys, Adair draws a comic for *Boys' Life* magazine and hopes to make a pop-up book. For his next crank toy, he's finishing a zombie cow tromping through a graveyard, called "Night of the Living Cud." When the cow opens its decaying mouth, a canned "moo" will escape.

—Laura Cochrane

Crank Animations in Action: mikeadair.com/Toys.htm



Bright Idea

The chandelier that **Eric Lawrence** built from the molded styrofoam his new Apple computer came in looks like barracks that Frank Lloyd Wright would have designed for the Imperial Stormtroopers in *Star Wars*, he explains. He's right.

Lawrence, 42, a web designer and former art student at the University of Texas, Austin, made the first Styrolight a few years ago. He'd just bought a new laptop, had all this styrofoam packaging lying around, and owed his nephew a Christmas present. He did the math.

"I like the way the foam diffuses light," Lawrence says. "It's keeping it out of the landfill, and I just like the shape."

More lights followed. He tested different glues (settling on a hot glue gun) to connect the white blocks of foam and play with new shapes. He joined these to homemade aluminum frames of used bar and angle stock using two-part epoxy.

He bought all kinds of compact fluorescent light bulbs in search of the right color and brightness. LEDs weren't simple and their color wasn't as nice as with CFs. Finally, he found some 5-watt, dimmable fluorescent bulbs that emitted the perfect glow and burned as brightly as 20-watt incandescents, yet didn't get dangerously hot.

"I've had [the 5-watt bulbs] on for 24 hours and can go grab a bulb in my hand," he says.

In May 2009, Lawrence entered a 16-bulb, 35"×35" Styrolight into the Austin Design Within Reach showroom's M+D+F furniture competition. When he won the sustainability prize, he took home a gift card, lots of attention, and endless bragging rights.

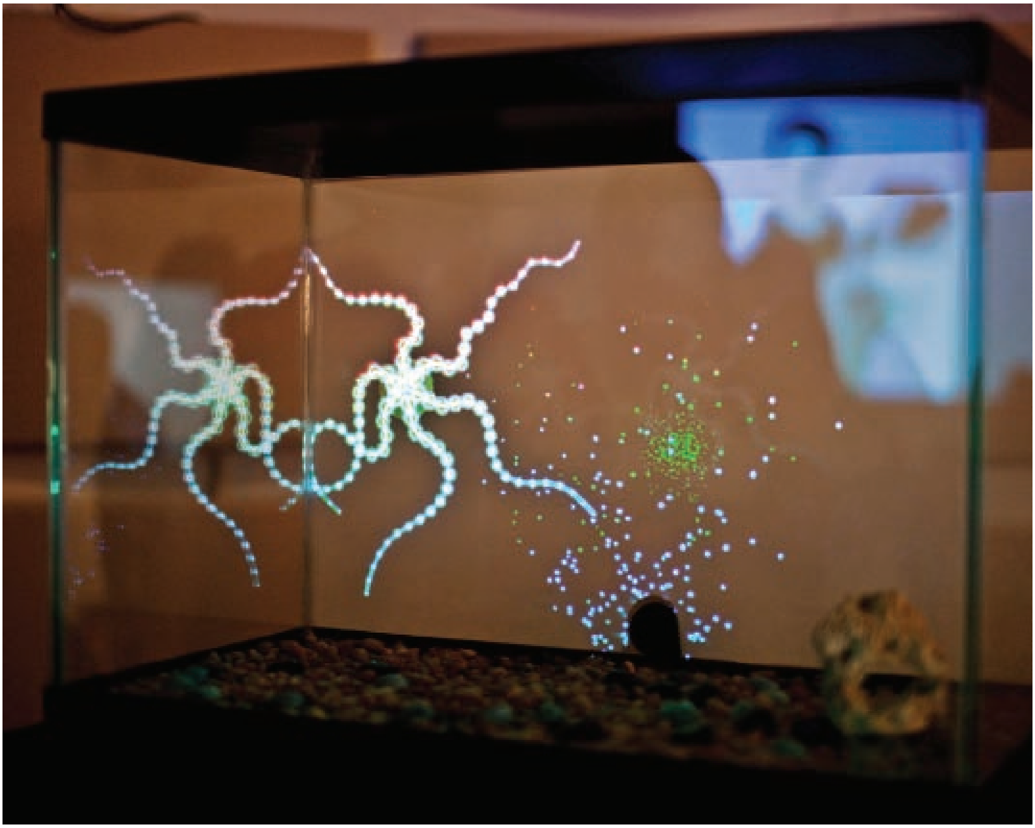
More commissions are coming his way, but he's got a problem. "Unfortunately, Apple has quit using styrofoam, so my free source of materials no longer exists. I have enough left to build one big one."

Be on the lookout for his next bright idea.

—Megan Mansell Williams

Foam Chandeliers: styrolight.com

Photograph by Eric Lawrence



Photograph by Rob Ryan

Emotional Aquatics

Inspired by Argentine writer Julio Cortázar's short story of a man's emotional obsession with aquarium life, *Axolotl* is about more than just an algorithmically enhanced animation displaying life-like traits from a fish tank. It's also about the responses it gets.

NYU Interactive Telecommunications Program (ITP) grad student **Eyal Ohana**, 35, came up with the idea for *Axolotl* while brainstorming ways to portray life — and instigate reaction — through motion and form. Classmate **Filippo Vanucci**, 28, joined forces for its physical and interactive implementation. The result is a 3D audiovisual display attracting onlookers with a digitized squid-like creature that responds to facial recognition by simulating a sense of interaction and involvement.

To create *Axolotl*'s creature, Ohana and Vanucci utilized the open source programming language Processing 1.0. Each of the creature's movements, such as undulating and contracting, are subject to physical forces like gravity and friction, but are also modified with unpredicted values. This generates non-repetitive, fluid motions similar to swimming, giving it a 3D appearance. "We're still waiting for the creature to surprise us and do something really stupid we didn't teach it," says Ohana.

The creature is projected onto a fish tank from behind while an attached camera captures faces, streaming them into the computer where OpenCV-based software detects each face and its position.

"Metaphorically speaking," says Ohana, "our creature can see." It then reacts in one of two ways: shy but playfully curious, or totally terrified — a shrinking retreat that viewers seem to favor. Sound texture correlating to the creature's movements adds ambiance. It was most recently shown at Brooklyn's MediaLounge festival in June 2009.

Responses are diverse. Some see *Axolotl* as something funny and cute. Others try to trick it, hoping for a sudden reaction. But one thing's certain: for eliciting interaction, it's a success.

—Laura Kiniry

***Axolotl* Video:** eyalohana.com/axolotl

Camper Van Bicycle

The connection between a three-wheeled bike, a shopping cart, and some paintings of old vans might not jump out to most people right away, but for **Kevin Cyr** the connection is obvious.

Cyr grew up in a Maine mill town whose economy is in decline. His vehicular art series, including the *Camper Kart*, *Camper Bike*, and paintings of vans, reflects his interest in the industrial working class.

Formerly a bike messenger in Boston, Cyr conceived of the *Camper Bike* while working in Beijing. In the Chinese capital, a large percentage of the populace use bicycles as a principal method of transportation and hauling, and only in recent years have people come to relate to cycling as a recreational activity.

"I was especially interested in three-wheeled bikes and how workers hauled gigantic loads on the bike's flatbed," Cyr explains. "I saw people carrying loads of building materials, large pieces of furniture, huge bags of styrofoam, really huge items that people in the West would use pickup trucks for."

The *Camper Bike* is an amalgamation of something quintessentially Chinese (bike transportation) and something classically American (camping).

Inspired by Cormac McCarthy's novel *The Road*, Cyr began sketching plans for the *Camper Kart*, essentially a pop-up camper affixed to a shopping cart. "I thought it was really interesting how McCarthy imagined the shopping cart as the most practical object in a post-apocalyptic time," he says.

These "functional sculptures" exemplify Cyr's nostalgic impulses. Cyr grew up with a 1977 Apache pop-up camper, and tried to limit the items he used to that period. After appropriating an abandoned shopping cart from Queens, he added canvas, vinyl, mesh, and accessories such as snaps, bungee cords, zippers, and velcro.

Cyr hopes the *Kart* will stimulate conversation about self-reliance, mobility, and shelter. He envisions it as a functioning sculpture emblematic of human perseverance.

—Thomas Walker Wilson

+ More Work by Cyr: kevincyr.net

Photography by Kevin Cyr

Photograph courtesy of Carl Berg Projects

The Art of Fusion

In art world lingo, an "artist's artist" is someone greatly admired by his or her peers, earning accolades from other artists that are oftentimes followed by critical and/or commercial success.

With his innovative use of plywood, fake fur, sawdust, foam, model-scale trees, and other familiar goods, **Jared Pankin** might inspire a new term: the "crafter's artist."

This is not to say that the art world hasn't also embraced Pankin's whimsically wild sculptures; his three solo exhibitions in Los Angeles got the stamp of approval from several contemporary art critics. But it's this combination of art and craft that make Pankin's chunky pseudo-naturescapes so compelling.

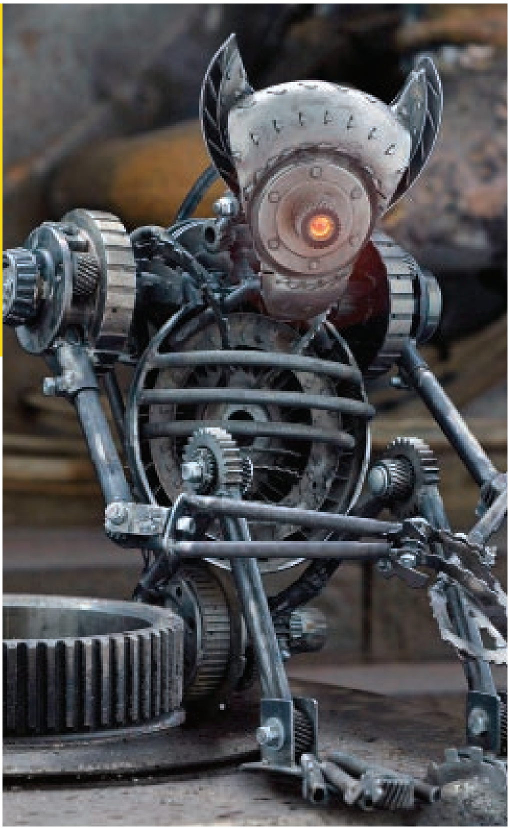
Pankin's tableaux are both serious and lighthearted. Constructed from wood that is either found or easily available at the local hardware store, his works often resemble floating landscapes. These reference and refute nature at the same time, as if their maker's knowledge of the organic stemmed from photographs or postcards, during an era when the natural world had been fully supplanted by the manmade, the constructed, and the built.

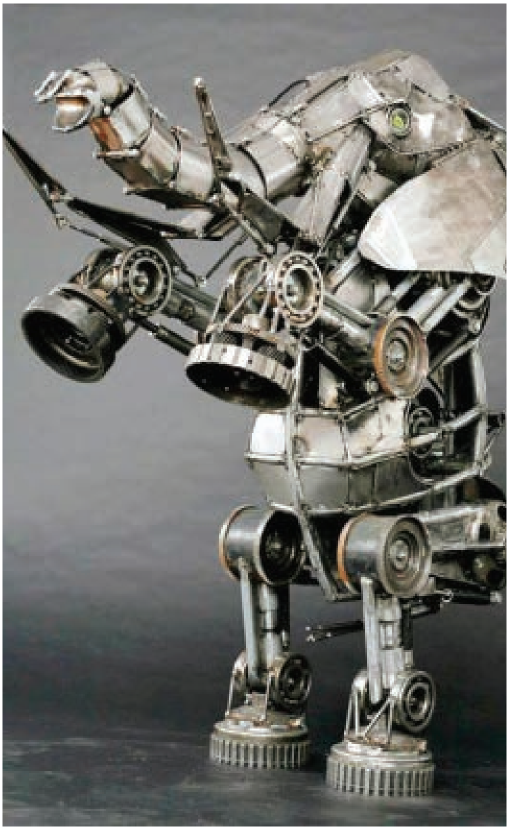
But before we take this apocalyptic scenario too seriously, Pankin — who actually lives and works in close proximity to the majestic Sequoia National Forest — steps in with tongue-in-cheek titles and visual puns. *Hog Wild* (2008) is a big hog's head made from patched-together fake fur and mounted on the wall like a hunting trophy. In *Half Knot* (2008), the front of a fox is completed by a chunk of dark wood in back, which doubles as a tail that eases effortlessly into a tree, stretching into the air above the animal as it teeters on a tower that seems part Tinkertoy and part craggy mountainside.

The environment is endangered, but Pankin isn't waiting for it to disappear. Instead, he leaps headfirst into a sea of imaginative re-envisioning, creating neither replica nor homage to nature, but a playful fusion of the organic and the manmade, of art and craft.

—Megan Mansell Williams

More Pankin: makezine.com/go/pankin





Mechanimals Menagerie

In the imaginary mechanical underworld they inhabit, the elephant is a bulldozer, the giraffe is a crane, the cheetah a courier. In real life, the mechanical animals, or "mechanimals," are the work of Salt Lake City, Utah, sculptor and commercial photographer **Andrew Chase**, who welded them together from sheet metal, iron pipe, and used car parts.

Chase, 42, began building the mechanical beasts in 2004 as props for a children's book he wrote and photographed, *Timmy*. In the as-yet-unpublished story, a robot leaves his subterranean home to explore the surface. Chase took the background photos first, then matched the lighting, and finally positioned the mechanimals in his studio, later merging the images via Photoshop.

About his use of old transmission gears and bearings, Chase says, "It is partly a financial decision — they're free." But beyond that, they look neat. "Things that are made for a purpose have a certain elegance about them," he says. "If I didn't incorporate gears and bearings, the animals wouldn't look as industrial and purposeful. They'd look less useful."

Each sculpture starts with what Chase considers the hardest part: the eyes and head. From there he creates the torso and legs, giving each limb fully functional joints, albeit in a single plane. Due to the nature of Chase's car-parts medium, the animals are all roughly the same size, averaging about 3 feet tall and weighing up to 125 pounds.

Chase's mechanical elephant went through four iterations before taking on its pachyderm form. "On my second try the body was better but still wrong. It looked too much like a dog. Finally, I swallowed my pride and found some good reference material," he admits. Now he relies heavily on photos and animal anatomy drawings.

"Each beasty takes between 60 to 80 hours," says Chase. Much of that time is spent scrubbing parts cocooned in sedimentary layers of oil, grease, and dirt. "The cleanup sucks," he says. "It's horrible."

—Ian Dille

» **Chase's Mechanimals:** makezine.com/go/mechanimals

Photography by Andrew Chase

Photo courtesy of Rob Bell

In the Zome

The next big thing in construction may follow the example of the car industry — it might be all about the hybrid.

Rob Bell and **Patricia Algara** created their own hybrid structure, a DIY greenhouse they call the Algarden Zome. A Zome is a "sort of hybridized structure; part geodesic dome, part jewel, and part yurt," explains Bell, who used the same concept to make a tent-like "Zomecile" that won accolades at the Austin Maker Faire in 2007.

By salvaging the plastic sheeting from an old collapsed greenhouse and making good use of their ShopBot CNC router, this software engineer and landscape architect duo were able to inexpensively build a replicable design. They based the structure on a class of polyhedra known as zonohedra.

"While a dome will tend to resemble a sphere, a Zome will resemble a jewel," explains Bell, who works as a designer and fabricator when he's not writing software.

Designed as a model for building similar structures, the Algarden Zome designs are open source and available free from the Google 3D Warehouse.

While the goal was to create a structure that anyone with access to a CNC tool could easily make and assemble, that's not to say the initial build was a piece of cake. The Algarden Zome took 80 hours of CNC cutting and assembly, then friends were recruited for more days of site prep, painting, and assembly.

The biggest difficulty Bell and Algara had was managing the many distinct but similar-looking parts. The Algarden Zome consists of 84 individual panels, each built from two separate frames encasing translucent plastic sheeting. The 168 panel frames are actually made from 1,344 individual pieces cut from marine-grade birch plywood, and keeping all these pieces organized was challenging.

The unique building pattern is extremely versatile, and its jewel-like symmetry makes it a nice fit for yoga studios and guest cottages, Bell points out: "The organic design is very aesthetically harmonious and spiritually resonant." —*Bruce Stewart*

More Zome Photos: makezine.com/go/zome

BY FORREST M. MIMS III

Snow Science

Depending on the circumstances, a landscape coated with snow can be a winter wonderland, a major nuisance, or a disaster in the making. There's another way to view the white stuff as well, because snow can provide an important resource for doing science.

Both scientists and photographers have long studied and photographed the astonishing beauty of individual snowflakes. Here we'll concentrate on snow that has reached the ground. We'll explore some of its characteristics and effects on the environment, aside from the moisture it provides.

Snow as a Heat Island Indicator

The temperature measured by many of the ever-diminishing number of climate monitoring stations around the world is biased in the warm direction by improper site selection or by changes at sites that were properly located when they were first installed.

In 2007 meteorologist Anthony Watts became concerned about this problem and began a project to survey all the climate monitoring stations in the United States Historical Climatological Network (USHCN). Watts' project has so far provided photographs and detailed descriptions of 1,003 of the 1,221 USHCN stations surveyed by Watts and his volunteer team of citizen scientists.

The most alarming finding from this study is that many stations are placed much too close to "heat islands" such as buildings, pavement, sidewalks, driveways, and even the hot exhaust from air conditioners. Only 10 percent of the stations surveyed meet the National Oceanic and Atmospheric Administration's (NOAA) two highest rankings for climate stations. Full details of Watts' project are at surfacestations.org.

Watts and others have used expensive infrared viewers to see how weather stations are influenced by nearby heat islands. Snow can also indicate a warming bias, and it can be easily recorded by an ordinary camera.

There is likely a problem if snow melts more rapidly in the vicinity of a temperature station than in a nearby open area. The temperature-sensing apparatus itself and its mounting hardware can provide a slight warm bias. But the most significant warming is often caused by nearby roads, parking lots, and buildings.

Snow also provides an ideal tool for photographing and studying natural heat islands. For example, rocks emerging through snow will quickly warm when exposed to sunlight and melt nearby snow. Stumps and living vegetation will also become warm and cause melting. This provides interesting clues about the survival of insects and microorganisms during winter.

You can do a variety of experiments that illustrate how heat islands affect snow. The simplest is to place various objects on snow in an open area with plenty of sunlight. Sheets of black and white construction paper will work if there is no wind. Take photos of the objects and the surrounding snow before and after the sun has done its work.

Snow as a Particle Collector

During the spring of 2004, fires in Southeast Asia sent smoke plumes across the Pacific Ocean to the United States. When the Navy Research Lab's NAAPS aerosol forecast (www.nrlmry.navy.mil/aerosol) showed that smoke would arrive in New Mexico, I headed west from Texas in my old pickup in an effort to both measure the smoke and capture some of it for study. Along the way, a homemade air sampler mounted on the truck blew air collected by a funnel over the sticky side of a piece of adhesive tape. (I'll provide details in a future column.)

The air sampler proved its worth by collecting mineral grains, fungal spores, pollen, and other matter while driving along West Texas and New Mexico highways. But it failed to collect any of the microscopic particles of coal-black soot that form smoke. The Asian smoke remained high overhead and none of it fell to the surface while I was sampling. The smoke covered much of New Mexico, but when I arrived in Las Cruces on March 25 it was much too high to be captured.

Finding particles of smoke that might have fallen from the smoke clouds before I arrived in New Mexico would require a very different kind of collector, so I headed for Cloudcroft in the nearby Sacramento

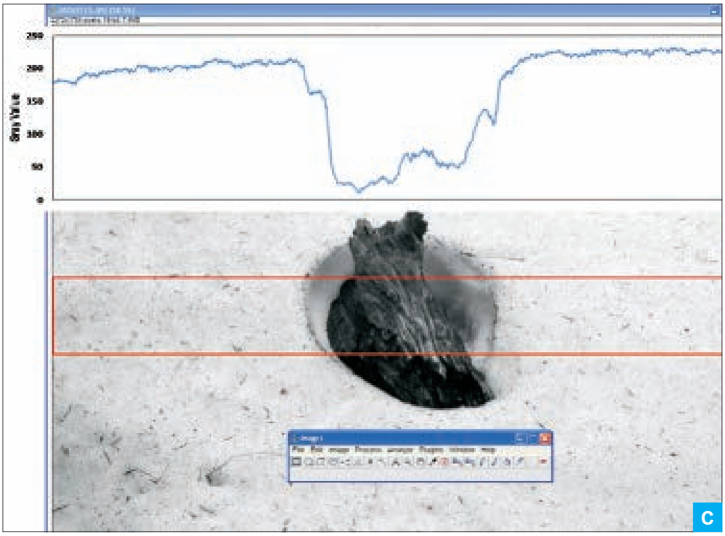


Fig. A: Sapling conifers like this one near Cloudcroft, N.M., form heat islands that melt surrounding snow, especially when sunlight warms their needles. Fig. B: This rock near Sunspot, N.M., formed a natural heat island when warmed by sunlight. Note the leaves peeking out from the ice. Fig. C: The heat island effect formed by this burnt log can be outlined using ImageJ image analysis software (see *MAKE, Volume 18, page 42*). The plot indicates the snow with high values and the burnt wood with low values.

Photography by Forrest M. Mims III

Mountains. The NAAPS forecast showed that smoke particles fell to the ground over that region on March 16–17.

Large patches of snow remained in the mountains, and they were coated with a surprising amount of dust. The snow under the dirty layer was much cleaner. The NAAPS model showed that a large dust storm had blown across the mountain on March 5.

In effect, the patches of snow served as giant air samplers that captured and stored whatever was falling from the sky. While smoke particles were the main objective, the dust provided a bonus. It was time to place a drop of melted snow on a glass slide and inspect it through a microscope.

A single drop of snowmelt from the dirty layer contained hundreds of fungal spores and many thousands of tiny grains of gypsum. Also present were plant matter, transparent orange crystals, and what appeared to be a few slivers of volcanic glass.

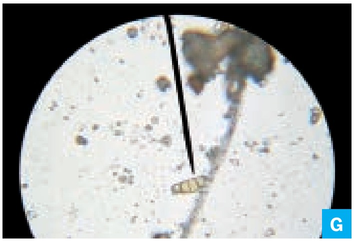
Dozens of samples were inspected, and many included dark black particles of soot scattered among the tiny grains of gypsum dust and sand. The soot was presumably from the Southeast Asian smoke that fell across the region the week before.

The obvious question about the fungal spores was, did they arrive with the dust or the smoke? Or maybe they blew from nearby evergreen trees?

The smoke hypothesis can't be ruled out. When my daughter Sarah was in high school, she discovered many spores and bacteria in biomass smoke that arrived in Texas from the Yucatan Peninsula. She established this beyond a reasonable doubt by capturing spores arriving with smoke from the Yucatan by means of a homemade air sampler she flew from a kite at the edge of the Gulf of Mexico.

This discovery became a "fast track" paper in *Atmospheric Environment*, a leading scientific journal (see makezine.com/go/smokespores).

While spores can probably be blown across the Pacific, it's much more likely that those in my snow



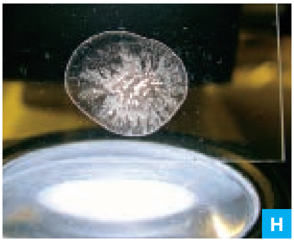


Fig D: A fresh blanket of snow has arrested the melting of snow sprayed with sand spread by a road crew atop New Mexico's Sandia Mountain.
Fig. E: Snow near Cloudcroft, N.M., coated with dust from White Sands and smoke from Southeast Asia.
Fig F: Samples of dirty (left) and clean snow collected near Cloudcroft, N.M.
Fig G: A microscopic view of gypsum sand, dust, plant matter, and spores from snow near Cloudcroft, N.M. The pointer indicates a *Curvularia* spore.
Fig. H: A drop of dirty evaporated snowmelt on a microscope slide left behind this deposit of dust, smoke particles, fungal spores, and plant matter.

samples came from much closer sources, such as nearby trees. In any event, it was quite a surprise to find so many fungal spores in snow atop a mountain. The spores included the genuses *Alternaria*, *Nigrospora*, *Curvularia*, *Cladosporium*, *Penicillium* (or possibly *Aspergillus*), and what resembles the ascospores *Splanchnonema* and *Leptosphaeria*.

I was unable to identify the most common spore in the snowmelt, as it's not shown in E. Grant Smith's *Sampling and Identifying Allergenic Pollens and Molds* (Blewstone Press, 2000) or Bryce Kendrick's *The Fifth Kingdom* book and CD (Mycologue Publications, 2000).

Going Further

If you reside in snow country, what's in your snow? Does apparently pristine snow contain fungal spores and protozoa? Is it contaminated with soot particles? If these and other contaminants are present, can you use satellite imagery to back-track the storm that dropped the snow, thereby possibly finding where the contaminants originated?

How do plants buried under snow exploit the heat islands formed by rocks and stumps?

What are the simplest and most efficient ways to melt snow outdoors? Ashes? Sand? Sunlight reflectors? Reusable black plastic sheets?

Finding answers to these and other snow questions can lead to a variety of intriguing science projects for those who reside in or who visit snow country.

Forrest M. Mims III (forrestmims.org), an amateur scientist and Rolex Award winner, was named by *Discover* as one of the "50 Best Brains in Science." His books have sold more than 7 million copies. He edits *The Citizen Scientist* (sas.org/tcs).

MAKER'S CORNER

BY DAN WOODS

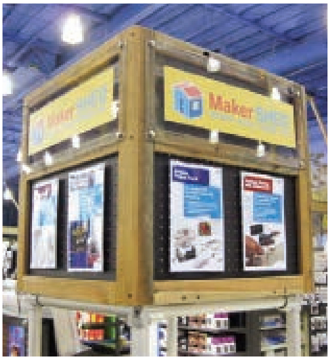
Maker Shed on the March

This past fall, Fry's Home Electronics and Maker Shed (makershed.com) reached an agreement to install Maker Shed retail kiosks in four of Fry's largest superstores as a kind of DIY retail test. Each kiosk was to merchandise MAKE magazine (natch), Make: Projects books, and a lineup of kits produced by some of our favorite indie makers like Mitch Altman, Ken Murphy, Dale Wheat, Amy Parness, and Ariel Churi.

Needless to say, we were elated. A big-box electronics store embracing DIY and the growing maker community! But this presented us with a bit of a challenge since we didn't actually have any retail kiosks, or a budget to go buy anything. Plus, we started walking retail stores and quickly realized we don't much care for most retail kiosks.

We wanted something that would effectively represent our magazines, books, kits, and the distinctive MAKE brand. It wasn't enough to simply display product, we wanted to celebrate the maker spirit. It had to exude the familiar ambience of a shed, make maximum reuse of stuff we had sitting around the shop as well as locally salvaged materials, and fit in a 2'×2' footprint. So after sketching up some ideas, we brought in local maker Joe Szuecs to make it all happen. Here he describes his process:

> The Maker Shed team had some ideas regarding the design. From what I gathered, they were looking for a rustic workshop look. Mention was made of pegboard along with weathered corrugated galvanized steel. The early prototypes were built around the tubular aluminum framing used for Maker Faire workbenches.
>
> I liked the idea of combining the modern look of the tubular aluminum with weathered natural materials. I've built furniture in the past using old corrugated steel roofing and weathered redwood fence boards. The materials work well together: think old barn. I threw together a prototype to see how it looked. The aluminum, redwood, and corrugated steel combination completely evoked the spirit of MAKE. I envisioned a CNC whirring away in the middle of some unfinished garage space.
>
> The functional components of the design were defined and sized. Now I needed to collect materials. I had a cache of reclaimed fence board in my workshop. But I needed more, so a visit was made to my source, a local fencing company that sells the fences they remove when installing new ones. I remembered a pile of corrugated metal sitting on a friend's property. So I got a few sheets from him. The rest came from the usual sources.
>
> Reclaimed fence board needs to be tamed a bit before use. A few passes through a planer evens out the thickness between boards. From there, it was just basic cabinetmaking: a solid interior structure of plywood, surfaced with the rustic materials.



Photography by Heather Cochran

The resulting kiosks are a nice combination of weathered shed and repurposed industrial tubing. They're uniquely MAKE, and Fry's is ecstatic. And in fittingly MAKE fashion, the kiosks were loaded up, trucked down, and set up by our own staffers Heather Cochran and Rob Bullington in one day.

If you'd like to check 'em out and maybe show Fry's how much you appreciate the program by buying a thing or two, you can find them at the following California Fry's stores: San Diego, San Jose (East Brokaw), Fremont, and Sunnyvale (East Arques). And hopefully, more locations and other electronics retailers will follow.

Dan Woods is MAKE's associate publisher and Maker Shed general manager.

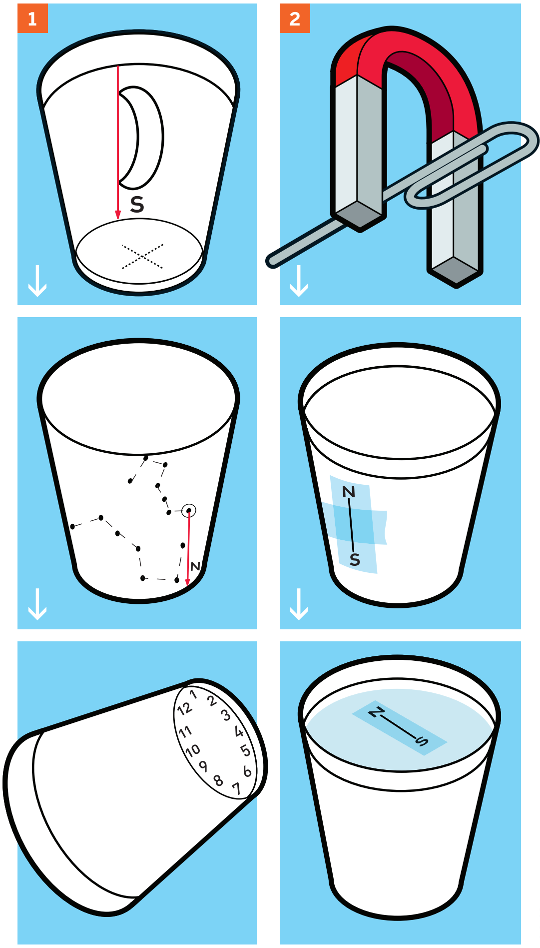
1+2+3 Cup Positioning System

By Cy Tymony

Not everyone has a GPS (Global Positioning System), but you can easily make a CPS (Cup Positioning System) from any cup and learn the art of orienteering!

YOU WILL NEED

Styrofoam cup, pen, staple or paper clip, magnet, and transparent tape



1. Mark the cup.

Draw a crescent moon on one side of the cup. Then draw a downward-pointing arrow that rests against both tips of the moon. Write *South* at the bottom.

On the other side, draw the Big Dipper and Little Dipper constellations. These resemble pans with handles. The Big Dipper's rightmost stars point to the Little Dipper's "handle" star, which is Polaris, the North Star. Draw a downward arrow from Polaris and write *North* at the bottom.

Turn the cup over and draw the numbers 1 through 12 on its bottom in a clock formation.

2. Make a compass needle.

Straighten a staple or small paper clip. To magnetize it, rub it 30 times with a magnet in one direction only. Place the staple lengthwise on transparent tape, and fold the tape over so the staple is sealed in the middle. Now float your compass needle on a cup of water and when it comes to rest, write *N* on the north-pointing end, and *S* on the other (south-facing) end. Tape it to the side of the cup for safekeeping.

3. Find your way!

Your Sneaky CPS device is ready to help you find your directions in several ways, day or night.

» **Sun** If the sun is visible and you know what time it is, you can easily locate directions. Turn the cup over to reveal the clock numbers. Keeping the cup level, aim the number that represents the current hour at the sun. For example, if it's 3 p.m., aim the number 3 at the sun. Halfway between the position of the sun and the number 12 is the direction south.

» **Moon** If there's a crescent moon in the sky, imagine an arrow pointing downward that follows the 2 tips of the moon. This points south. This trick also works fairly well with a half or gibbous (¾) moon.

» **Stars** Position the cup so you can see the Big Dipper and the Little Dipper images on it. Now look up to find them in the night sky. It's easier to locate the Big Dipper first, then follow its rightmost stars that point to the Little Dipper's "handle," the North Star.

» **Compass** Add water to the cup to transform it into a compass. Float your compass needle on the surface. When it comes to rest it will point north!

Cy Tymony is the author of the *Sneaky Uses for Everyday Things* book series. sneakyuses.com

Illustrations by Julian Honoré/p4rse.com

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Eddie Paul builds custom cars and choppers for movies like ***Cars, Grease, Cobra, The Fast and the Furious, Triple X***, and others.

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-Eddie Paul-

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Maker

SELF-MADE MAKER: Engineer Eddie Paul builds everything from Hollywood custom cars and special effects to submarines and wind turbines in his formida-bly equipped Southern California shop.

Cutting His Own Paths

Inventor Eddie Paul does more before lunch than most people do, ever.

By Keith Hammond

At first impression, Eddie Paul's machine shop in El Segundo, Calif., takes me back to my grandpa's auto body shop: cars on lifts, racks of sheet metal, rollaway toolboxes, a Pacific breeze scented with Bondo and grease.

But Paul is making ultra-complex things Grandpa couldn't dream of, with a phalanx of CAM/CAD workstations and computerized mills, lathes, and plasma cutters. After 40 years creating custom cars and stunts for Hollywood movies, this self-taught engineer, inventor, and DIY author has assembled a high-tech shop that can prototype and build just about anything. His clients include not just film studios but also fire departments, energy companies, NASA, and the Department of Defense.

Not bad for a high school dropout who got his big break stunt driving on *The Dukes of Hazzard*. A voracious reader with no formal engineering schooling, Paul has developed unique designs for pumps and engines, optics, and hydraulics. He's invented and built new camera rigs, animatronics, autonomous vehicles, even a shark-shaped submarine.

What's his secret? "Just do it, don't let anyone stop you," Paul advises. "You've got to learn every skill you need to get things done, and it's not that hard. You learn as you go and develop your skills."

(His assistant Dave pops in with a ruined O-ring. Paul tells him, "I'll show you how to make an O-ring when we get done.")

"I go to the bookstore and buy every book I can on the subject, and I buy the tools. Since I dropped out of high school, I've just read technical books. It's all I read, technical books. In fact I just read my first novel, *The Road* [by Cormac McCarthy]."

That may explain why the next book he's writing is a DIY "urban survival guide."

Photograph by Noah Webb

SON OF AN INVENTOR

Growing up in California, Paul apprenticed with his father before setting out on his own. "My dad was an inventor," he says. "He invented all-threaded rod, rotisserie chicken machines in supermarkets, a new kind of domed navigational chart. He taught me to find a need and invent a solution — and make it as simple as possible. I worked in his shops; he taught me how to weld, grind, drill, all that stuff."

"I was on my own at 13, making a living working on motorcycles in L.A. and San Francisco, and living off my '45 meter maid trike. This was in the late 1960s." Soon Paul got into building and flying hang gliders, which got him a movie stunt job, which led him to *The Dukes* and a storied career in stunts, special effects, and custom cars.

E.T., SHARK WEEK, AND PIXAR

Since the 1970s his auto division, Customs by Eddie Paul, has built vehicles and effects for movies ranging from *E.T.* and *Back to the Future* (yes, the time-traveling DeLoreans) to *The Fast and the Furious*. His shop has earned a reputation for completing huge jobs on improbably tight deadlines — for *Grease* they built 48 cars in two weeks, and for *2 Fast 2 Furious* they did 200 in a month.

Along the way, Paul evolved into much more than a hot-rodder. Today he's relied upon for industrial design and prototyping, marine engineering, and complex movie imagineering. Pixar hired him to build full-sized, running replicas of Sally, Mater, and Lightning McQueen from *Cars*. He built life-sized animatronic horses for *The Mask of Zorro*, and decades' worth of aquatic camera gear for the Cousteau clan.

More than once, Paul has been the Discovery Channel's secret weapon for Shark Week. An experienced deep sea diver and underwater photographer, Paul designed plastic body armor and a scuba muffler to help divers get closer to the predators, and rigged a "gut-checker" camera to peer into their stomachs. But his sharky masterpiece was built for Fabian Cousteau: a 17-foot, swimming, shark-shaped submarine piloted by a diver inside, to get right up in a great white's grill.

"I'm basically an inventor," Paul says. "I do the rest for money. Ninety percent of what we do is invention."

Fed up with balky pumps and compressors, Paul invented his own. His high-efficiency Cylindrical Energy Module (CEM) is one-sixth the size of comparable pumps. It's used by fire departments to blast firefighting foam and by Navy Seals to spray decontamination chemicals.

Run it in reverse, and it's an engine — six pistons, 12 cylinders, no valves, and only seven moving parts — that's achieved 98% volumetric efficiency and 3hp per pound of engine weight. "No one's ever done that," Paul says. Now he's building one that's only 12 by 13 inches, and eyeing the X Prize for the world's first 100mpg passenger car.

Paul also invented Circlescan 4D, a 3D camera technology based on the psycho-optical Pulfrich effect, unlike the anaglyph and lenticular 3D technologies currently in use. And he's produced dozens of how-to books and videos ranging from basic welding and plasma cutting to advanced customizations.

SHOP OF ALL SHOPS

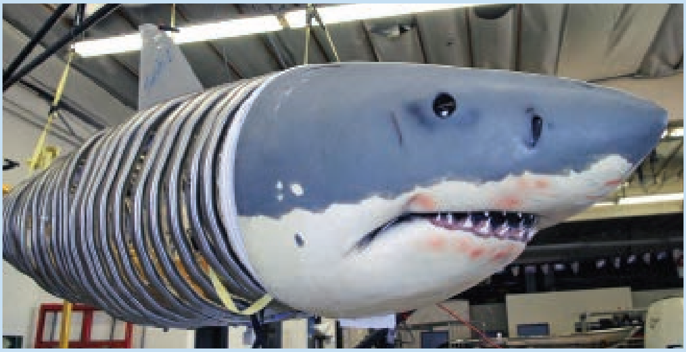
If you're any kind of tool-user, a tour of Paul's shop is mouth-watering: ten CNC metal lathes and mills, two CNC 3D routers, a 4-by-8-foot vacuum former, and a 5-by-10-foot PlasmaCAM table that will cut steel up to 1¼ inches thick. "I love that machine," Paul declares. "Everything in here's cut on that — motorcycle parts, turbine blades, you name it."

There's a Ford Model T hot rod he's building for his new how-to book, and a badass midnight blue '67 Pontiac GTO from Vin Diesel's movie *xXx*. (For stunt scenes, Paul says, "We bought LeManses and turned them into GTOs. It's a lot cheaper — and you don't ruin GTOs.")

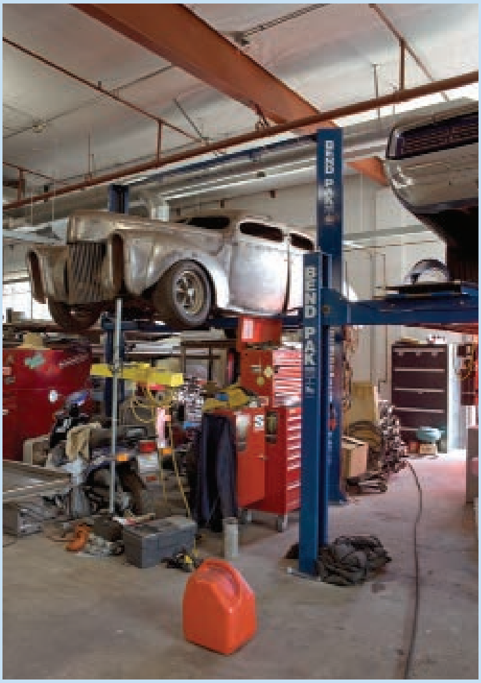
Out back are mini fire trucks — Polaris ATVs fitted with Paul's CEM pumps — next to electric motorcycles for George Clooney's *Leatherheads*. And you can't miss Paul's custom Chopper 1, a crazy-overpowered motorcycle with a 502 big block Chevy engine, dual Weiand blowers, and nitrous oxide.

As cool as all this stuff is, I'm more awed by Paul's library. Shelves sag under a lifetime of learning: CNC robotics, mathematical physics, blacksmithing, electronics, fluid mechanics, and thermodynamics. Ancient inventions, nuclear weapons, lasers, and computer animation. *The*

BY AIR, LAND, AND SEA: Paul's pulsejet hang glider; Hollywood stunt driving (he survived this plane collision); shark submarine piloted by diver inside; remote-control car rig; L.A. to Vegas ride with no hands; diver armor for Shark Week; and a half-sized Nissan sub (he broke his neck during this stunt).



Photography courtesy of Eddie Paul



American Boy's Handy Book, shipbuilding, and of course sharks. A collection of massive brass diving helmets looks on, as though we're in Jules Verne's own chart room.

Then there are the Eddie Paul stories that rival Chuck Norris or the Dos Equis Guy. He invented a pulsejet hang glider and buzzed LAX. He once fell 360 feet and lived. He's been attacked by sharks, on purpose. He taught Twisted Sister how to ride motorcycles. He got a secret clearance from DoD, and then redesigned their lasers. He once rode a Harley-Davidson from L.A. to Vegas — with no hands.

But I think I'm most impressed by the enjoyable, almost incredible variety of work that Paul is doing. Just during our brief interview on a Saturday morning, he explains his process for replicating Pixar's *Cars* characters at life size (a huge CNC router carves 3D forms out of stacked plywood, then ABS plastic is vacuum-formed over these). He greets a customer from WePower who's there to inspect Paul's beautifully machined prototype wind turbines.

He demonstrates his patented pump/engine, then pulls up his CAD design for a steam-powered motorbike that would be at home at Burning Man. He shows me the insane 20-foot chainsaw he's made out of a motorcycle — and the big red fire engine he'll bisect with it — for a National Geographic pilot called *Cut in Half*.

By cutting his own paths, Paul has not only become highly skilled and knowledgeable. He's also carved out a wide, satisfying creative space in which to make a living.

You can't meet Eddie Paul without wanting, at least a little bit, to have Eddie Paul's job. But it's not the kind of job someone can give you. It's the kind you make for yourself.

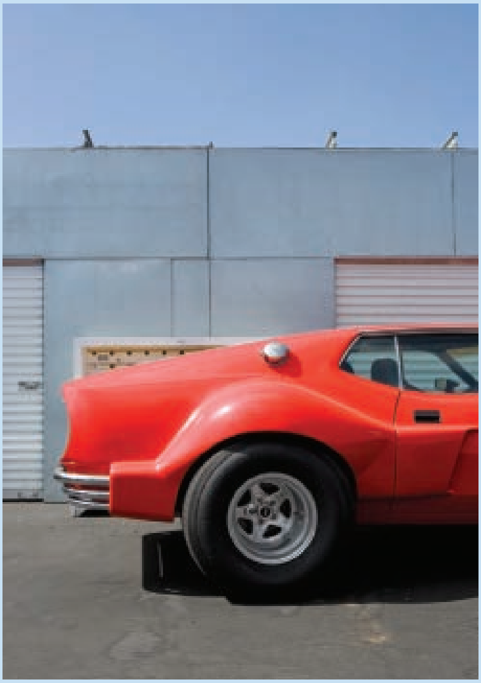
His advice to aspiring makers today? Read those technical books. "And learn to use two tools: AutoCAD and the CNC plasma table. And write how-to articles for magazines – that's how I got the job for *Grease*, the guy saw my article."

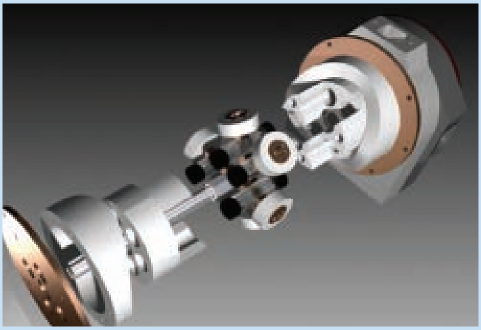
I ask, would he have had the same opportunities if he weren't in L.A. and the movie business?

"It got me started," Paul admits. "But I could have done this anywhere. People will find you if you do good work."

Keith Hammond is copy chief of MAKE. His grandfathers were a technical writer and a body-and-fender man.

Photography by Noah Webb





Photography by Noah Webb (Mustang, router, plasma cutter) and courtesy of Eddie Paul

RODS, MODS, AND INVENTIONS: (Opposite) Rods on racks; Chopper 1 superbike. (This page) Mustang fender flares; CNC 3D router station; plasma cutter in action; full-sized Mater from *Cars*; *Cut in Half* fire engine; replica of *Akira* anime motorcycle; Paul's patented pump/engine with double-ended pistons and sinusoidal cams.

Big Kid Bikes

Bending bicycles with builder Greg Degouveia.

By Nik Schulz

From his skunkworks in Chico, Calif., metal fabricator and bike builder Greg Degouveia of Big Kid Bike (bigkidbike.com) forges a new breed of vehicles that push the envelope of awesomeness.

Behold the 205-pound Kitten, a behemoth that rolls on steamroller-like car tires. Observe the Jesus Lizard, a four-person pedal-pusher that corners like a modded gecko. Witness the Bigger Wheel, a grown-up version of the childhood favorite that looks like it came of age on the set of an *Easy Rider* remake. All three push cycling to the next level (or perhaps the one beyond that).

After a spin on the Kitten at last year's Maker Faire in San Mateo, I had to learn more.

Nik Schulz: How and when did you get started building big kid bikes?

Greg Degouveia: I've always been a tinkerer and designer, taking things apart to see how they work (and sometimes not being able to put them back together). After a few years of renting a pedicab in college to pay the bills, and a summer of learning how to weld and fabricate metal, I decided to build my own. Because of that experience, I saw that I had a natural skill for building and fabrication. Following that, I re-enrolled in college, changing my major to manufacturing.

NS: So now you make your living as a bike fabricator?

GD: No, not yet. The pedicab keeps my head above water while I try to make metalwork art my main source of income. My marketing skills need a lot of

Photography by Greg Degouveia

work, though. All of the work I've received has been from people that have been referred to me or have seen me at my shop.

NS: Tell us more about your shop.
GD: It's a mix of storage and workspace dominated by different bike parts and metal creations. One-quarter of it, filled with some basic shop tools — a 110-volt MIG welder, band saw, a few angle grinders, a drill press, pipe bender, and a 2-gallon compressor — is devoted to steel fabrication.

I also have a table for electronics tinkering and one for sewing, but the welder, angle grinders, and band saw see the most use. I build large items on the floor or design them modularly to be assembled from multiple small pieces.

There's also a very long, expensive wish list of things I would like to have: TIG welder, plasma cutter, lathe, mill, tubing bender ...

NS: Describe your design and development process.
GD: The initial design usually comes from a basic concept, which is followed by designs on paper. There I'll add and subtract features and figure out if the original concept is workable. I used to build a proof-of-concept piece with chopped bikes, scrap metal, poor welds, and sharp edges. Now I build straight from the design when the concept is clear and I understand the method of execution. I've also been toying around with Google SketchUp but I'm still learning how to use it.

NS: How long does a bike typically take to design and build?
GD: Depending on complexity, from a few days to a few weeks. The Jesus Lizard took me six weeks from design to completion, with design taking about two weeks. Each pedaler had multiple sets of gears: a basic set for road riding and a super-low "sand-crawler" gear. Working with multiple gear sets took some time.

The Kitten took me about a week for the frame and wheels. The headlights and brakes took about another week.

NS: What sorts of reactions do you get from people who have ridden the bikes?
GD: People like them. Some like the ride, some like the look, some are impressed by their sheer size. Each bike is different. The Bigger Wheel was built to be ridden like a caffeinated 10-year-old. When the right person rides it really hard, they come back with a devilish grin on their face. That's when I feel

NEVER GROW UP: The Kitten (opposite) weighs in at 205 pounds (yes, those are car tires). The Jesus Lizard (above) seats four and can go up to 17mph.

fully satisfied. The Kitten was built because the wheels were free. It's excessive and inefficient — it's sort of the anti-bike.

NS: What's your favorite project so far?
GD: As far as bikes go, the Jesus Lizard; it's a lot of fun and rides like nothing else. Although it's 25 feet long, it has a 7½-foot turning radius. You can ride it at full speed (about 17 miles an hour), throw it into a hard corner, and it will hold firm regardless of whether or not the passengers can. Assuming that acceleration is not a limiting factor, a person on a two-wheeled bike would find it hard to outmaneuver the Lizard.

It used to have a head that would go up and down, move side to side, and open its mouth, but this one time, at Burning Man, the neck didn't make it back.

NS: What's next in terms of future projects?
GD: The Choo-Choo Train, a pedal-powered train with multiple cars, capable of being pedaled by kids or grownups. It will resemble a toy train and have similar design characteristics to the Lizard but be a lot lighter. I'm hoping to get it going by next summer but I'm in need of more funding.

NS: Will the public be able to see it somewhere?
GD: When it gets built it will be in Chico but I would love to tour it around different cities. I'd actually love to bring it to Golden Gate Park in San Francisco.

NS: Why do you do what you do?
GD: Let me step up on my pulpit ... I would like to get more people on bikes for fun, transport, and health. I'd like to see more folks bike-commuting and reducing their car and fuel dependence. Creating interesting, functional, fun bikes is my way of coaxing more people into the bike-riding fold.

Nik Schulz is an illustrator and writer, and a fan of almost anything with wheels.

Locally Grown

Carving boards and waves with the maker of all-wood Grain Surfboards. By Peter Smith

Mike LaVecchia and Brad Anderson own Grain Surfboards, a small company on the coast of Maine making wooden surfboards and DIY surfboard kits from sustainably cut, locally milled northern white cedar. Born in LaVecchia's basement in 2005, the company now employs seven people.

The handmade boards are computer-designed to maximize the efficient use of the wood — to "save some trees but also save some money," LaVecchia says — and constructed in a modern rib-and-keel style with roots in traditional boatbuilding. Grain also offers weeklong surfboard-building classes whose pupils each go home with a beautiful wave vehicle they've made with their own hands. I spoke with LaVecchia from his workshop in York, Maine.

Peter Smith: What goes into building an all-wood board?

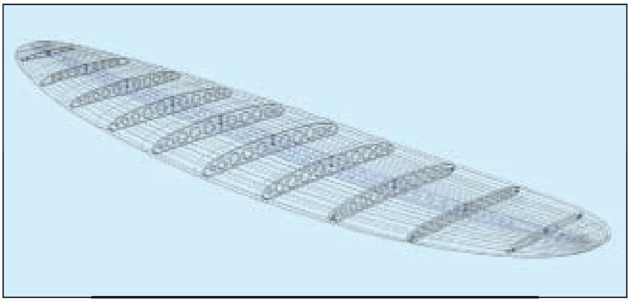
Mike LaVecchia: Our boards are hollow and are built around an internal frame, which a lot of people equate with an airplane wing. So you've got an internal structure that gives the board the shape, then cedar planks and these specially milled strips that you build up around the frame.

PS: Why did you choose hand craftsmanship?

ML: I've been around wooden boats most of my life. Love the feeling of them. Love the fact that no matter where you are, you can repair it. You can fix it with common materials. There's no real mystery

Photography by Mark Marchesi

WITH THE GRAIN: Mike LaVecchia (opposite), president and founder of Grain Surfboards, stands outside his shop next to a book-matched beauty he built. (This page) A student in a surfboard building class shapes his rails with a hand planer; a Grain employee teaches a lesson on board building; CAD drawings, like this one showing the "airplane wing" structure of a funboard, let the makers refine their designs based on customer feedback.



technology there. If you can build it by hand, then you can fix it by hand.

Our boards are designed in AutoCAD, so we can get it really dialed in. We send designs back and forth to a customer and get feedback and tweak things. Then, the idea is to build it as accurately as possible. We don't quite have the freedom that somebody shaping a foam blank does.

PS: But you don't wear dust masks either.

ML: Exactly. We do all of our work with edge tools. Never wear a dust mask. You're not worried about breathing dust, fumes, and all that kind of stuff. We do have to sand, but compared to what you're doing with a foam board — power planers and sanding screens — it's just such a nicer process.

PS: Why did you create kits and classes for people?

ML: Once we really dialed it in, we thought, "This is easy and fun." We can't get the prices down to where most foam boards are, so we thought, "Why not offer them as a kit?" We still think of it as selling a surfboard, it's just they have to put it together. We've put a ton of time into our manual. We get a lot of satisfaction that people are out there doing it.

PS: What tools would I need to build one at home?

ML: Everything that goes into the board comes with the kit. All the planking, the rail strips, the frame, all the glues, the fiberglass, the epoxy, fin boxes, all the hardware. You need clamps, and some edge tools — like a hand plane and a spokeshave. You could spend 75 bucks and have everything you need.

The clamps can add up [but] if you take a 4-inch PVC pipe and cut pieces off it and open the pipe up, it's got tension in it. It's a real inexpensive way to make your own clamps.

PS: Is it ever too cold to surf?

ML: Rarely. Wetsuits have come a long way. There's some cold days, though. Luckily, we all live close by, so it's nice to run home and jump in the hot shower.

Peter Smith lives in Maine and has covered food, culture, and technology for *Good*, *Gastronomica*, and *The Atlantic Online*. peterandreysmith.com

The Nonsense Factory

The Maywa Denki collective makes instruments of mass whimsy. By Lisa Katayama

ROBOTUNES: Nobumichi Tosa is the man behind the machine behind the music. He holds regular "non-sense toy"-making workshops at his studio in Tokyo.

Nobumichi Tosa stares straight into my camcorder. He presses a button on the small rectangular switchboard on his chest. The wings strapped to his body start to slowly rise. He pauses, expressionless. He raises his arms.

Then, with a snap of his fingers, he launches into an upbeat, 20-second musical performance triggered by the beat of his snapping. Every snap makes mallets at the end of his wings drum on a pair of temple blocks. It sounds like a mashup between a Buddhist funeral and a trance party.

Tosa is the president of Maywa Denki, a Tokyo-based art collective whose quirky instruments have made waves among musically inclined geeks and artists across the globe. His warehouse is full of handmade electronic instruments. He shows me an automated folk guitar controlled by an external pick; daisy-shaped xylophones with petals that open and close to a beat; and a bellows-powered artificial vocal cord connected to a PC that emanates sound through a fake human ear.

He's wearing blue work clothes over a shirt and tie, which he tells me is his stage costume. "I used to wear a tuxedo," he says, "but it made me feel like a magician."

The name Maywa Denki comes from an electronics store that Tosa's father used to own. Tosa always knew he wanted to be an artist, but it wasn't until he got to college that he realized his creative tool of choice would be the machine.

"There was a workshop at my university that looked exactly like my dad's old store," he says. "And I thought, Maywa Denki has become a forgotten thing of the past, but maybe it's time I can resurrect it."

Working closely with Masamichi, his older brother, Tosa made a collection of 26 gadgets themed around different species of fish. "We realized that the Japanese would never understand this as conventional art, so the electronics store turned out to be a good way to present ourselves." The work-clothes are also an homage to their dad — a replica of the standard uniform for small- to mid-sized blue-collar jobs during the economic boom of the 1970s.

Tosa's inventions range from working instruments to dysfunctional robots to skeleton-shaped extension cords. They all have one thing in common: they are "nonsense machines."

"Usually, machines are logical parts put together in logical ways. I have a background in art, and I like to make things that are illogical. Of course, there's engineering behind it all, which means I'm putting logic behind illogic — it's all very oxymoronic," he explains matter-of-factly.

Most of Maywa Denki's creations are sold through their website (maywadenki.com) and online retailers like Amazon Japan. Tosa's latest invention, a tadpole-shaped, theremin-like instrument called the Otamatone, hit the consumer market in August 2009. He also does musical performances with his kooky instruments and silly robots in Paris, Osaka, and Washington.

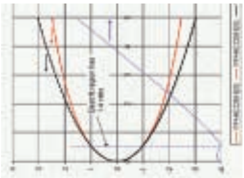
As I watch Tosa and his instruments in action, I realize that his entire studio has taken on an unparalleled life of its own. "Japan is a country of animism," Tosa says when I mention this. "We believe everything has a spirit. Tools are fun, and by using them in different ways, you can figure out your own path. Just like judo and bushido, what I'm showing you is Maywa-do — the path of Maywa Denki."

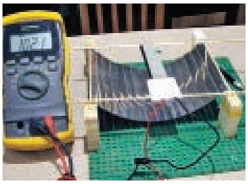
Lisa Katayama writes for *Wired*, *Popular Science*, *New York Times Magazine*, and her own blog, TokyoMango. She's a contributing editor at Boing Boing and the author of *Urawaza*.

Photograph by Lisa Katayama

The Solar Catenary Reflector

Build 21st-century renewable technology using 17th-century mathematics. By Tho X. Bui





HOW TO FAKE A PARABOLA: (Clockwise) Backyard solar catenary reflector (SCR) cooker built in 20 minutes using sheet steel and wood; experiments with miniature catenary reflectors doubled the output of a solar PV cell; overlaid symmetrical catenary (red) and parabola (black) show their closest match at 1:4 height-to-width ratio.

You can divide most solar power research into two camps: increasing efficiency or reducing cost. A few years ago, when I decided to do some amateur solar research of my own, I chose the "cheap" route.

I had the idea to use mirrors with a catenary curve to concentrate sunlight. The catenary, described by $y = \cosh x$, is the curve that ropes or other flexible materials naturally fall into between two supports. This curve was mistaken for the parabola ($y = x^2$) until the difference was cleared up by 17th-century mathematicians.

Parabolas are often used for concentrators since they focus parallel rays into one point. I reasoned that if I could find parameters under which catenaries and parabolas are similar, I could make a solar catenary reflector (SCR) that would effectively concentrate sunlight.

The advantage of the SCR is that it's self-forming. Solid parabolic shapes don't occur naturally, and you need to make them stiff and strong to maintain their shape against wind, snow, and other destructive outdoor forces.

And the SCR is quick and inexpensive to build, requiring no special tools or knowledge. Just hang some flexible, reflective material and you have it. SCRs could ultimately be more durable than rigid parabolic reflectors because of their Zen-like ability to deflect with the wind, instead of fighting against it.

To determine when a catenary will reflect like a parabola, I modeled the problem mathematically on a computer. As expected, I found an aspect ratio where a catenary reflector almost matches a parabolic mirror at concentrating light: 1 high to 4 wide, for a symmetrical reflector.

Photography by Tho X. Bui

In other words, let the material hang down ¼ the distance between the posts. Following this formula, a couple of teenagers built an effective SCR cooker using hand tools in 20 minutes, under my guidance.

Surprisingly, it turns out that a properly proportioned asymmetric catenary reflector (ACR), where one support is higher than the other, will do a good job at concentrating light that's not exactly perpendicular to the axis of the curve. This means that within certain limits, an ACR can concentrate the light as the sun travels across the sky.

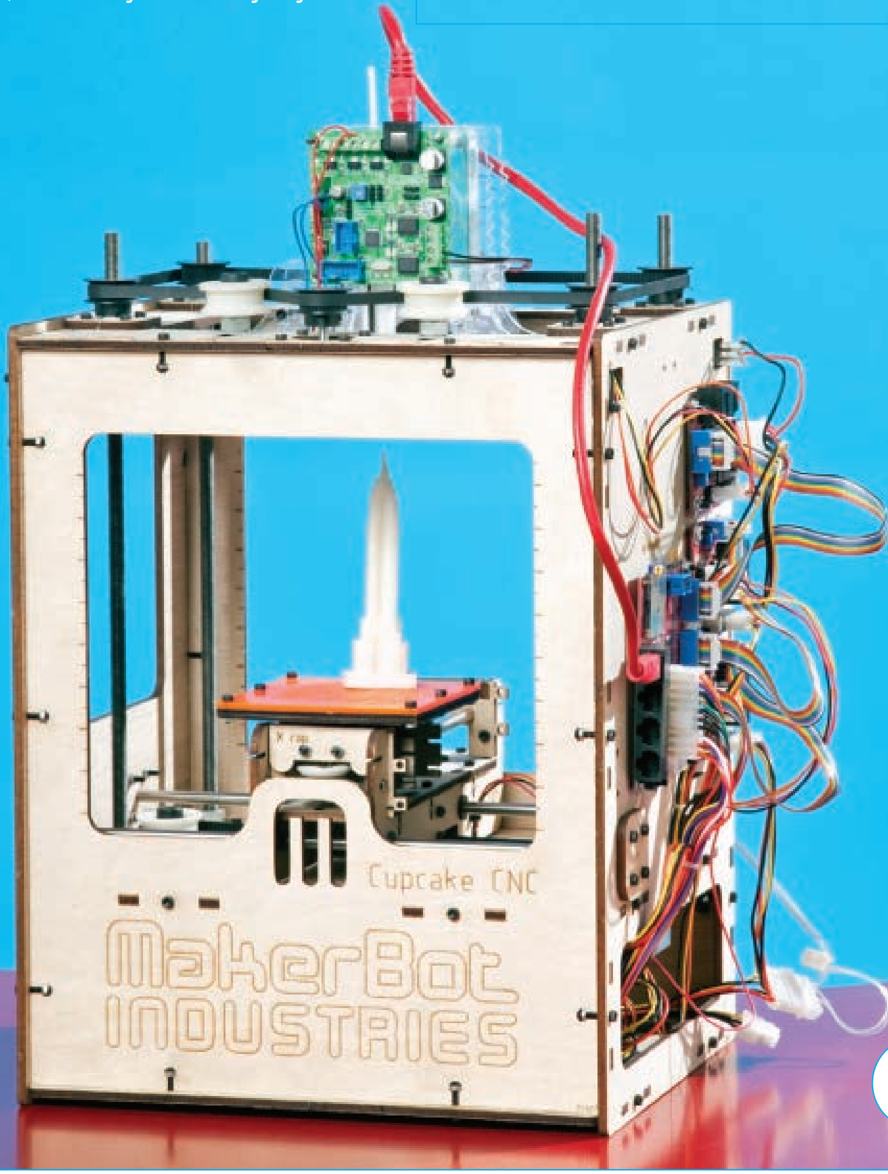
Large, inexpensive ACRs hold promise as a way of getting more out of smaller, more precious photovoltaic panels. I'm currently researching this pairing, and want to explore whether such designs are better than parabolas at focusing diffused light — the Achilles' heel of the parabolic concentrators. To keep the program within my kitchen-science budget, I'm working with miniatures. In my early experiments, I doubled the output of my photovoltaic cell.

You are welcome to join me in this grassroots research. Email me at blahx3@thoxbui.com.

Tho X. Bui (thoxbui.com) lives in Phoenix, Ariz., with his lovely wife and three turtles. He used to do research for a living, now he's doing it for fun.

Make: DESKTOP MANUFACTURING

In the late 1980s laser printers became inexpensive enough for home use, leading to a desktop publishing revolution. Twenty years later we're witnessing a similar revolution in 3D printing. It's now possible to set up a parts factory on your desktop. In this special section of MAKE, we'll show you the many ways how.



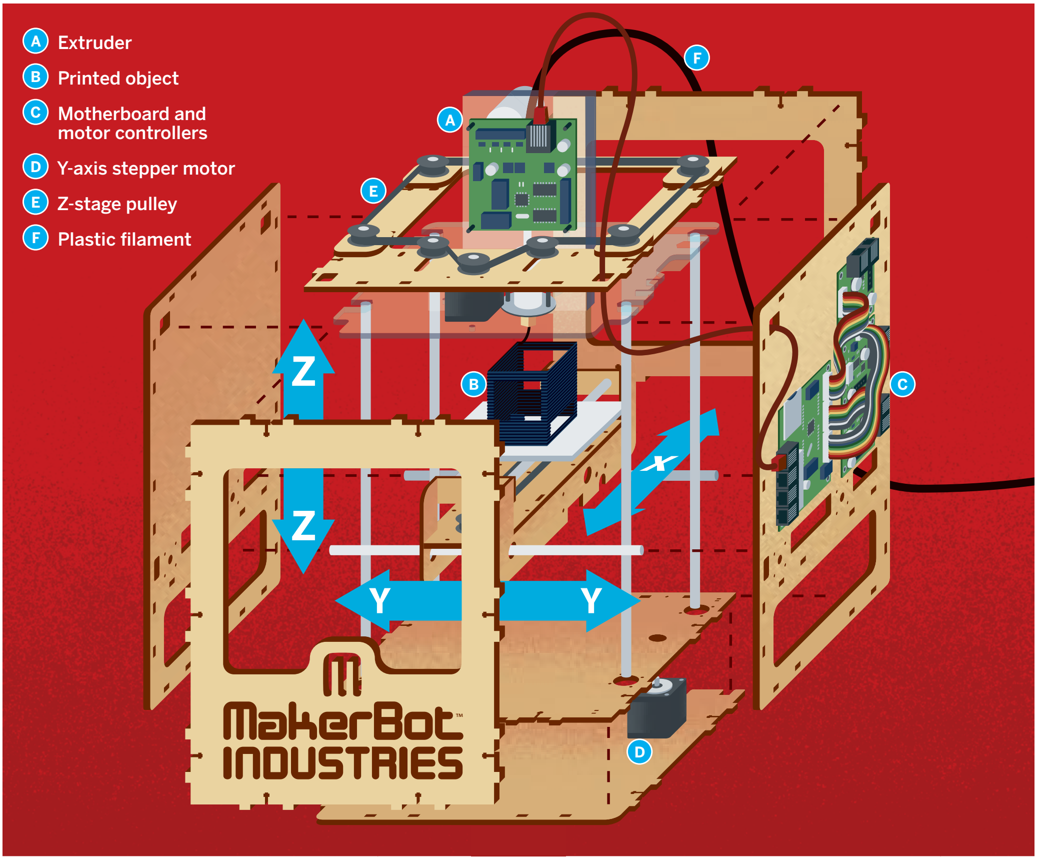
THE REVOLUTION WILL BE SQUIRTED

An inside look at MakerBot Industries.

BY BECKY STERN

THREE CUPCAKES: Mayer, Smith, and Pettis with their open source 3D printers.

Photography by Kate Lacey



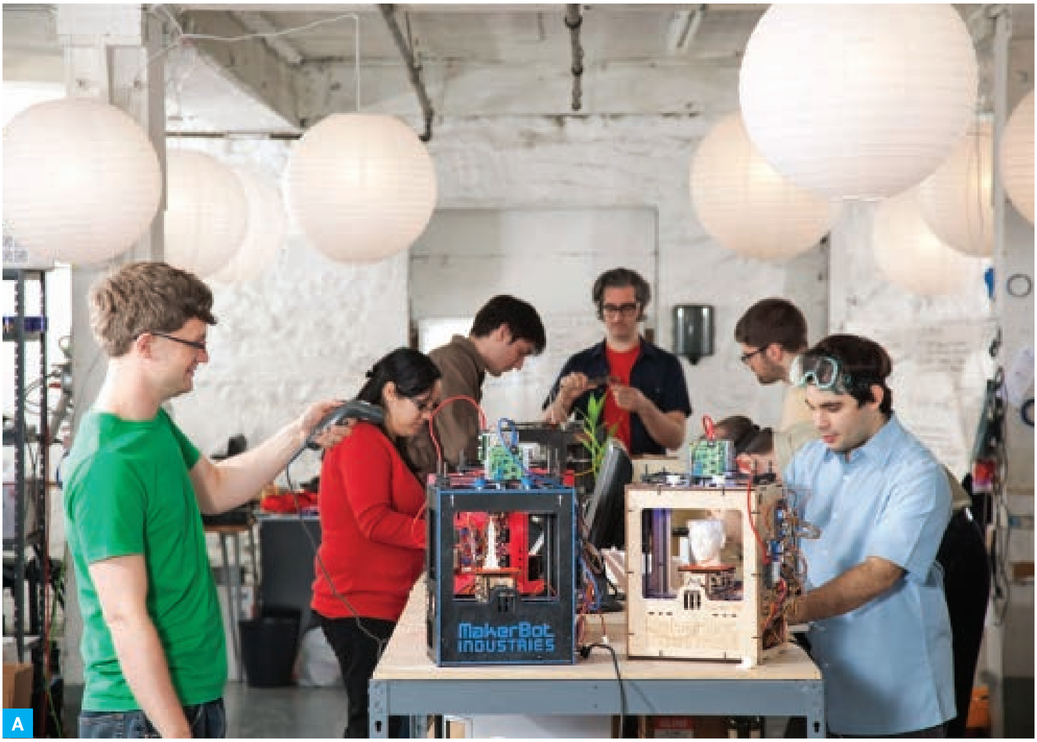
"This is the Wild West of 3D printing," Bre Pettis explains as we stand inside the so-called "Bot Cave." This warehouse space in downtown Brooklyn, N.Y., is home to MakerBot Industries, an open source hardware startup with the mission of making the dream of desktop fabrication a reality for every person on the planet. More hackerspace than superhero lair, the Bot Cave and its shelves are full of electronics, packing materials, and prototype machines. Something about the place has that feeling of a secret hideout, even if the high-tech superhero vehicle in the garage is a single-speed with drop handlebars.

The fledgling firm is in the business of making kit-based 3D printers. Also called "rapid prototyping" or "fabbing," 3D printing is a catchall term to describe a group of technologies that are used to translate virtual 3D plans into real objects. Unlike computer-controlled milling machines, which start with a block of material and whittle it down into a final form, 3D printing involves building up layers of material.

This additive process is commonly achieved in one of two ways: powder bed or extrusion. In the powder bed method, a toolhead deposits a binder selectively across a bed of powdered build material, then lowers the bed and sweeps over another layer of loose powder. This process repeats until the object is complete, at which point it can be lifted from the vat of loose powder and dusted off. In the extrusion method, the toolhead deposits a thin filament of heat-softened material (usually ABS plastic) in layers that harden as they cool, building up a finished object.

Zach "Hoeken" Smith, Adam Mayer, and Bre Pettis founded MakerBot Industries less than a year ago. All three men, who met through Brooklyn hackerspace NYC Resistor, have been active in the DIY community for the past five years (Pettis produced videos for

Illustration by James Provost



The CupCake CNC is significantly smaller than mainframe-style rapid prototypers — so portable that people bring it to parties.

MAKE in years past). The first prototype of the CupCake CNC, MakerBot's flagship 3D printing machine, was finished just in time to bring to Austin's SXSW music, film, and tech conference in March 2009.

Pettis spent the weekend printing plastic shot glasses, and, thanks to lots of positive press and enthusiasm in the online DIY community, by mid-April the three had shipped the first batch of 20 machines to the eager hands of early adopters.

Hoeken, Mayer, and Pettis quit their jobs and lived on savings for the first ten months of the operation. Friends Adrian Bowyer (of the RepRap Research Foundation) and Jakob Lodwick (founder of Vimeo) provided seed money, and since then the business has grown steadily. By year's end, the batch size had increased from 20 to 150 machines, with one batch shipping approximately every month. The basic kit sells for $750.

The technology behind the Cup CNC is similar to the RepRap, the first open source 3D printer, which was designed specifically to be able to replicate its own parts. The CupCake uses the RepRap motherboard, which Smith, 26, designed. It uses his own Sanguino microcontroller platform, itself a compatible derivative of Arduino.

During the design stage for the machine, Smith, Mayer, 35, and Pettis, 37, prototyped parts for the CupCake on NYC Resistor's laser cutter. They worked round-the-clock, settling on a design by the end of their second case of ramen noodles.

Unlike RepRap, whose toolhead moves around depositing plastic on a stationary platform, the CupCake extruder only moves up and down. The 10cm-square build platform moves laterally to spread the thinly extruded filament of plastic along in the shape of the layer being printed.

Having a stationary toolhead minimizes power and size requirements, making the CupCake CNC significantly lighter than the RepRap. And it's leaps and bounds smaller than "mainframe"-style rapid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prototypers — so portable that people bring it to parties. The CupCake whinnies and purrs as it prints. Watching the machine — internally illuminated with LEDs for dramatic effect — is like sitting around a campfire.

MakerBot ships the machine as a kit that includes motors, pulleys, circuit boards, and laser-cut plywood, which means you build it yourself. They accept pre-orders and ship machines in batches. As owners of previous batches build and use their machines, they make suggestions and improvements to the design of the machine. These improvements are implemented in future batches, and are made available to current users as an upgrade.

While the first batches required the painstakingly tedious task of soldering many surface-mount ICs to the motherboard, the latest CupCakes ship with completely assembled electronics, taking a lot of the effort out of the assembly process. The machine comes together like Ikea furniture; it's assembled with little more than an Allen wrench.

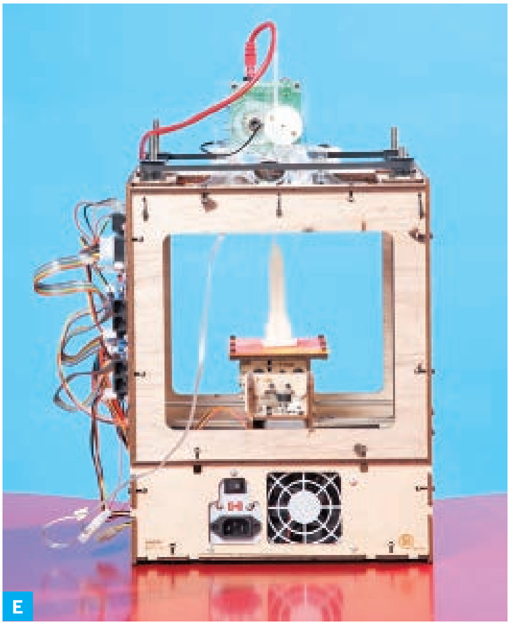
The CupCake CNC is the first of its kind in its field. Pettis confidently compares it to early personal computers like the Altair and Apple I, citing the hack-it-yourself hardware and savvy user base of enthusiastic tinkerers. Where previously having something fabbed required the use of large mainframe-style machines housed in restricted-access research facilities, building a CupCake CNC moves the mainframe onto your desktop.

Fig. A: The CupCake design is in perpetual beta. Fig. B: New CupCake parts can sometimes be built on a CupCake. Fig. C: The CupCake can make parts from a variety of 3D modeling platforms. Fig. D: Samples of the CupCake's output, available in cream and black.

The types of items that the CupCake CNC can make are similar to those of a traditional 3D printer, but the paradigm is completely different. The level of user engagement with the nuts and bolts of the technology is much deeper, and the cost is much lower.

MakerBot operators communicate through groups on Google and Flickr, and rely on each other to solve problems and help keep their machines running smoothly. This distributed support network means less customer support for the three founders to maintain — although they admit to answering many hours of support emails daily.

A parallel project, Thingiverse, is helping the MakerBot community thrive. Launched by Smith and Pettis in summer 2008 as a website for sharing laser cutter source files, Thingiverse was easily



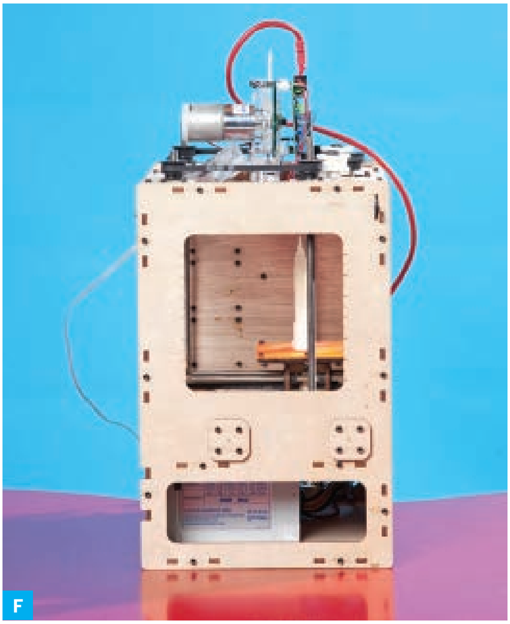


Fig. E: Maximum part size is 4"×4"×6". Fig. F: The case is made from laser-cut ¼" birch plywood. Fig. G: Electronics include a stepper motor driver, motherboard, extruder controller, and opto-endstop. Fig. H: A belt and pulleys move the extruder in the z-axis (shown from above). Fig. I: The Brooklyn HQ.

expanded for sharing 3D files as well. The design of the site encourages the same iterative process used to design the CupCake in the first place.

Thingiverse allows users to create a page for a "thing," which contains machine-readable plans for cutting or printing, pictures or renderings of the thing, and instructions for creating your own. Users can then post their own versions of the thing, or even make improvements and release a derivative thing, which is linked to the original.

Users far and wide can share models for printing. For example, user Zaggo in Offenberg, Germany, posted a model of a whistle, and half an hour later users in New York held the freshly printed object in their hands, hot off the 'Bot. Discussions ensue on each object's page about assembly technique or future revisions. Since problems are solved collectively and publicly, the community benefits.

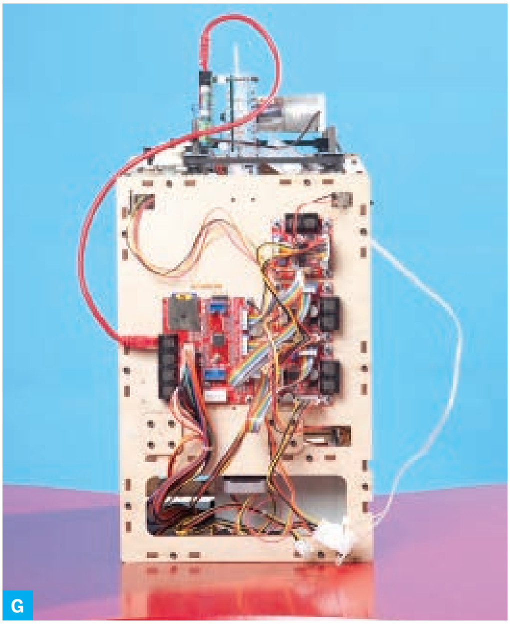
Different versions of the CupCake CNC kit are available to fit the needs of folks who already have some of the components on hand. If you already have access to a laser cutter or CNC toolhead, you can pick up a kit that comes without the laser-cut body pieces, or buy just the extruder. The machine's modularity and its open plans make it attractive to tinkerers who are turned off by hacker-unfriendly "black box" technologies.

Open source modeling for 3D printing is also in development. In hacking circles, the standard (closed source, expensive) 3D modeling platforms like Maya and SolidWorks are slowly losing ground to free, open packages like Art of Illusion and Blender.

Regardless of how they make their models, however, most CupCake users employ Skeinforge (a clunky-but-free Python script) for slicing the virtual object into a set of layer-wise instructions for the plastic extruder and moving platform. Yet another open source package, ReplicatorG, is used to send these toolpath instructions to the machine for printing.

It's possible to circumvent the big 3D modeling software packages altogether by scripting objects entirely through mathematical rules. These scripted or "parameterized" objects can come about in two ways: a script either generates an STL file (the de facto standard data transmission format) to be sliced the same way as a standard model, or it generates the G-code to control the toolhead.

The list of planned improvements to the CupCake CNC is long and exciting. What you can currently print is limited because of a lack of printable support material. Commercial extrusion-based printers have two extruders: one for the main plastic and another for support material, which is deposited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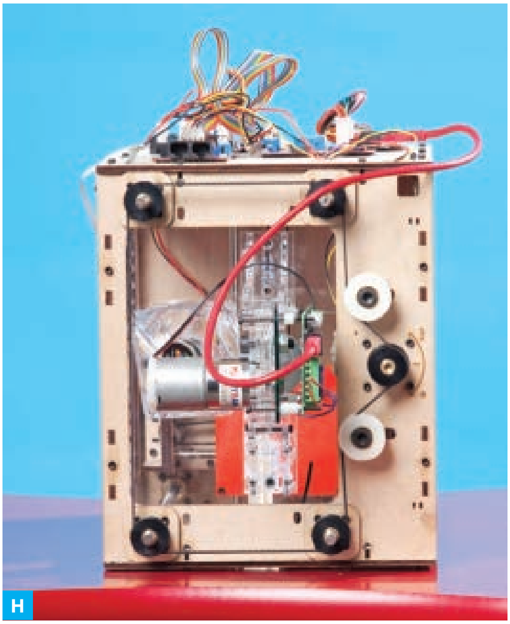
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MakerBot: Specs and Deets

Outside dimensions: 16½" tall × 13" wide × 9½" deep
Weight: 10.5lbs
Build volume: 10cm×10cm×13cm
Printable materials: ABS, HDPE, PLA plastic (soon)
Material strength: Very strong. You can stand on objects without breaking them.
Typical layer thickness: 0.375mm
Printing speed: 30mm/sec
Price: $750 (Basic kit), $950 (Deluxe kit)
Controller software: ReplicatorG (free open source)

where necessary to give the main extruder a place to put plastic that may overhang a previous layer. Implementing support material is a high priority for MakerBot, but it's also a big challenge.

When they were preparing for the Consumer Electronics Show this month, the three hoped to unveil electronics improvements like a new Arduino Mega-based motherboard, onboard USB support, and new microstepping motors for finer motion control.

Other members of the maker community are getting involved, too. Charles Pax, a fellow NYC Resistor member, is working on ideas for a conveyor belt to carry finished objects away from the CupCake's build area to help automate the printing process. "I want a desktop factory," he says, "but I don't want to have to be a factory worker."

But MakerBot's goals don't stop at the CupCake. Plans are already in the works for a desktop 3D scanner, which would pair with the CupCake CNC printer to create the washer/dryer combo of DIY fabrication (see also Andrew Lewis' SplineScan system, page 54).

They're also working on being able to print in PLA, a corn-based biodegradable plastic. The *pièce de résistance*, however, is an extruder that uses cake frosting instead of plastic. The Frostruder prototype is currently in its second revision; the days of CNC cupcake frosting are coming soon.

+ MakerBot Industries: makerbot.com
+ Thingiverse: thingiverse.com
+ Marc de Vinck's blow-by-blow account of building a CupCake: makezine.com/go/cupcakecnc

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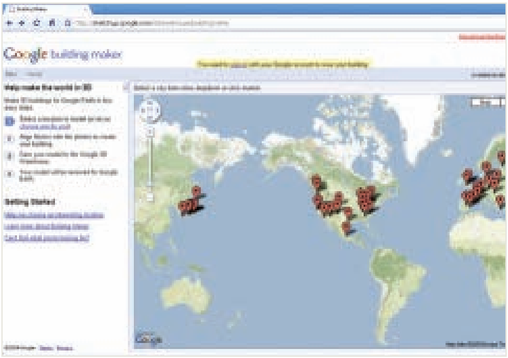
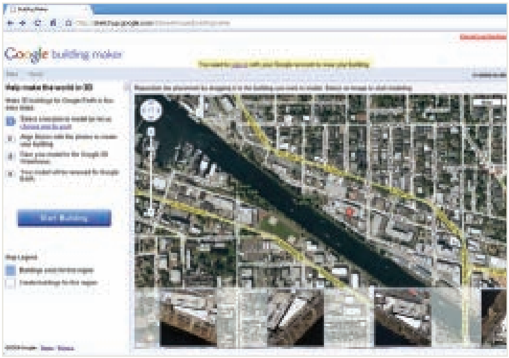
Becky Stern is associate editor of MAKE: Online and CRAFT.

ARMCHAIR ARCHITECT

A new way to create 3D models for Google Earth.

BY COLIN BERRY





I live in Los Angeles, but, like Tony Bennett, left my heart in San Francisco, whose charming Victorians, swooping hills, and rolling fog spark my fondest memories. So when I heard Google was releasing Building Maker, a tool for amateur designers like me to create geo-located 3D models of buildings in their favorite cities, I looked to see if mine was listed: sure enough, there she was. I updated my Google Earth, cracked open an Anchor Steam, and got to work.

Building Maker exists for a couple of purposes. It's a way for Google to beef up the infrastructure of Google Earth — adding height, width, and thickness to those weird, flat maps that comprise the application. But the tool also allows folks to virtually tour a place, to experience a city in all its architectural splendor from their PC desktops. My time spent modeling was to be the trade-off for sharing my love of the City by the Bay.

As it turned out, using Building Maker was easy. From the home page, I chose San Francisco from a drop-down menu, and a zoomable map allowed me to find a particular location I wanted to model. I picked my first apartment building, a flat-topped, blocky rectangle in the Western Addition.

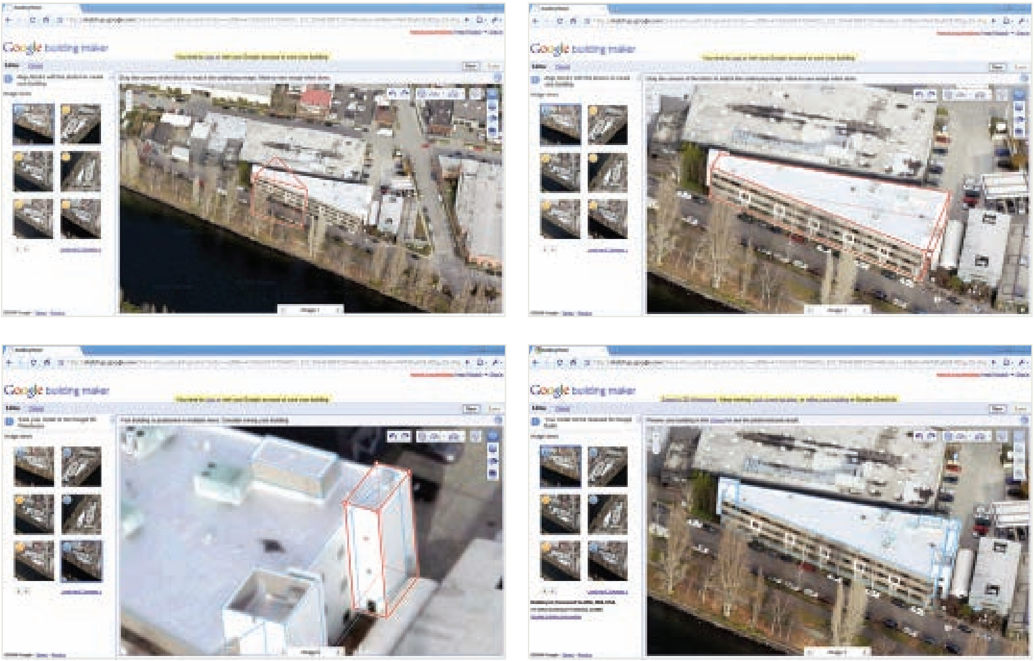
Once I'd selected it, I simply clicked to align the corners of transparent 3D blocks superimposed on a series of satellite photos, tugging here and there to fine-tune each view. Some photos were clearer than others, but Building Maker was smart enough to average my work out as I progressed.

Before long, I'd advanced my building enough to save it in the 3D Warehouse — just a folder, really — awaiting approval by Google's QA experts. I got a message: "Your model will be reviewed for Google Earth."

I was excited! I immediately tackled more complex designs: a building with a gable; a stately Edwardian overlooking Golden Gate Park; my pal Jeff's restored loft in Pacific Heights. As my skills improved, I incorporated more of Building Maker's features, which include a stackable block tool, a magnet for aligning and connecting disparate features — a gable, say, to a roof — and a free-form shaping tool. I previewed each new model in 3D on a city map.

I had some questions, though, so I tracked down Mark Limber, Building Maker's product manager at Google. Limber explained how the tool was born of SketchUp, Google's free 3D modeling software acquired from AtLast, which allows people to design everything from furniture to floor plans.

"We want to create a map of the world," Limber said of Building Maker. "We have 50 cities now, and we're adding new ones all the time." He likened the



Once you choose the city (facing), a zoomable satellite map lets you choose the street and the very building you want to model. Then pick from a series of fully adjustable 3D icons (this page) that most closely match the building shape. The accurate model emerges incrementally through various satellite views.

effort to the internet, explaining that the nascent infrastructure — Google Earth — already exists and merely needs to be filled in. “Plus, we want to create a community of mapmakers,” he said, and I had to admit: I loved modeling buildings in my favorite city.

But I was curious: how long would it take Google to approve — or reject — my models? And what were their criteria for doing so? About a week, Limber said, once Google techs determined it was a reasonably good likeness and not a duplicate of one already further along in the process.

A week passed as I attempted more complicated buildings: places I’d worked and visited. Some were modeled already; others required more time than I was willing to spend. Still, I liked how Building Maker made me see architecture anew, encouraged me to scrutinize a building’s aesthetics. Even an edifice as drab as the DMV became interesting once I discerned it was made of a series of staggered slabs.

Yet after a week, my models remained unapproved. I phoned Limber back. The popularity of Building Maker’s launch meant they were a little backed up, he explained sheepishly. But at my behest, clicking into my warehouse, he crowed, “Those are awesome!”

“We want to create a community of mapmakers.”

I glowed with pride.

Sure enough, a few days later, my little phalanx of San Francisco models appeared on Google Earth — abrupt, odd-looking edifices springing up from the flat map and beginning to populate the city’s impossible topography. Every day I see more of them, modeled by me and others, and soon anyone will be able to tour the San Francisco I know and love. I hope that in time, Google will perfect a technology that models the fog, too, that clings like cotton candy to her hills in the afternoons.

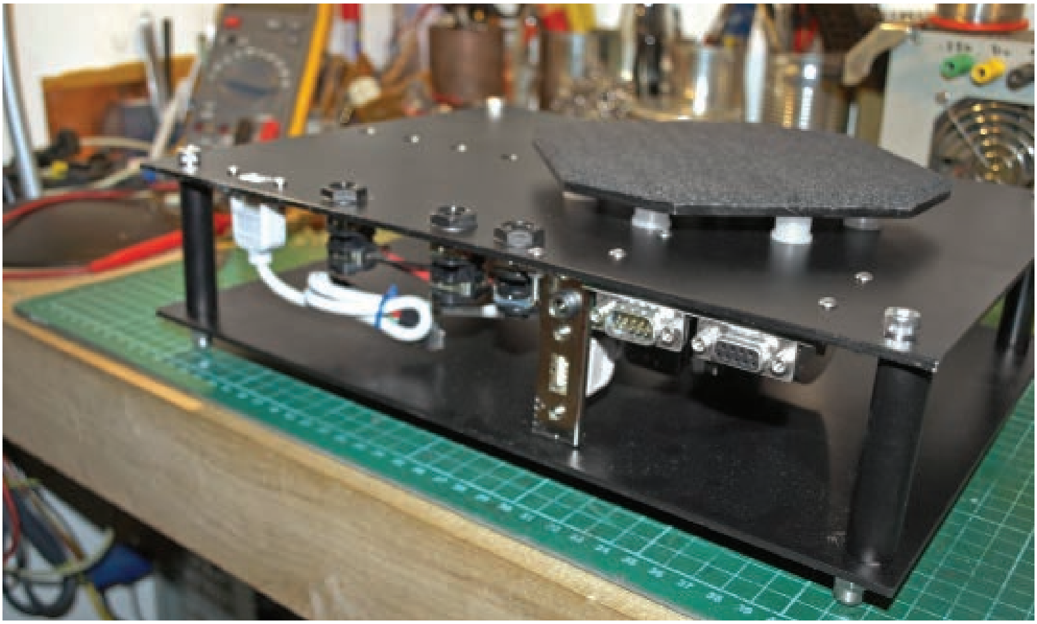
+ Building Maker: sketchup.google.com/3dwh/buildingmaker.html

Colin Berry (colinb@sonic.net) is a freelance arts and design writer who lives in Los Angeles. He is the author, with Isabel Samaras, of *On Tender Hooks* (Chronicle Books).

DIY 3D SCANNER

Introducing the SplineScan computer-controlled turntable.

BY ANDREW LEWIS



Photography by Andrew Lewis

The last couple of years have seen an explosion in home fabrication, with fantastic projects like RepRap and Fab@Home really helping to bring the open source community together. Unfortunately, 3D scanning — in many ways the flipside of the home fabrication coin — seems to have fallen by the wayside.

I decided to start the 3D scanning ball rolling by creating the SplineScan computer-controlled turntable. The turntable uses a gearbox for precise positioning, and has fixings for lasers, lights, and cameras. The obvious use of the turntable is for 3D scanning, although it can be adapted very easily to rotate objects for accurate photography or interactive display.

I'm currently using the turntable to archive and measure ancient artifacts as part of my Ph.D. studies (mara-3d.org), and I have to say that I'm very happy with the results so far.

The parts list might look a bit daunting, but the project isn't difficult to make. The scanner itself consists of 3 main parts:

Chassis This is the backbone of the scanner. Everything fits onto the chassis, and it needs to be rigid enough to withstand the weight of all the other components, and whatever you intend to put onto the turntable.

Gearbox This part takes the turning force of the stepper motor and turns it into something more suitable for our needs. It's a simple design with only a few components.

Electronics The brains and nerves of the scanner allow you to control the turntable from your computer. The wiring isn't difficult, and only limited soldering knowledge is required.

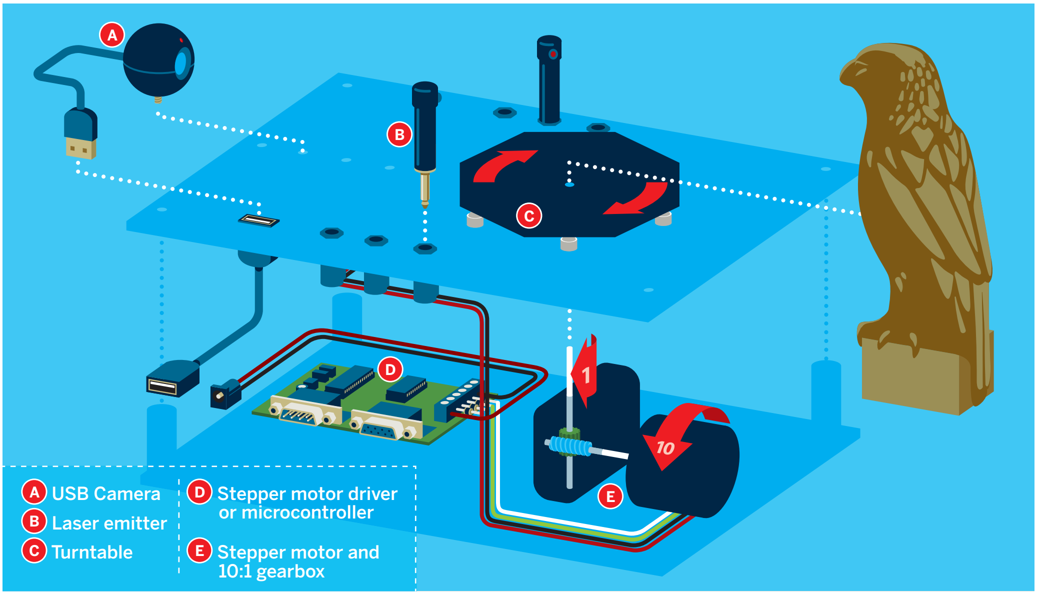


Illustration by James Provost

MATERIALS

PC running Linux or Windows
USB A-to-A cable

FOR THE CHASSIS:

Aluminum sheets, 333mm×250mm×3mm (2)
Try Technobots in the U.K. (technobots.co.uk). Rigid sheet plastic may suffice, but I find metal easier to work with and more durable, and it can be finished with conventional spray paints.
Spray mount adhesive or glue stick
Rear panel USB double socket
22mm copper pipe, 65mm lengths (4) Smaller or larger diameters will also work.
Plastic ball casters (6) Technobots part #4262-100
M3×25mm bolts with nuts (9)
M4×75mm bolts with nuts (4) Threaded bar also works.
Photographic gimbal head
2.5mm DC socket, inline mounting
¼" mono jack sockets, panel mounting (6)
Red and black hookup wire, about 1m each 20 gauge or so (12V at 2A)
1N4001 diode (optional) or similar power diode

FOR THE GEARBOX:

Bipolar stepper driver/motor combo Milford Instruments part #5-595, ppmilinst.redcetera.com. You can also use an Arduino microcontroller with a suitable motor shield, from makershed.com; future versions of this project will probably use Arduino.
Plastic worm drive Technobots part #4600-030
Nylon gear with brass hub, 10-tooth, 4mm bore Technobots part #4600-131
Silver steel shaft, 4mm×333mm Technobots part #4426-004
Miniature flange ball bearing, 4mm bore, 8mm OD, 3mm width Technobots part #4255-162
Aluminum project enclosure, 160mm×103mm×43mm Maplin Electronics part #1455N1601, maplin.co.uk
12V 2A power supply
Packing washers (optional) for spacers

FOR THE TURNTABLE:

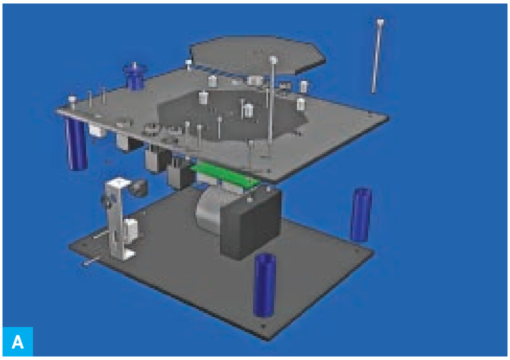
3mm sheet aluminum, 150mm×150mm
Epoxy or 3mm bolts with nuts
Sticky-backed foam sheet, or matte finish paint (optional)

FOR LASER EMITTERS:

LM317 voltage regulator ICs (2)
Resistors: 240Ω (2), 620Ω (2) I used these with the LM317 to get 4.5V; your resistor values will depend on your laser's voltage needs. The calculator at reuk.co.uk/LM317-Voltage-Calculator.htm is handy. Aim low on the voltage, since lasers can be quite fussy about maximum voltage.
Neutrik ¼" cast phono plugs (2)
½" copper pipe, about 6" lengths (2)
Laser line generators (2) I found 5mW, 5V infrared line laser modules cheap on eBay.
½" plumbing end caps (2)
Hot glue and/or setscrews

TOOLS

Hacksaw or band saw to cut aluminum sheet and copper pipe
Epoxy
Drill press or hand drill and drill bits
Screwdrivers
Allen (hex) wrenches
Soldering iron and solder
Electrical tape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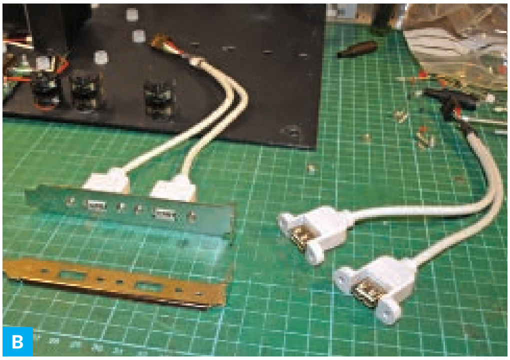
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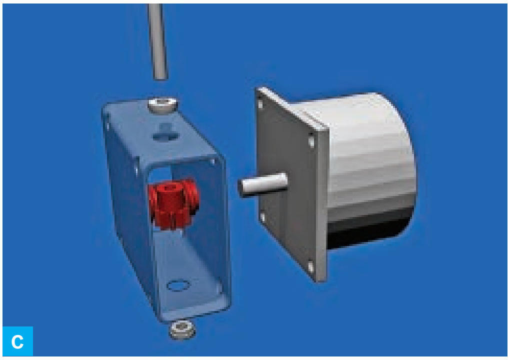
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Build Your 3D Scanning System

Time: **A Few Weekends** **Complexity:** **Moderate**

1. Make the chassis.

Print out the top and bottom templates from the SplineScan website (splinescan.co.uk/downloads/construction) and glue them to the aluminum sheets. These templates show you where to drill all the holes. Drilling them will be easiest if you have access to a drill press, but a hand drill will work just as well.

Drill 4mm holes in the corners of the top and bottom plates, to accept the 65mm bolts that hold the chassis together. The 6 larger holes along the longest sides of the top plate are for the ¼" audio jacks. The outer diameter of the jack may vary depending on the brand you use.

Use the exploded parts diagram (Figure A) and the template to decide on the hole sizes for the other parts of the chassis. Hole sizes will vary depending on product brands, and the best rule (after measure twice, cut once) is to start small and drill bigger if need be.

The small oblong marked on the top template is just a guideline for positioning the USB socket.

The best source of USB sockets is a computer port extender that fits inside your computer and connects to the motherboard (Figure B). Most computer shops have these on the shelf, but the design isn't standard and the mounting holes can be in any position. If you want to fit your USB socket to the chassis, now's a good time to mark and drill the holes using your socket as a template.

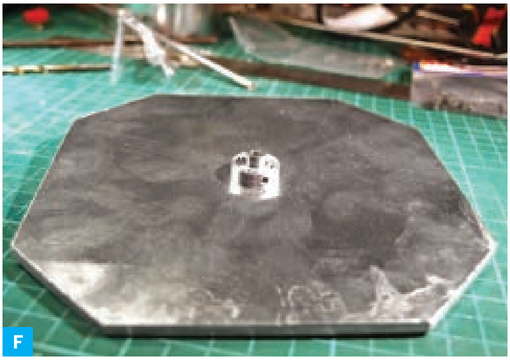
The 2 aluminum plates are held together by 75mm M4 bolts and spaced apart by bits of copper (or plastic) pipe. The exact diameter of the pipe is not important. Cut four 65mm lengths of pipe and put one at each corner of the top and bottom plates. Feed the bolts through the corner holes in the top and bottom plates, and secure them temporarily with a nut. Make sure everything lines up correctly, and then disassemble the parts again.

Now that all the holes are drilled, you can apply any finishing touches, like painting the copper and aluminum, and polishing any plastics.

The turntable is supported by 6 plastic ball casters, which can be pushed into place at this stage. These should be a tight fit, but a little glue won't do any harm.

Install the six ¼" jacks, which go down both sides of the top plate; these will let you use 2 laser

E



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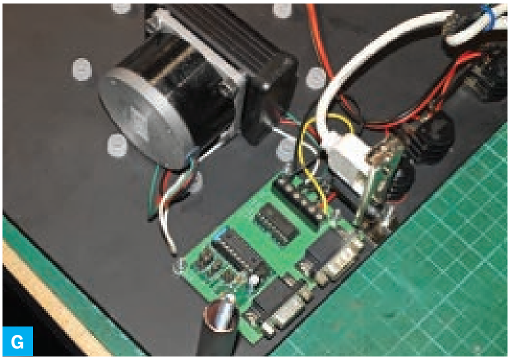

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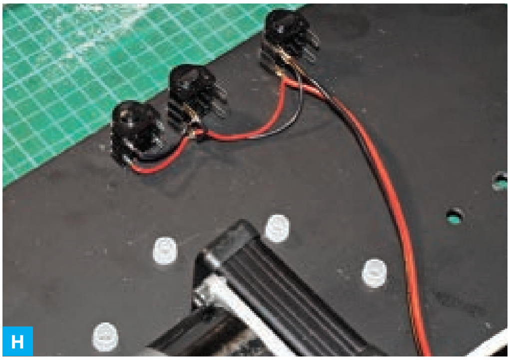


H

modules in various positions. With that done, you can turn your attention to the gearbox and motor.

2. Make the gearbox.

The gearbox is easy to make with readily available parts. It gives a 10:1 reduction ratio, which turns the 1.8° stepper motor into a 0.18° motor and puts a right-angled turn into the motor shaft (Figure C).

Start by cutting down your aluminum box so that it's just wider than the motor. The exact width isn't important, as long as you leave enough of the box on either side to allow for the plastic end caps.

Drill a hole through the center of the largest side of the box, to allow the shaft and the plastic worm drive to pass inside. Drill holes at the corners of the box that line up with the mounting holes on the motor, using the motor as a template.

Next, enlarge the hole in the plastic worm drive to 6.5mm so it will fit onto the motor shaft, and cut the worm drive to the length of the motor shaft. It should be a tight fit, and you might want to dab a little epoxy on the end to make sure the shaft stays put.

Drill 8mm holes through the narrowest sides of the box, to house the miniature shaft bearings. This step is quite tricky; the holes need to be positioned so that plastic cog and the worm gear mesh together accurately. Measure carefully, and allow plenty of tolerance in the motor mounting holes. Remember that it's much easier to reposition the motor than to reposition the bearings.

Push-fit the bearings into the holes (they shouldn't need glue) and then slide the shaft through the first bearing. This will be quite a tight fit, and might need a gentle tap with a heavy object to push the shaft through.

Slide the 10-toothed gear onto the shaft inside the case. Continue pushing the shaft down through the bearing until it fits into the second bearing.

Now fit the motor (with the worm drive on the shaft) into position and bolt it in place. You can also move the 10-toothed gear on the 4mm shaft so that it meshes with the worm gear, and fix it into position using the small setscrew on its brass hub.

Fit the end caps in place, and you've almost completed the gearbox. Screw the gearbox into the chassis top with M3 screws, using the top as a template for the holes in the gearbox (Figure D). If you use a 3.5mm drill bit, you can tap the holes in the gearbox and screw directly into it. You may want to include some packing washers between the top of the gearbox and the top plate of the chassis, to accommodate the plastic sides of the gearbox.


I


J


K


L

3. Make the turntable.

Cut the turntable from a piece of 3mm aluminum or rigid plastic using the template at splinescan.co.uk.

Drill a 4mm hole in the center (Figure E, previous page) and fix a 4mm mounting hub in position, using a 4mm shaft as a guide. You can glue this if you wish, but I modified the hub and used 3mm countersunk bolts to hold the hub in place (Figure F).

Fit the turntable in position on the chassis, and cut the shaft so it won't protrude above the turntable. Fix the turntable onto the shaft by using a long Allen key to tighten the grub screw (setscrew) in the hub on the underside of the turntable.

To finish the turntable, you can cover it in sticky-backed foam or paint it with a matte finish.

4. Mount the electronics.

The Milford Instruments motor controller takes a serial port signal and converts it into motor movement.

NOTE: You can also use an Arduino with a suitable motor shield to control the stepper motor, and future versions of the scanner may use Arduino as standard. The truth is that I already have several of the Milford Instruments controllers left over from another project, and I don't have any spare Arduinos at the moment.

Attach the controller to the top of the chassis using M3 bolts, with a couple of extra nuts as spacers between the controller board and the top plate.

The motor wires connect directly to the controller board, leaving only the power wires, which are attached to a 2.5mm DC socket on the side of the chassis (Figure G).

I mounted the DC socket in an old blanking plate from the rear of a PC (the same plate I took the USB socket from). The DC socket is wired directly to the USB socket in the top of the chassis plate (red to red, black to black). Connection is made to the PC using an ordinary USB A-to-A cable.

The motor controller needs 12V to operate, and a 12V 2A power supply should be adequate to run the system.

The power supply also powers the ¼" jacks (Figure H). You can connect the jacks directly to power via the DC socket; this is acceptable if you don't like soldering and you want to keep things as simple as possible.

The drawback is that the power to the jacks will be constant, meaning that any laser emitters or lights plugged into the system will always be switched on, even when the machine is idle.

M

N

A more elegant solution is to draw power from the motor, using diodes to prevent current feeding back between the coils (Figure G). The advantage of this method is that when the controller board powers down the motor, any lights or laser emitters will switch off. If the motor is idle but locked, the lights will be switched on.

5. Make 2 laser emitters.

If you're interested in 3D scanning, then you'll need to make laser emitters to plug into the ¼" jacks. Similarly, you could make plug-in LED modules for illuminating objects on the turntable.

Power taken from the jacks will be around 12V, and since most laser emitters and LEDs use substantially less, you'll need to step down the power using a monolithic voltage regulator. I recommend the LM317, which can be wired to produce a range of different voltages.

The design of the emitter casings is quite simple. I used Neutrik ¼" cast phono plugs, which fit neatly into ½" copper pipe (Figures I, J, and K). I had ample space to fit the power regulator circuit (Figure M) and a tiny laser line generator that I got on eBay.

I used a standard plumbing end-cap to finish the top of each emitter and then painted them black (Figure L), and held the copper tube onto the cast plug using a combination of hot glue and grub screws.

6. Install and run the control software.

Controlling the turntable is very easy using either Milford's own software or simple serial communication. I have provided a Python library to interface with these motor controllers, motorcon.py, in the code section of my website at monkeysailor.co.uk/code.php.

My "Babylon" version of the SplineScan software (I used it to scan Babylonian stone tablets) will support this turntable directly. It's completely open source and was released in December 2009 at splinescan.co.uk, so if you're interested in 3D scanning then you're in luck.

SplineScan Babylon uses Python and Pygame, and has been designed to work on Linux, although it should work quite happily on Windows machines, too.

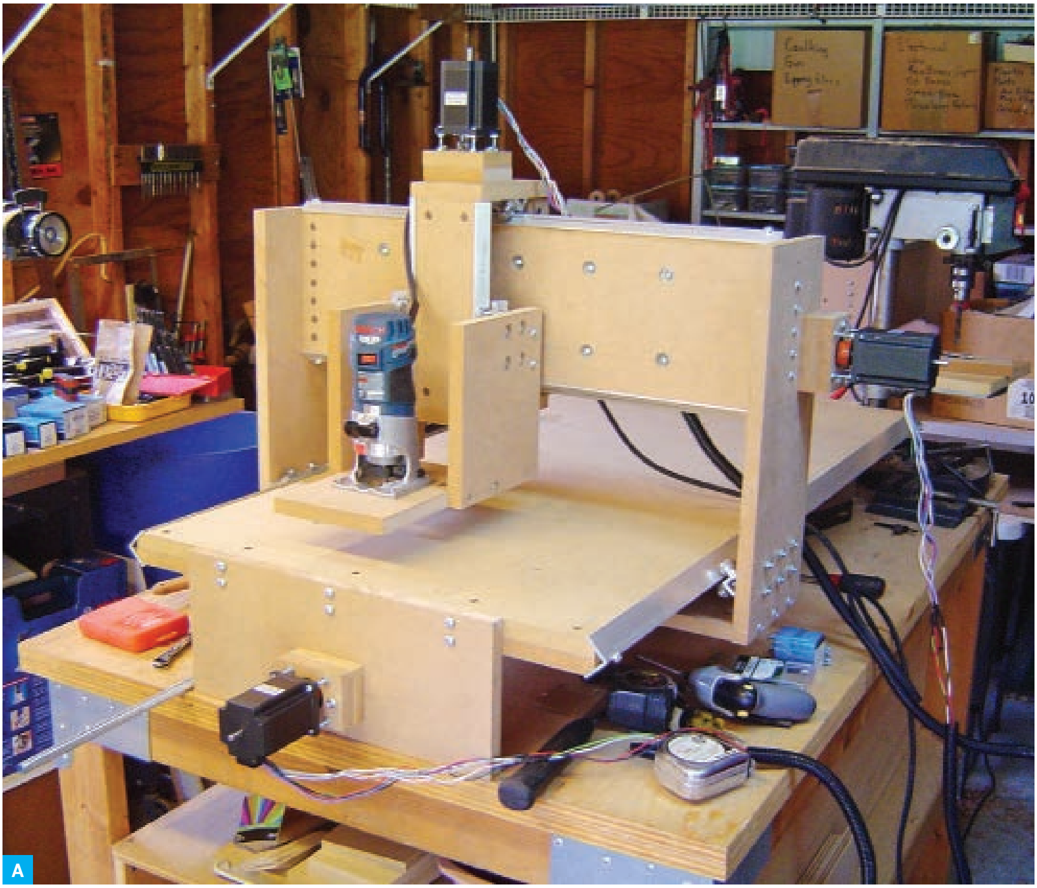
So, there you have it: an earnest attempt at a computer-controlled turntable suitable for open source 3D scanning, photography, or display. I mounted mine in an outer casing (Figure N), so I can scan objects without bouncing laser light all over the room. In the future, I might even modify the design to include a moving extrusion head, and develop a polar 3D printer.

Andrew Lewis (andrew@monkeysailor.co.uk) is a keen artificer and computer scientist with interests in 3D scanning, computational theory, algorithmics, and electronics. He's a relentless tinkerer whose love of science and technology is second only to his love of all things steampunk.

YOUR OWN CNC FOR LESS THAN $800

An overview from the co-author of the new book *Build Your Own CNC Machine*.

BY JAMES FLOYD KELLY



A

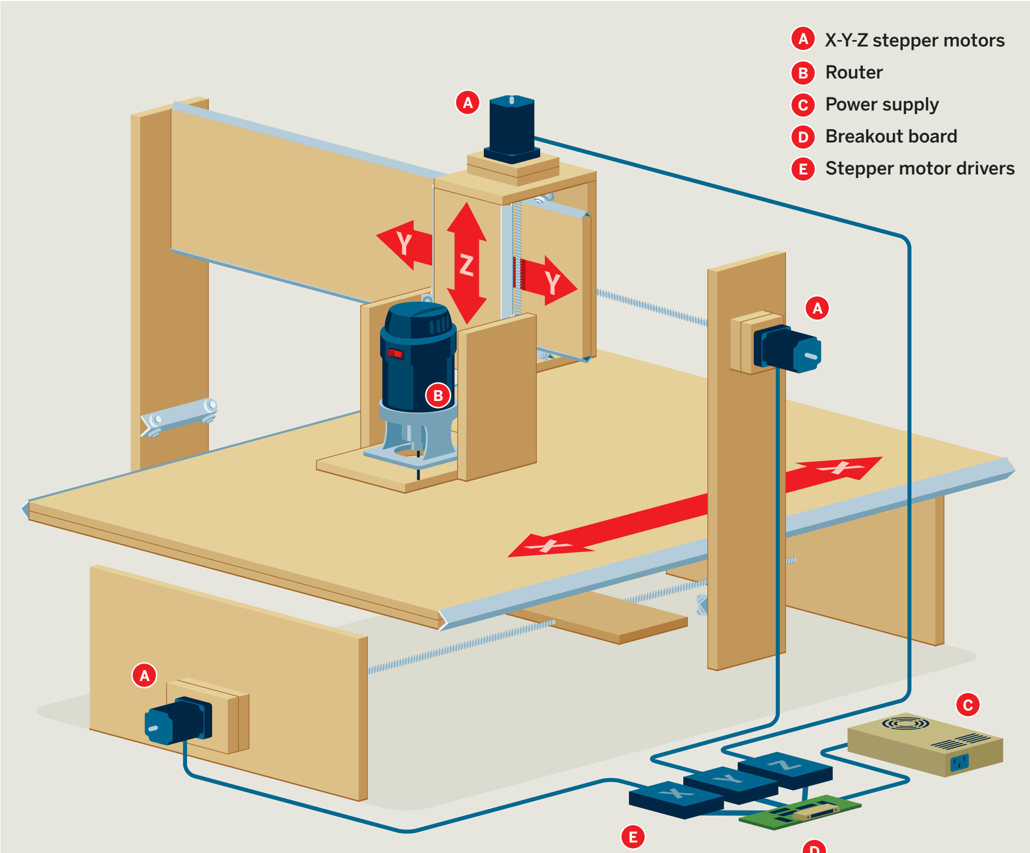
Photography by James Floyd Kelly

I never expected to have a working CNC machine in my workshop, but there it is. What makes it even better is that I didn't have to spend a small fortune on it ... and neither will you.

While small desktop CNC machines can be found between $2,000 and $5,000, and workbench-sized machines are costing $7,000 and up, I'm happy to tell you that for less than $800 you can have a 2'×4' CNC machine of your own.

Of course, this being MAKE, you've probably already guessed that it's a DIY project, but before you start getting nervous about whether you have the skills and tools to do this, let me add that phrase all us DIYers love to hear: if I could build this machine, you can build this machine.

And I've documented the entire process with my co-author, Patrick Hood-Daniel, the designer of this particular machine, in our new book, *Build Your Own CNC Machine*, from Apress.



B

Illustration by James Provost

Machine Overview

You can see the final CNC machine in Figure A. Its frame is built from medium-density fiberboard (MDF) — sturdy and strong, affordable, easy to cut, and best of all, no welding required. The entire machine can be built from just two 4'×8' sheets of MDF. Its parts are connected by a combination of bolts and cross dowels, providing the machine with a tough and reliable frame.

Believe it or not, many of these machines have been built with nothing more than a miter box, saw, portable drill/screwdriver, and a tap (check out the videos at buildyourcnc.com for proof), but having a drill press, table saw, and a few other basic workshop tools will make your build go a little faster and smoother. Ultimately, though, a DIYer can easily build this machine with a bit of patience and the most basic of tools.

The machine uses threaded rod for lead screws (Figure C, following page). Three stepper motors each mate to a lead screw to control the forward/backward (x-axis), left-to-right (y-axis), and up-and-down (z-axis) movements of the machine's router. A full-sized router or smaller laminate router (also called a hand router) can be attached to the CNC machine (Figure D) and to the nozzle of a dust collection system (and CNC machines create a lot of dust).

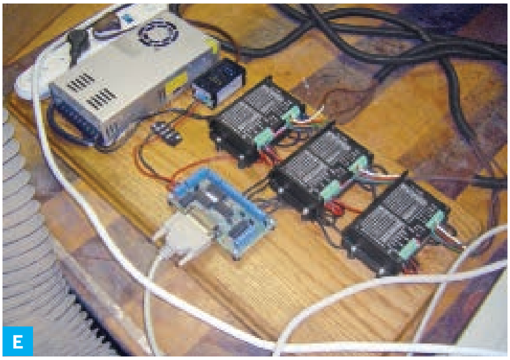
The three stepper motors are controlled via a small collection of electronics: three stepper motor drivers, a power supply, and a breakout board (Figure E). The breakout board connects to your PC, which runs the control software. We use the free version of ArtSoft Mach3 (machsupport.com) but any CNC control software can be used.

How well does it work? That depends on what you do with it. Patrick uses his DIY CNC machines to cut and drill the parts required to build more DIY CNC machines — how's that for trusting in your own design?

I'm just getting started with using mine, but engraving is something that a novice (like me) can get immediate satisfaction from, and the results are sharp and clear (Figure F).

C

D



E

F

Building the Machine

If you're wondering whether building this machine is really within your skill range, let me assure you that if you're comfortable cutting wood with a table saw or handheld circular saw, if you can change and use bits with a drill press or handheld drill, and if you can use a ruler, you can do this. (If you're a master DIYer with tools galore, you won't have any trouble building this machine.)

This project is great for shop classes, after-school programs, and Boy/Girl Scout troops, but it's also the perfect parent-child project. I don't have many opportunities to work with my dad these days, but I really enjoyed working with him as we built two (!) of these CNC machines together. Having someone else to double-check measurements and hold pieces as you drill or bolt them down is invaluable, but it's also nice to have someone else around to troubleshoot a problem as well as share the success when the machine runs for the first time.

Our goal for writing the book was to provide a good walk-through of the process, with plenty of pictures, from start to finish. After a handful of chapters that explain CNC, the basics of joining MDF pieces, and building the unique parts that give the CNC machine the ability to move smoothly, you'll get straight to the electronics and building the CNC machine frame.

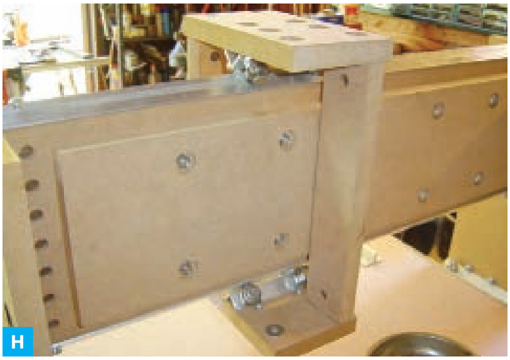
Your first task will be to cut, drill, and assemble the machine's tabletop that also serves as the x-axis (Figure G). Completing the tabletop will not only give you a place to attach the remaining components of the machine, but you'll also become quickly familiar with the handful of standard tasks required for the rest of the project (counterboring, using cross dowels to connect parts, cutting lead screws, and so on).

As you build your machine, you'll cut and drill some special pieces called bearing and rail assemblies, or BRAs (Figure H). These allow your CNC machine to move smoothly and accurately on all three axes by riding on another piece of angled aluminum rail. Patrick's method for building and using the BRAs is extremely simple as well as reliable.

Building chapters are short, so you'll always have a good starting and stopping point. You'll begin with the x-axis, add on the parts needed for the y-axis (Figure I) and finish up with the z-axis (Figure J).

While building the CNC machine frame, you'll also be given instructions for wiring up all the electronics. We tell you exactly what motors, drivers, and power


G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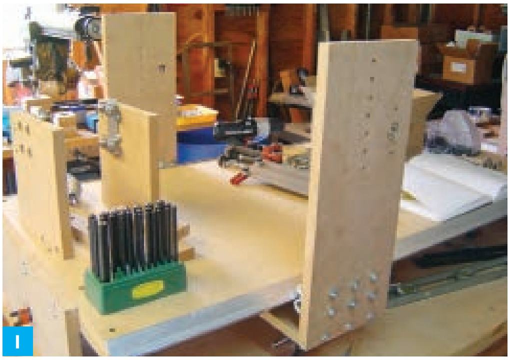
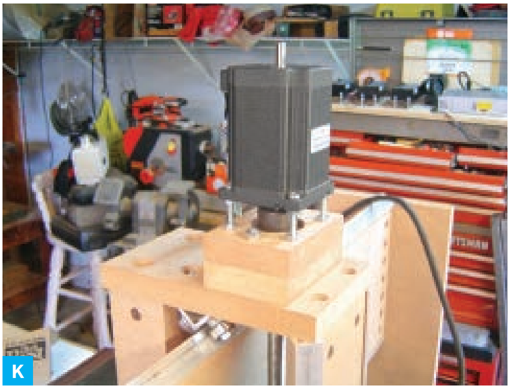

I


J

supply to buy — you can easily substitute parts but you'll need to read the documentation carefully to match it up to our wiring instructions. Basic soldering skills are helpful, but not required; you can easily skip the soldering by using wire nuts to connect wires.

When you're done, you'll bolt the stepper motors onto their respective axes (Figure K) and connect them to the lead screws. Next, you'll mount your router to the router plate, follow our instructions for installing and configuring the Mach3 software, and then put your new CNC machine through a few tests to verify movement along the three axes.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Have Fun

Building my own CNC machine was just as enjoyable as using it. During the assembly, I learned some new woodworking techniques, became more proficient with a table saw, and learned to love the Forstner bit (which I highly recommend for counterbores and drilling holes in general).

I've also started to dig deeper into the use of CAD software for designing, and CAM software for converting my designs into G-code, the instructions that Mach3 uses to control the motors and direct the router.

The most surprising thing I've learned after completing this project, however, is that *I* am the real limit to my CNC machine — the machine is just waiting for me to learn new techniques and methods to push its capabilities further. You'll find, as I have, that after building your CNC machine, the real work is just beginning.

James Floyd Kelly (byocnc@gmail.com) is a freelance writer in Atlanta. He is the editor-in-chief of the Lego Mindstorms NXT blog, The NXT Step (thenxtstep.com).

DIRECT DIGITAL WEDDING RINGS

Create custom jewelry using CAD software and a 3D printer.

BY JONATHAN OXFORD

After giving my wife a handmade plastic faux-diamond engagement ring, I decided I'd better get serious and come up with more permanent wedding rings. The polycarbonate ring was funny, but even made out of an engineering plastic, there was no way it would last.

We scoured the vintage jewelry shops, and then the dreaded mall stores, until we finally decided that the only way to get exactly what we wanted was to design the rings ourselves. And like any self-respecting industrial designer, I'm prone to believing that I can design and make anything.

Luckily for me, the making part turned out to be easy — I simply sent my CAD design to a 3D wax printing house, then sent the wax prints to a jewelry foundry and got back platinum rings.

Photograph by Sam Murphy

MATERIALS & TOOLS

3D CAD software I used SolidWorks.
Access to a 3D wax printer
Access to a jewelry metal foundry
Finishing and polishing tools

Design and Make Your Rings

Time: Variable **Complexity:** Moderate

1. Design the rings in 3D CAD software.

If you're into highly detailed, complex forms you'll probably need some experience using sophisticated software, but for simpler shapes you can even use the free Google SketchUp. There are many CAD platforms out there, some of them specifically for jewelry design. I chose SolidWorks because it's what I use every day (Figures A and B).

2. Scale your design for the material being cast.

Each metal has a different shrinkage rate, so the last operation you do in the CAD process should be to scale the design to account for shrinkage. The casting house you choose may use a custom-formulated metal, so ask them what the shrinkage will be.

3. Output the design file.

Once the design is done and scaled, output it to whatever file format your 3D printing house needs. Typically this is an STL file (Figure C), but not always. The printing house will let you know what they need.

4. Email the file to a 3D printing house.

Then wait for the 3D wax prints to show up in the mail. Choose a place with a machine that's designed specifically for direct lost wax casting. I wasted a bunch of money having the designs printed in a plastic material that I was told could be burned out of the investment (the mold) directly.

This may work for some metals, but for platinum it produced unusable parts with air bubbles. In the end, I went with a high-precision wax printer designed specifically for jewelry casting.


A


B


C


D

5. Send the wax prints to a jewelry foundry.

If you're a hobbyist jewelry maker, you may be able to cast the rings yourself. Not having a metal foundry in my closet, I chose Platina Casting in New York to cast them in platinum.

NOTE: You'll pay for a little bit of extra material in the form of a sprue attached to the design. This is where the molten metal enters the mold cavity. The caster will cut the sprue as close as possible, but a bit will remain that will contribute to the total weight. The sprue will be sanded off during the finishing process.

6. File, sand, and polish — a lot!

Or have a professional jeweler do it for you. Since I was having stones set, I chose the latter. Stone setting is a complex task better left to the professionals.

For my final file output, I filled in the area where the stones would be except for a small hole to locate the center (Figure D). This step was recommended by the jeweler who did the stone setting.

Stone setters have special tools to create the correct hole shape for each specific stone. Trying to predict these shapes before shrinkage is risky and could leave you with not enough material. Better to leave some extra for the setter to work with.

TIP: Inside sharp corners are almost impossible to polish. Even the small raised areas around the holes in my ring had this problem. Making separate parts that can be soldered together after polishing, or even adding small fillets to inside corners, can help.

Alternatives

Of course, creating a simpler design and not setting stones will save time and money and will allow you to do more of the work yourself. Also keep in mind that precious metals are very expensive and currently rising in cost on a daily basis.

Most jewelry foundries use silver to test designs before wasting expensive gold or platinum, and silver can be very affordable as the final material. Alternately, try titanium, copper, or bronze if you really want something unique.

Jonathan Oxford is an industrial designer living and working in San Francisco. He is also a sculptor, machinist, welder, woodworker, and all-around tinkerer.

OPEN SOURCE SELF-REPLICATOR

This plasma cutter promises tool interchangeability, and synergy with its RepRap cousin.

BY ABE CONNALLY

This is not just an ordinary CNC, plasma-cutting monster of a machine. It can copy itself, too. And on top of being inherently self-replicating, the project is completely open source. Meet Open Source Ecology's (OSE) newest badass tool: RepTab.

Based on the much-praised RepRap project, RepTab is an open source CNC plasma cutter. It boasts a 4-foot by 8-foot work area, and can cut anything that conducts electricity, from aluminum to steel, up to 1 inch thick.

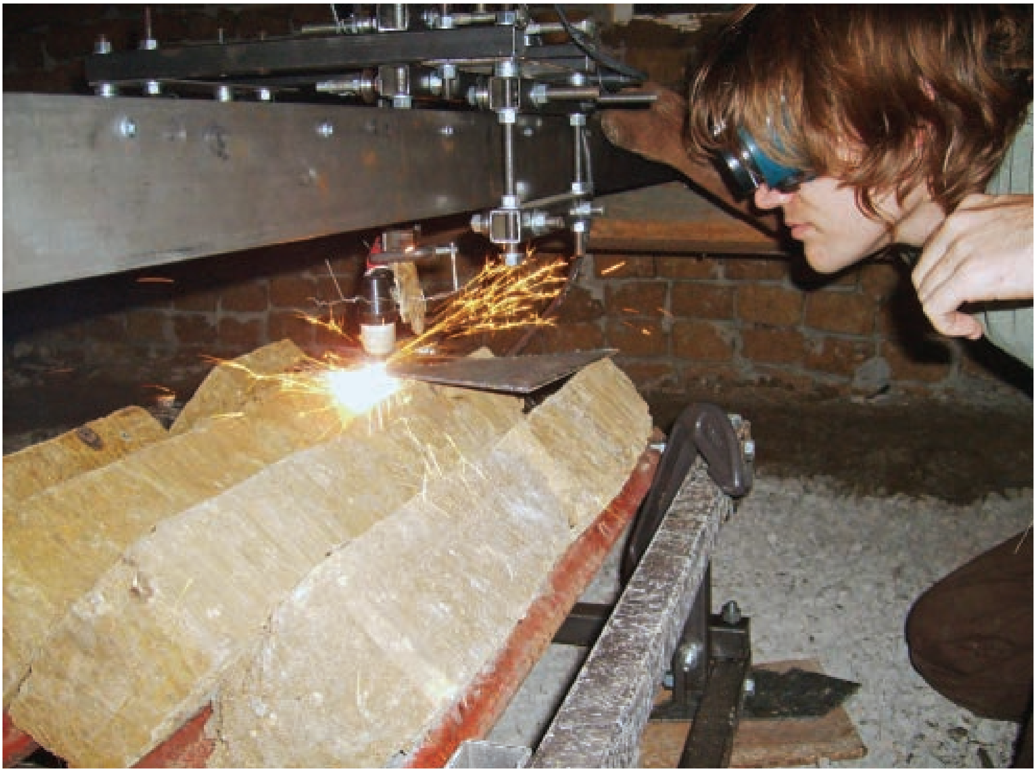
Made mostly of steel, the RepTab torch table can actually make a copy of itself (minus the motors and controller electronics). The machine was designed on and is run with popular open source software, including Blender (conceptual designs), Inkscape (cut paths for the machine), Linux (laptop OS), and EMC2 (motor controller).

One of the interesting features of RepTab is that the cutting head is interchangeable (router, plasma, oxyacetylene, laser, water jet, etc.), making it versatile and extremely useful.

"Other machines make that difficult without major modifications," says Marcin Jakubowski, the group's founder and director. "We can make up to 10-foot-long windmill blades if we modify the table as a router table. That's pretty useful."

But RepTab is more than a self-replicating machine. It's also been a major experiment in developing open source hardware at the group's

Photograph by Marcin Jakubowski



IN THE THICK OF IT: (Opposite) Lawrence Kincheloe and Marcin Jakubowski pose inside the RepTab cutting table. (This page) Kincheloe practices cutting with the plasma cutter tip on the RepTab.

Photograph by Lawrence Kincheloe

Factor e Farm headquarters in rural Missouri.

Lawrence Kincheloe, who created the current RepTab design, says his motivation to contribute to the project was to "answer some serious questions as to how to make a living doing open source work."

The team hopes that the current prototype will lead to a design that can be successfully marketed to the DIY community as an open source product or kit.

"The hardest part," Kincheloe says, "is balancing between keeping it as open as possible and still making it viable and worthwhile to distribute and develop."

RepTab can be built for $1,000, if you don't count the laptop and plasma cutter. So, it's not the cheapest tool in your shop, but the team hopes that open source collaboration will help bring the cost down, as well as improve the overall design.

"I believe that's where community development can really play a big part in making it possible for everyone who wants to get one," says Kincheloe.

He envisions a time when the RepTab project can incorporate RepRap components to create a completely new concept that could work with many different materials.

"The synergy between the two machines means that each has the possibility to work with materials the other isn't equipped to handle, and also hints at the possibility of merging the functionality into a table that can work with both metals and plastics," he enthuses. "At the moment, if you put a plasma cutter onto a RepRap Darwin, it would likely melt or cut through the table!"

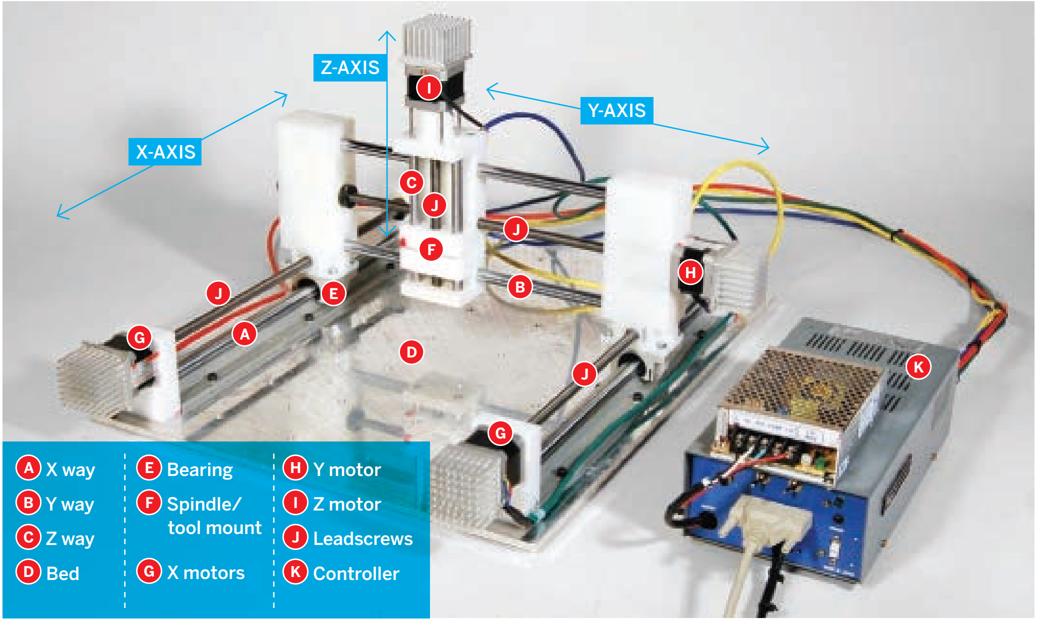
RepTab is the latest in OSE's open source hardware toolbox (see their LifeTrac tractor in MAKE, Volume 18). The group maintains a well-documented website and wiki for every project. Makers are encouraged to join in the development of RepTab at openfarmtech.org/weblog/?cat=214.

Abe Connally follows open-source hardware projects from his secluded off-grid hideaway. His experiments with architecture, energy, and sustainable systems are documented at velacreations.com.

CNC MACHINE KIT

Meet the mighty micRo, a tabletop CNC robot kit from Lumenlab.

BY STEVE LODEFINK



For the longest time, I've wanted to start tinkering with CNC milling and routing. But despite the number of well-documented homebuilt CNC machines out there, I could never quite get the momentum to start building one. So I decided to fast-track my entry into DIY CNC by starting with a kit.

I chose the micRo, a tabletop CNC robot kit from Lumenlab (the base price is $999). I wanted something small enough to be stowed under the workbench when not in use, but stout enough to cut aluminum and hard plastic.

The micRo looked great (in a NASA sort of way) with its white technical plastic connecting block construction and shiny aluminum base, and, although diminutive, the working area is about 12"×10"×4", which is big enough to be quite useful to the broad-spectrum hobbyist. I couldn't resist.

Anatomy of a Gantry Robot

Traditional milling machines are configured sort of like a drill press with a stationary spindle mount, and have a movable X-Y table such that the workpiece is moved around below the cutter. The micRo, on the other hand, like most (but not all) DIY CNC machines, is of the "gantry crane" design, whereby the work is stationary and the tool holder moves around on 3 axes, bringing the cutting tool to work the piece.

Building the Machine

The kit came with all the parts I needed to build the machine: bed, ways, leadscrews, collars, bearings, stepper motors, power supply, machined structural blocks, all fasteners, stepper driver boards, DB-25 parallel port breakout, spindle, and spindle mount. The only things I had to procure were the wiring and enclosure for the driver boards, and an old PC.

Photography by Steve Lodefink

NOTE: Lumenlab has since changed its offerings a bit, and is now selling an assembled machine controller rather than discrete electronics boards and components. But if you prefer to roll your own controller, you can still purchase the DIY machine kit by itself, and use stepper drivers from one of the many vendors who offer CNC drivers and driver kits. A PC with a parallel port, running the free and open source EMC2, makes a fine CNC controller.

The basic machine assembly went pretty effortlessly, with almost no opportunity for mistakes. Documentation and assembly instructions reside on the Lumenlab website, and the companion forums are full of helpful tips from other CNC machine builders.

Once you get the machine all bolted together, you need to use a framing square to make sure that the X ways are perfectly parallel, and that the y-axis carrier (gantry) is perpendicular to the x-axis. This is referred to as tramming the machine.

The optional spindle kit for the micRo is a flexible shaft, hanging grinding tool, and a set of mounts for attaching the toolholder/chuck to the Z blocks. It worked well for me, though you could easily mount a Dremel, or other type of rotary tool, if you choose. The spindle had more than enough power to cut through hard plastic without bogging down.

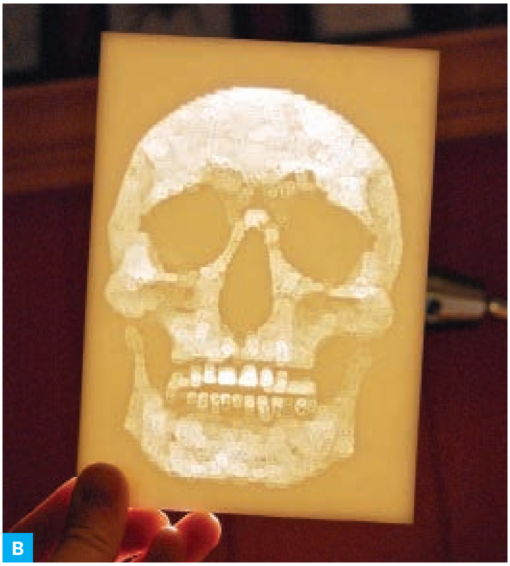
Running a Job

There are two fundamental software steps to preparing a job for a CNC machine. First you have to draft the part in a CAD (computer-aided design) program. Next, you use CAM (computer-aided machining) software to interpret the model and generate the appropriate tool path for the machine to follow. CNC tool paths are written in a language known as G-code. The machine controller software then uses the G-code as a map, and drives the tool around appropriately to carve the piece (Figure A).

I have a confession to make: I'm not really up to speed with CAD just yet, but I did find a cool CAM program called Image to G-Code, which converts a grayscale image into a cutting depth map. I fed a photograph of a skull, along with the size of my material and cutting tool, into the software, and it generated the proper G-code to mill the photo into a translucent material. I machined the image into a sheet of white Corian acrylic, and when held up to the light, it looks like the original picture (Figure B)!

I've got some CAD learning to do before I can start making robot parts, but let me just say that this desktop CNC tinkering feels good, and I'm really glad I started with a kit.

A



B

Fig A: My micRo CNC robot, built from a kit. It was easy. Fig. B: The bot milled this plastic to different depths, using a simple CAM program.

Resources

Image to G-Code program: makezine.com/go/gcode
GeckoDrive (good CNC drivers): geckodrive.com
EMC machine controller software: makezine.com/go/emc
Lumenlab: lumenlab.com

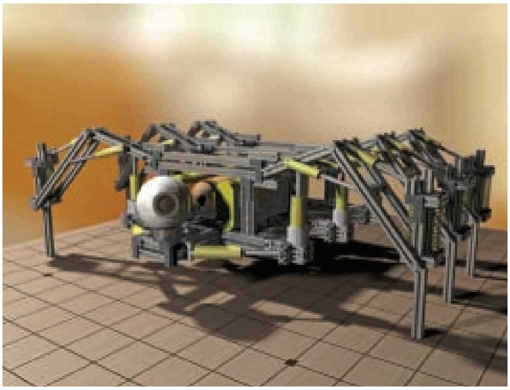
My build photos: makezine.com/go/lodefinkcnc

Steve Lodefink (steve@finkbuilt.com) is a designer by day, and by night he likes to learn new skills. Building small projects using fabrication methods and materials that he has never tried is his hobby and his therapy.

MAKERBEAM

An open source building system for project boxes, robots, and more.

BY JOHN BAICHTAL



Tinkerers have been using construction toys to build project enclosures for years: Google's Sergey Brin and Larry Page famously built their first server case out of repurposed Mega Bloks. The next logical progression is a construction set that's built specifically to mount PCBs, sensors, and stepper motors, yet still accommodates traditional projects like robots and vehicles.

One of these building sets is MakerBeam, a system of open source aluminum girders and connectors that resembles an Erector set for adults. It uses a "Mini-T" standard that's a miniature version of T-slot building systems.

MakerBeam's Sam Putman, Glenn Powers, and James Coddington chose to fund their project via micro-patron site Kickstarter (kickstarter.com), which allows hundreds of donors to contribute a few dollars each toward specific projects. MakerBeam raised almost $18,000 this way. Recently we chatted with Putman to find out what was going on.

John Baichtal: Why did you choose Kickstarter to fund your project?
Sam Putman: Kickstarter let us reach our community directly. Instead of investment and debt, we're starting with manufacturing paid for and our alpha and beta test teams ready to go. With a bank, giving your IP away is a loss of value; for the makers who will work with it, it's an asset. The bounty we've raised will let us develop some kits in-house, which we're considering offering through Kickstarter. I can't say too much now, but we're talking robots, and not the kind that sit on your desk.

JB: MakerBeam is open source hardware — you even have a "copyleft" backward C as part of your logo. But what's stopping someone from just snagging the 3Ds you create and "printing their own"?
SP: We posted a demo of our beam profile on Thingiverse in early October [2009]. People all over the world were printing it and modifying it within days. This is exactly what we want.

Current 3D printing can't touch the precision and strength of tempered aluminum alloy, but it can produce an endless array of connectors and compatible parts. We'll be publishing all our models and standards as we develop them. Anyone can print, CNC, extrude, or injection-mold the parts as they please. We intend to stay right in the middle of the game we started, and have fun doing it.

JB: One interesting subplot to this project is your interaction with MicroRAX, a company with a similar product, only not open source. What's going on?
SP: Parallel innovation is more common than not, and MicroRAX got their profile to market just as we were launching on Kickstarter. Their beam is a spinoff of the Space Elevator Games, and there are some odd design choices in there, so we'll see.

On the proprietary versus open front, I've talked to MicroRAX's Chris Burrows and I get the sense they're thinking it over. There's nothing stopping MicroRAX from making their design open source, or even from cloning our design and selling it. Basically, mini T-slot building systems are brand new and it's good to see an alternative, if only to keep us on our toes.

» MakerBeam aims to offer kits at Bay Area Maker Faire 2010. Learn more at makerbeam.com.

John Baichtal is a writer on geekdad.com and makezine.com.

3D FABBING STATE OF THE ART

3D printing and desktop manufacturing innovators tell us what's currently on their radars.

BY GARETH BRANWYN

We asked leaders in the field of 3D printing and desktop fabricating, and early adopters of this technology, a simple question: What are you most excited about right now; what has your attention? Here's some of what they told us.

Fig. A: Jeffrey McGrew shows off the puzzling Wikipedia logo, modeled in Blender and cut on his studio's CNC machine named Frank.

Jeffrey McGrew and Jillian Northrup, Because We Can, design-build studio becausewecan.org
Everything has gotten so much more accessible, both the technology itself and the amount of help online. We could now buy a plastic extruder kit from **MakerBot**, mount it on our inexpensive **ShopBot** machine, and have a 3D printer that could make something 4 feet by 8 feet by 6 inches thick. That's insane! For next to nothing, we'd have a machine that would've cost tens of thousands of dollars just five years ago!

In terms of tools, we love **Blender**, a super-powerful, open source 3D modeling app. We used it for the globe logo we did for Wikipedia.

Most commercial CAM software is either buggy and looks like it was written in VB in the mid-90s, or is staggeringly expensive. Or both. We don't see a great option yet on the open source horizon. However, **Vectric**, a small company in England, writes high-quality, easy-to-use, and affordable CAM software that does 80% of what the expensive packages do, at about 20% of the cost.

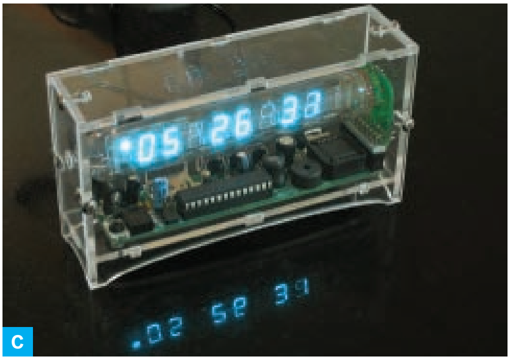
David ten Have, CEO, Ponoko, direct digital fabrication marketplace ponoko.com
For me, the most exciting thing is the emergence of a **common vernacular** (more people are starting to understand the processes required to handle the creation, distribution, and consumption of 3D design files). When we started, we spent lots of time explaining this process to people.

The second thing is the **appreciation of these new technologies and systems** by established businesses. We're learning how to talk to one another productively and with the rest of the economy. We're able to help unleash the creative forces that we all know we need unleashed, and reward designers/creators/engineers with new opportunities.

100kGarages (100kgarages.com) is a fine example of companies appreciating the tech that's starting to emerge. [Editor's note: 100kGarages is an organization, started by Ponoko and ShopBot Tools, to bring together digital fabricators, makers, and those looking to have things made.]

Ted Hall, CEO, ShopBot Tools, makers of CNC routing equipment shopbottools.com
One exciting aspect is increasing social organization being built around digital fabrication. This includes the **Fab Labs** around the world — offshoots of Neil Gershenfeld's book *Fab: The Coming Revolution on Your Desktop* — where additive and subtractive digital fabrication tools are made available to all. Also, sites like **Ponoko** that offer digital fabrication services as well as designer galleries of digitally fabricated products.

More and more people "get it." We may not have *Star Trek* replicators yet, but we do have tools that allow anyone to make almost anything with just a little learning and effort. And, it can be shared and



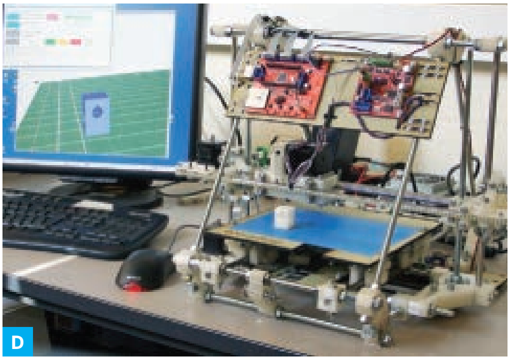


Fig. B: A growing map of fabber "garages" around the world. Not 100,000 yet, but it's a start. Fig. C: An Adafruit Industries Ice Tube Clock kit with a laser-cut acrylic enclosure. Fig. D: The newest RepRap, Version II "Mendel." It's both bigger and smaller than Version I: it can make bigger things, but is physically much smaller.
Fig. E: CandyFab is an open source 3D printer designed to print candy or other 3D objects using low-melting-point materials like sugar.

reproduced elsewhere, by many others.

And the prices for both "subtractive 3D printers" (CNC tools) and 3D additive printers have become much more affordable. Together, these digital fabrication tools contribute to the emerging understanding of how digital models of practically anything can be translated into real objects: a laser cutter can make a plexiglass clock, a 3D additive printer can produce a housing for an electronics project, and a ShopBot can cut out children's furniture. Digital fabrication makes a new type of manufacturing possible.

Phillip Torrone and Limor Fried, Adafruit Industries, open source hardware pioneers and electronics kit-makers adafruit.com

We're cautiously optimistic about **3D printing**. We'd love to use one just like we use our Epilog 35W laser — to create enclosures and cases for kits in an economical way. The laser cutter ($20,000 a couple years ago) paid for itself many times over. But as 2009 ends, there isn't a 3D printer for what we want to do at a price that makes sense for us yet.

We're on the lookout for a $10,000-range printer that can produce models with fairly good structural strength, can support things like threaded screws, and with good "cosmetic quality" without needing to paint, sand, and finish the model. We might get a CNC machine, or go with injection molding, and we'll likely continue investigating contract 3D printing services for now, since it's more affordable than settling on a so-so machine.

That said, the **Solido 3D printer** (solido3d.com) caught our eye. It uses sheets of plastic, cut out with glue and anti-glue, and builds up the model a sheet at a time. While there are variations, the Solido uses a PVC-based plastic, it can be drilled, it's dust- and powder-free, and it's just under $10,000.

And, we think **CandyFab** and **Bathsheba Grossman's art** are two of the coolest things we've seen.

Fig. F: Bathsheba Grossman's amazing geometric sculptures 3D-printed in metal. Fig. G: A multi-material (two different colors of glass) set of Vitraglyphic glass pots produced on a 3D printer. The Vitraglyphic process combines finely powdered glass and binding materials.

Mark Ganter, professor of mechanical engineering and co-director, Solheim Rapid Prototyping Lab, University of Washington open3dp.me. washington.edu

1. **Objet** (objet.com), the first multi-material printer.
2. The American Society for Testing and Materials (**ASTM**) now has a formal working group on rapid prototyping (RP).
3. Open source printers like **RepRap** (reprap.org), **Fab@Home** (fabathome.org), and **MakerBot** (makerbot.com) are really democratizing RP.
4. The **new materials** coming out of our lab. Like printing in glass!
5. The idea of **open sharing** or open innovation exchange in RP. Traditionally RP has been very closed.
6. Really high-quality free software like **MeshLab** (meshlab.sourceforge.net) and **MiniMagics** (minimagics.com).
7. The fact that more people are getting involved as the price of entry is coming down.

Lenore Edman, Evil Mad Scientist (EMS) Labs and CandyFab, an open source 3D printer for candy candyfab.org

The burgeoning business of printing objects for those without printers, for example **Shapeways** (shapeways.com), is exciting. This allows you to print your own objects, even if you don't have your own 3D printer. Or maybe you do, but you want larger production runs, or the ability to sell your designs without even printing them. These services also enable printing in media like metals that aren't yet easily accessible to the home 3D printer.

Windell Oskay, EMS Labs and CandyFab

I cannot overemphasize how cool I think the blossoming world of **Thingiverse** (thingiverse.com) is, where folks share their 3D designs so others can download and print them out. Once you have a 3D printer, what are you going to print?

The thing that has me really excited is the emergence and success of **maker-oriented job shops** with low cost of entry. Services such as **Shapeways** that let anyone fab designs without significant setup costs are a huge advance.

Maybe I can't afford an exotic-car-priced laser sintering machine that makes incredible 3D objects, but I can use one for just a few dollars. The precision and quality of parts that are fabbed this way are shockingly good. Laser cutting is also available from similar online services these days — like **Pololu** (customlasercutting.com) and **Ponoko** — making it so that just anyone can start fabbing.

This situation reminds me of desktop publishing in the late 1980s: nobody had their own professional-grade laser printer, but the copy shop down the street had one that you could use for a few bucks. It's 20 years later. The copy shop is farther away, but feels closer, and they've got wonderful new lasers. Stands to reason that we'll each have one at home 20 years from now.

+ Read more of our favorite 3D enthusiasts' recommendations at makezine.com/21/stateoftheart.

Gareth Branwyn is editor-in-chief of Make: Online.

Make: television

John Park- VCR Powered Cat Feeder

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"Totally Fabulous!"

"Way to look out for the little guy/girl, MAKE!"

"Embodies a philosophy of highly innovative DIY"

"Creative cascade of American Spirit"

"Keep the good stuff comin'!"

Episode 7: Urban Projections

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—Robert Stephens, Geek Squad Founder and Chief Inspector

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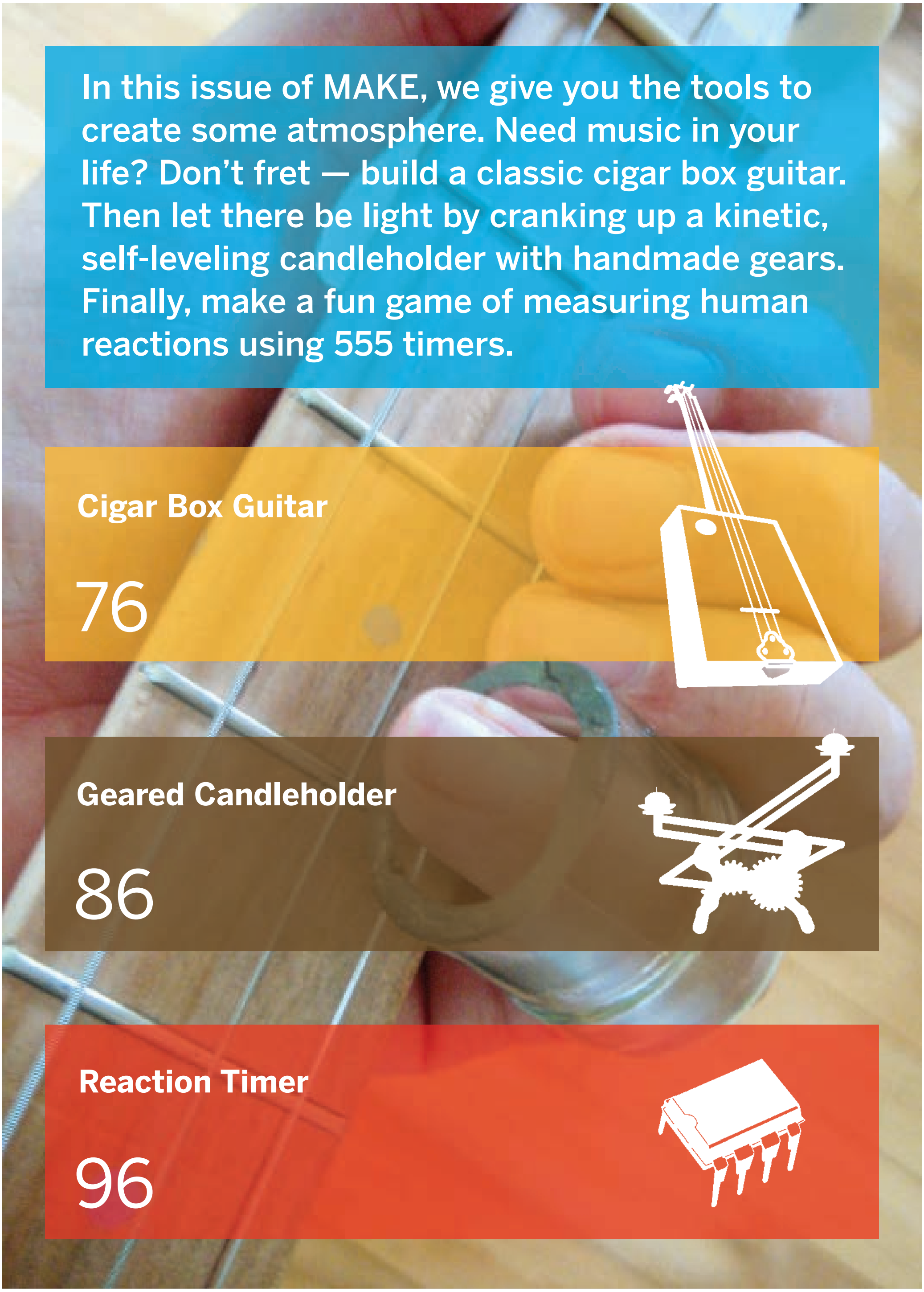


In this issue of MAKE, we give you the tools to create some atmosphere. Need music in your life? Don't fret — build a classic cigar box guitar. Then let there be light by cranking up a kinetic, self-leveling candleholder with handmade gears. Finally, make a fun game of measuring human reactions using 555 timers.

TRADITIONAL CIGAR BOX GUITAR

By Mark Frauenfelder

HAND-ROLLED MUSIC

Five years ago, MAKE featured an electric Cigar Box Guitar project (*Volume 04, page 76*). The project's author, Ed Vogel, designed a simple instrument using only parts you'd find at a hardware store. I made one myself, and had a wonderful time playing it.

Last year, I decided I'd like to make a more traditional cigar box guitar. I soon found Cigar Box Nation (cigarboxnation.com), a fantastic online hangout for homemade stringed instrument enthusiasts. The photos, videos, and MP3s posted by these happy strummers and pluckers were inspiring, and the variety of guitars in the photo galleries was astounding.

I joined the group and was warmly welcomed by its members, who kindly answered my newbie questions about frets, choices of wood, and other aspects of guitar building. In a matter of days, I had built my first cigar box guitar (or CBG for short). I've now built more than a half dozen CBGs, and I guess you can say I'm hooked.

Because every CBG is built by hand, using different found and scrounged materials, no two sound alike. I love the suspense of not knowing what kind of "personality" a CBG is going to have until it's completed. Here's how to make a plain-vanilla, 3-string CBG that requires a minimum of tools and parts, yet sounds great.

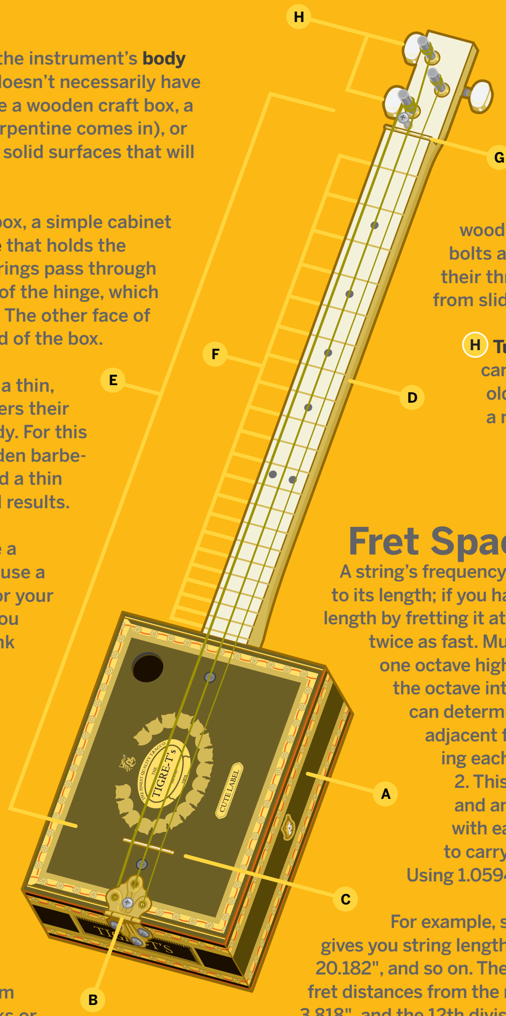
Set up: p.79 **Make it: p.80** **Use it: p.85**

Mark Frauenfelder (markf@oreilly.com) is editor-in-chief of MAKE.

Photography by Mark Frauenfelder

A String, a Stick, and a Box

A cigar box guitar is much like a regular guitar except it usually has fewer strings. Before buying parts for one, rummage around in your junk drawers. A plastic comb can be cut and used as a bridge. An old cabinet hinge can serve as a tailpiece. A bolt makes for a dandy nut. The photo section of cigarboxnation.com shows ingenious and oftentimes humorous examples of CBG builders' resourcefulness.



A The cigar box serves as the instrument's **body** and resonating chamber. It doesn't necessarily have to be a cigar box. You can use a wooden craft box, a boxy tin can (like the kind turpentine comes in), or anything else with flat, light, solid surfaces that will push the air as they vibrate.

B At the lower end of the box, a simple cabinet hinge serves as the **tailpiece** that holds the strings' bottom ends. The strings pass through the screw holes on one face of the hinge, which holds back their end barrels. The other face of the hinge attaches to the end of the box.

C The strings stretch over a thin, blade-like **bridge** that transfers their vibrations to the guitar's body. For this guitar, I used a piece of wooden barbecue skewer, but I've also used a thin paintbrush handle with good results.

D The guitar's **neck** can be a piece of oak or maple. Don't use a softwood that bends easily or your neck will bow (especially if you use 4 or more strings or crank up the tension).

E The **scale length** (distance between the bridge and the nut) is up to you. Most guitars have a scale length somewhere between 24" and 25½". If you want to make a cigar box bass, try 30"–34".

F **Frets** determine the note a string plays, by restricting the length along which it vibrates. I made them using fret wire, but toothpicks or small nails with the tips and heads clipped off will also work. Or you can go fretless, which is great for slide guitar.

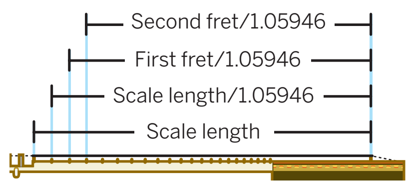
G The **nut** supports the upper ends of the strings so they can vibrate freely. I used another piece from the wooden barbecue skewer, but bolts also work nicely because their threads prevent the strings from sliding sideways.

H **Tuning pegs** and strings can be scavenged from an old guitar, or purchased at a music store or online.

Fret Spacing

A string's frequency is inversely proportional to its length; if you halve the string's vibrating length by fretting it at its midpoint, it vibrates twice as fast. Musically, this means it plays one octave higher. Western music divides the octave into 12 equal intervals, so you can determine the distance between adjacent frets by successively dividing each length by the 12th root of 2. This is an irrational number, and any rounding error accrues with each division, so you'll need to carry it out with a lot of digits. Using 1.05946309436 should be safe.

For example, starting with a 24" string gives you string lengths of 22.653", 21.382", 20.182", and so on. These lengths correspond to fret distances from the nut of 1.347", 2.618", and 3.818", and the 12th division takes the distance up to 12". Visit makezine.com/21/cbg for links to online fret calculators that perform these operations instantly.



BONUS!

Illustrator Rob Nance created a sheet of Papercraft Guitar Picks to help you rock out in style with your new cigar box guitar! Get it at makezine.com/21/cbg.

Illustration by Rob Nance

SET UP.

MATERIALS

[A] Cigar box I buy them at my local cigar store for $3 each. You can also find them on eBay.

[B] 1×2 oak or maple lumber, 3' length The actual dimensions are ¾"×1½". A 6' stick (enough for 2 necks) costs about $10. Pick the straightest, flattest, clearest (free of knotholes) piece you can find.

[C] Guitar strings Standard medium-gauge strings work well. CBGs typically use open G tuning. I use strings 5, 4, and 3 (A, D, G) and tune them to G-D-G.

[D] Tuning pegs Elderly Instruments (elderly.com) sells a set of 6 (enough to build two 3-stringers) for $10. Sometimes they're called "tuning machines."

[E] Fret wire $10 at elderly.com or cbgitty.com. You can also use flat toothpicks or go fretless.

[F] Cabinet hinge with 3 mounting holes on each side

[G] 1" wood screws Phillips head Grip-Rite Fas'ners work well.

[H] Bamboo barbecue skewer or other hard, thin rod for the bridge and nut. A 3⁄16"×2" bolt also works well for the nut.

[I] Super glue (optional)

TOOLS

[J] Hole saw, ¾"

[K] Stanley Surform shaver from a hardware store

[L] Miter box hobby size

[M] Coping saw

[N] Wire cutters

[NOT SHOWN]

Yardstick A decimal inch or millimeter scale is best, as opposed to fractional inches.

Wood saw

Drill or drill press and bits for wood

Phillips head screwdrivers

Hammer

Marker or paint

Sanding block and sandpaper of various grits

Files

T square or carpenter's square

Jeweler's file (optional)

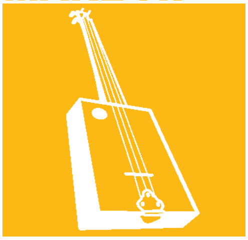
Pencil

Sharpie or paint

Magnifying glass

Utility knife

MAKE IT.



BUILD YOUR CIGAR BOX GUITAR

START **Time:** An Afternoon **Complexity:** Easy

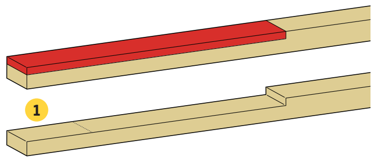
1. MAKE THE NECK

To begin, we'll cut the neck to length, make the headstock (the part where the tuning pegs go), and saw off a rectangular slice so that the fretboard is flush with the cigar box lid. Making the neck and installing the frets are the most time-consuming parts of the build. Once you're finished preparing the neck, you'll be surprised by how fast the rest of the build goes!

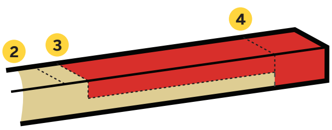
1a. Using a wood saw, cut the oak or maple lumber to 36". You'll have to cut it a little shorter later on, but it's good to start out with more than enough.

1b. Saw off a rectangular slice from the lower end. This is the end that goes into the cigar box. Measure the length and thickness of the cigar box lid. I use the box itself as a guide, tracing along the oak stick with a pencil. Mark these dimensions on the wood, then use a saw to remove the part shaded red in the illustration.

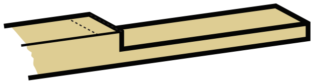
Also make a pencil mark 2¼" from the end. This is where your bridge will go later on.



1c. Mark the lines for the nut and headstock. Starting from the pencil mark you just made for the bridge, make another mark indicating the scale length (I decided on a scale length of 24½"). This second mark is where the nut will go. Make a third mark ½" farther past the nut. Make a fourth and final pencil mark 3½" beyond the third mark.



1d. Cut out the headstock. Your third and fourth pencil marks indicate the beginning and the end of the headstock. Use your saw to cut away the material shaded in red in the illustration above. The headstock should be half as thick as the neck, or ⅜".



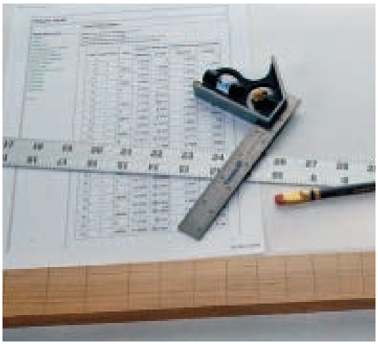
1e. Sand the fretboard. Now is a good time to sand the top surface of the neck so it's dead flat. Use a sanding block, starting with rough sandpaper and finishing with fine-grit sandpaper.

2. INSTALL THE FRETS

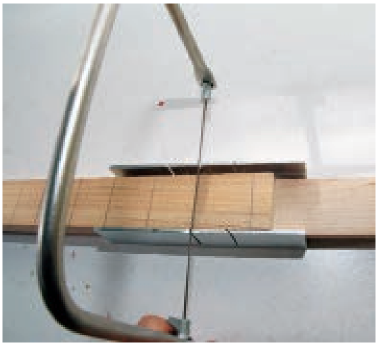
I used to be intimidated by the idea of frets. The process seemed mysterious and difficult. But it's really not. If you take your time and make careful measurements, you'll have no problem.

2a. Mark the fret locations. Enter your desired scale length into an online fret spacing program (see makezine.com/21/cbg) and print out the table it generates. Using a yardstick and a square, make pencil marks along the length of the neck to indicate the location of the frets.

NOTE: If you don't want to install metal frets, you can glue flat toothpicks over the pencil marks. They work quite well, but will eventually wear out. If you want a fretless guitar (which also sounds great), go over the pencil marks with a Sharpie or with some paint. In either case, skip to Step 3.

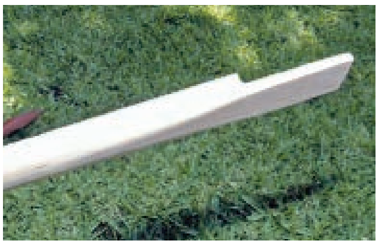


2b. Cut the fret slots. About 1⁄16" should be deep enough. The saw blade should be thin enough so the fret tangs bite into the slots you cut. I buy medium-gauge fret wire and have had no problem with frets popping out. A coping saw and a hobbyist's miter box will help you keep the fret slots square with the neck.



2c. Form the back of the neck. On the backside of the neck, shape the sharp 90° edges into soft curves so your fretting hand can easily slide up and down the neck. A Surform shaver tool will quickly rough out a rounded edge. Follow up with sandpaper until the wood is very smooth.

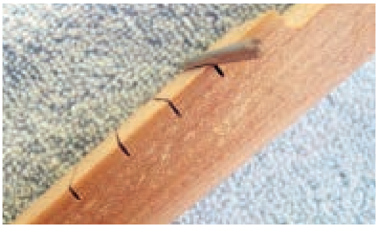
NOTE: Don't shave the headstock or the part that will fit into the cigar box — only work on the area under the frets and nut.



2d. Tap the frets into the slots. Fret wire usually comes pre-cut, and each piece is about an inch longer than the width of the neck. The wire's cross section is T-shaped, and the barbed center rail goes into the slot.

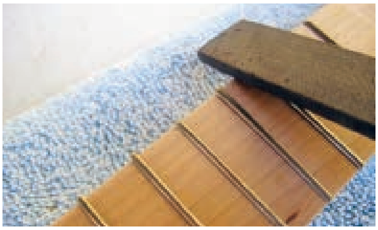
At each fret slot, align one end of the fret wire so it overhangs the side of the neck just a fraction of an inch. Press the fret wire into the slot, then place a thin block of wood on the fret and tap on the block with a hammer until the fret is all the way in.

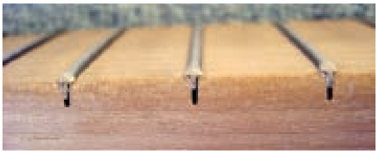
NOTE: You can smear a tiny bead of super glue across the part of the fret that fits in the slot if you wish, but I usually skip it, because it's hard to keep the glue from getting onto the neck.



2e. Clip the fret wire. Cut it almost flush with the neck. Repeat Steps 2d and 2e until all frets are installed. I installed 21 frets on my cigar box guitar.

2f. File the ends of the frets. The cut ends of the fret wires are very jagged and would shred your hands if you attempted to play without filing them smooth. Use a file to form a gentle curve on both ends of each fret. (If you have a store-bought guitar handy, inspect it to see how the frets should look.) Run your hand up and down the neck. If your skin snags, you need to keep filing! Use a magnifying glass and look for any small burrs that need to be filed off with a jeweler's file.





3. INSTALL THE TUNING PEGS

Study the geometry of your tuning pegs and determine where the headstock holes need to be drilled so that the strings and pegs won't interfere with each other. Keep in mind the location of the mounting screws — they shouldn't be too close to the edge of the headstock, or they might split the wood.

3a. For each peg, drill a large hole for the post and 2 small pilot holes for the mounting screws. A drill press will make things easier, but if you use a handheld drill, try your best to drill straight down.

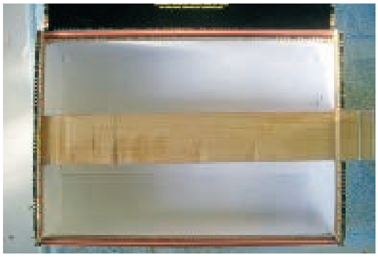
TIP: When you drill the holes for the posts, use drill bits made for wood. I used the wrong kind of bit and it tore out big splinters. (You can see a missing piece above the top tuning peg, inside the orange circle in the bottom photo).

4. ATTACH THE NECK AND HARDWARE TO THE CIGAR BOX

Now that the neck is complete, the rest is smooth sailing!

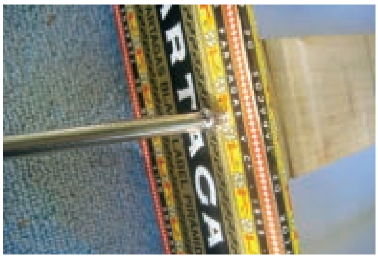
4a. Cut a hole (a 3-sided notch) in one end of the box for the neck. Measure the cross section of the part of the neck that fits inside the cigar box, and draw a matching rectangle on the inside of the box. Use a coping saw to cut the 2 vertical lines, then use a utility knife to score the horizontal line several times until you can snap off the rectangle.

Insert the neck, close the lid, and make sure the fretboard is flush with (or a tiny bit higher than) the lid. If the fretboard is lower than the lid, sand down the cut-out part of the neck that comes into contact with the lid until the fretboard and lid are flush.

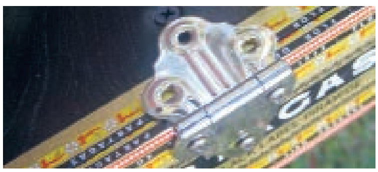


4b. Now we'll screw the neck to the box. I try to use as little glue as possible when I make a cigar box guitar because I don't like waiting for the glue to dry, and screws make it easy to take the guitar apart for repairs, modifications, or salvage.

Drill a pilot hole in the far end of the box and drive a screw through the box into the neck. Close the lid and then pilot-drill and drive 2 more screws through the lid of the box into the neck (if you later want to install a pickup, you can remove these screws).



4c. Attach the tailpiece. Fold the cabinet hinge centered over the front lower edge of the cigar box, then drill pilot holes and screw it to the lower end of the box. The hinge will sit over the screw you inserted in the previous step, 4b.



4d. Paint position marker dots on the neck. Use paint or a Sharpie to make dots above frets 3, 5, 7, 9, and 12.

4e. String the guitar. Thread the barrel ends of the strings through the hinge's unused mounting holes. Wind the other ends of the strings onto the tuning pegs, but not too tight yet. Here's a good video that will teach you how to wind a guitar string: makezine.com/go/guitarstring

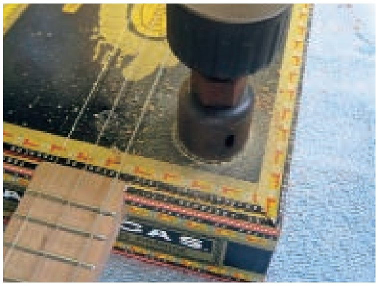
NOTE: I inserted a screw to keep the middle string centered in the headstock. You might have to do this, too.

4f. Slip in a bridge and a nut under the strings. I used a wooden barbecue skewer to make the bridge and the nut. Snip 2 pieces to size and place one above the line you drew for the nut. Place the other under the strings on the cigar box at a distance equal to the scale length you chose; this is the bridge.

4g. Screw down the tailpiece. Drill a hole through the hinge and drive a screw through it into the lid and the neck. This will increase tension on the strings and prevent rattling.

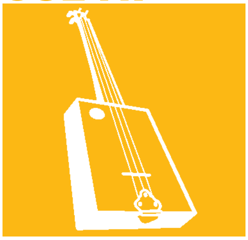
4h. Make a sound hole. Use a small hole saw (¾" diameter or so) to cut a sound hole in the top of the box. Make sure to position the hole so it doesn't cut into the neck. (I made this mistake when I made my first cigar box guitar!)

Guess what — you've built your guitar! In the next section, I'll explain tuning and playing, as well as direct you to other helpful cigar box guitar resources.



FINISH X **NOW GO USE IT »**

USE IT.



TUNE UP AND TURN ON

GET IN TUNE

The most popular tuning for cigar box guitars is called open G tuning. Many of the original blues guitar players used open G, and it's a favorite with Keith Richards of the Rolling Stones.

Visit makezine.com/21/cbg for an MP3 file of this tuning played string by string on a six-string guitar. For the CBG, you can ignore the first string that's plucked, and tune it to the 3 strings after that: G, D, and G.

FREE ONLINE LESSONS

Keni Lee Burgess, a well-known New York street musician, has posted a terrific series of cigar box guitar lessons on YouTube. Shane Speal, co-founder of cigarboxnation.com, also has fun lessons on YouTube that show you how to use a slide, and how to experiment with different tunings and scales. Visit the URL above for links to both of these series.

MAKE A BOTTLENECK SLIDE

Bottleneck slides sound great with open tuning, and both Burgess and Speal use them to enhance their playing.

To make one, take an empty wine bottle and score a ring around the neck with a Dremel cutting disc (wear eye protection). Wearing a pair of oven mitts, tap the score line with a spoon and snap off the neck (do this over a trash can to capture the shards). Sand off the rough edges and you've got something far superior to a store-bought slide. YouTube has instructional videos on making bottle-neck slides using different techniques.

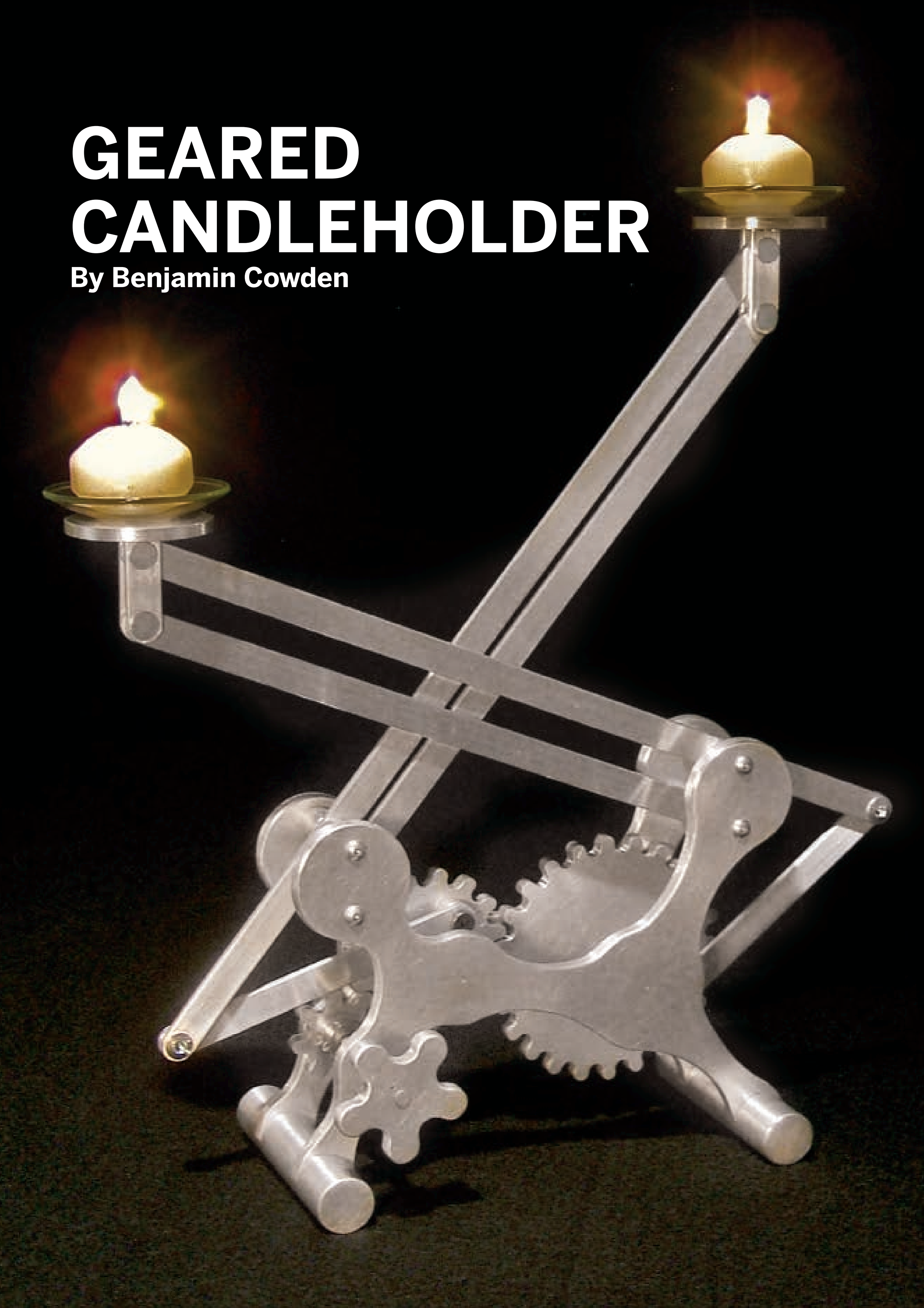
TURN IT UP

You can electrify your cigar box guitar in 2 ways. The easiest is by adding a piezoelectric buzzer. Buy one at RadioShack or salvage one from a discarded smoke alarm. Carefully crack open the plastic housing, remove the metal disc, and sand-wich it between the neck and lid of your guitar. Wire it to a patch cord jack and plug into an amp (if you don't have an amplifier, make our Cracker Box Amp featured in MAKE, Volume 09, page 104).

Another way to electrify a cigar box guitar is by adding an electromagnetic pickup. In a future issue of MAKE, we'll show you how to wind your own.

GEARED CANDLEHOLDER

By Benjamin Cowden



ENLIGHTENMENT AESTHETIC

Nothing says "machine" quite like a bunch of gears turning in time with each other. It's an iconic image. Unfortunately, gears are expensive and hard to find pre-made. You can scavenge them from discarded machines, but the selection is limited, and it's possible to amass a whole drawer of gears without having any two that actually fit together.

When I began making kinetic sculpture, this was one of my major dilemmas. So I developed an easy and relatively fast technique for making my own gears out of metal plate that also has the advantage of giving them an inviting, toy-like appearance.

Here's an elegant, all-aluminum candleholder with a movement containing 3 handmade gears. The drive gear or pinion on the left pushes 2 candle-bearing arms up and down on either side, and because of the different sizes of the gears, the candles move at different rates.

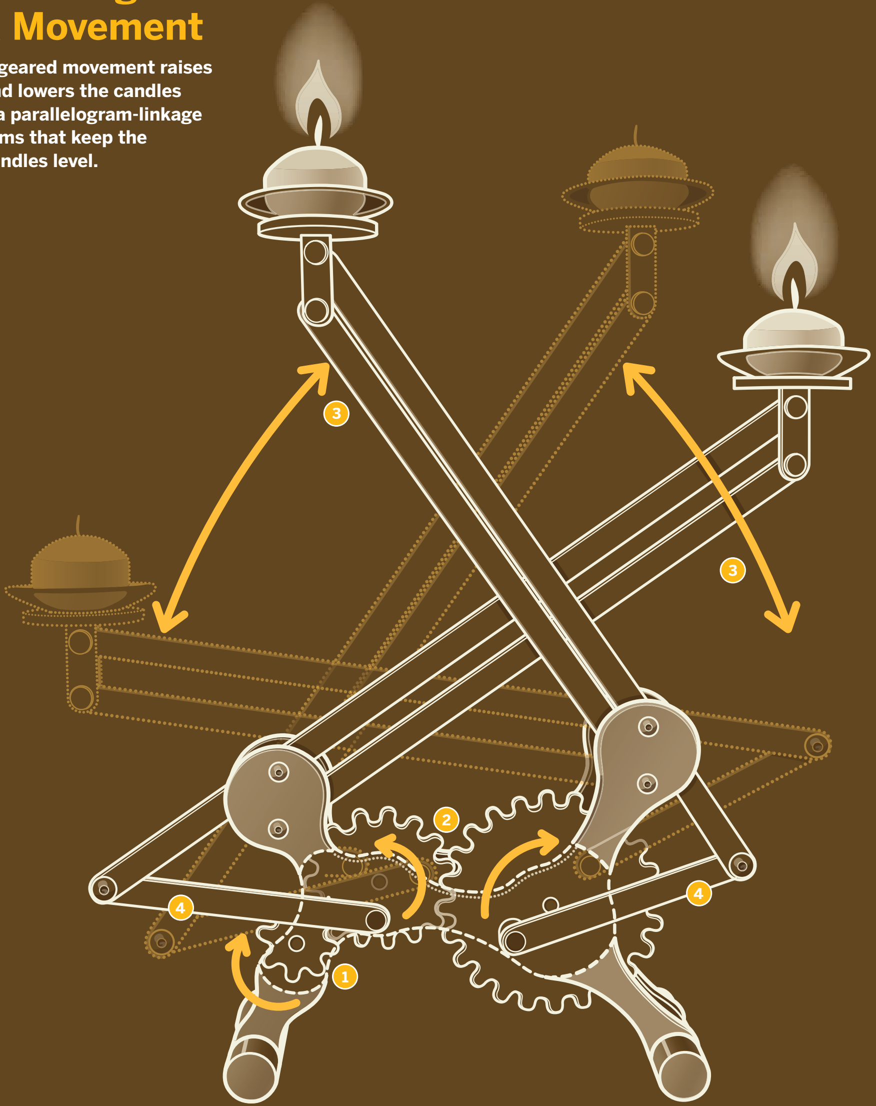
Photography by Benjamin Cowden

Set up: p.89   **Make it: p.90**   **Use it: p.95**

Benjamin Cowden (ben@twentysevengears.com) is a kinetic sculptor and metal fabricator living in Oakland, Calif. He thinks the number 3 is green, and he is actively resisting the conversion to metric.

Creating a Movement

A geared movement raises and lowers the candles via parallelogram-linkage arms that keep the candles level.



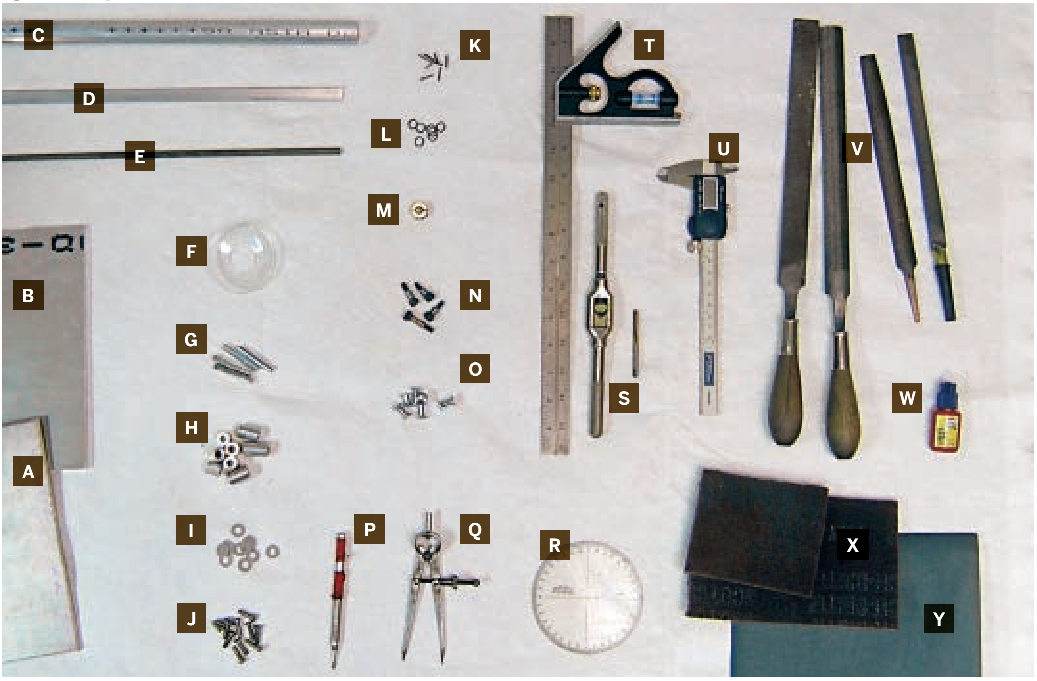
An 8-tooth **drive gear** or **pinion gear** (1) turns 15- and 24-tooth **driven gears** (2), each of which moves a different arm. The 2 driven gears have a gearing ratio of 5:8, so the 2 candleholders reach the same relative position, such as maximum height, with every 8 revolutions of the smaller gear or every 5 of the larger one. Either way, it takes 120 teeth for an arm to transit its full range of motion, which corresponds to 15 full turns of the drive gear knob.

Movable **parallel arms** (3) hold the candles, using the same principle as the classic Luxo L-1 desk lamp: the 4-bar, parallelogram linkage. On each arm, the lower pair of pivot points and the upper pair of candleholder anchor points are both vertical and 1" apart, and it's this relationship that keeps the candle cups level in any arm position.

The gears move the parallel arms by means of a **connecting arm** (4), a simple crank linkage that converts rotary motion to reciprocating (back and forth) motion.

Illustration by Damien Scogin

SET UP.



MATERIALS

[A] ¼" aluminum plate, 1'×2' for the body and gears. Aluminum plate and rod are available from a metals supplier such as Metal Supermarkets (metalsupermarkets.com).

[B] 3/16" or ⅛" aluminum plate, 2"×4" for the candleholders

[C] ⅞" aluminum rod, 8" length for the feet

[D] ½"×⅛" aluminum bar, 6' length for the arms; McMaster-Carr part #8975K527 (mcmaster.com)

[E] ¼" steel rod, 4" length from a metals supplier

[F] Candle drip cups, glass (2) from a crafts store; I bought them at Michaels.

[G] Threaded standoffs, ¼"×1½", 8-32 thread (4) McMaster-Carr #93265A482

[H] Unthreaded spacers, ½"×2", ¼" bore (4) McMaster-Carr #92511A085

[I] Hard fiber washers, 1/64" thick, ¼" ID (8–12) pack of 100: McMaster-Carr #90089A315

[J] Button-head machine screws, ⅝" long, 8-32 thread (8) pack of 100: McMaster-Carr #92949A196

[K] 1/16" tension pins, ½" long (2) pack of 100: McMaster-Carr #92383A106

[L] Wave spring washers for ¼" screws (10–15) pack of 25: McMaster-Carr #9714K24

[M] Clamp-on shaft collars, ¼" bore (3) McMaster-Carr #9961K13

[N] ¼"-diameter shoulder bolts: 5/16" (2), ⅜", and ⅝" long McMaster-Carr #91259A534, #91259A535, and #91259A539

[O] Binding posts, 8-32 thread (13/64" diameter): ⅜" (4) and ¼" long packs of 25: McMaster-Carr #95519A625 and #95519A617

TOOLS

[P] Metal scribe

[Q] Drafting divider

[R] Protractor

[S] 10-24 tap and tap handle

[T] Combination square

[U] Calipers

[V] Metal files, coarse and fine

[W] Thread locker

[X] Scotch-Brite scouring pads or steel wool

[Y] Sandpaper

[NOT SHOWN]

Center punch

Small hammer

Band saw

Hacksaw

Tapping oil

Vise

C-clamp

Drill press and drill bits: 1/16", ¼", #25

Scrap board or plywood, at least 1'×2'

Respirator mask

Oval drafting template (optional)

Epoxy

MAKE IT.

BUILD YOUR GEARED CANDLEHOLDER

START **Time: 20 Hours Complexity: Moderate**

1. CUT THE GEARS

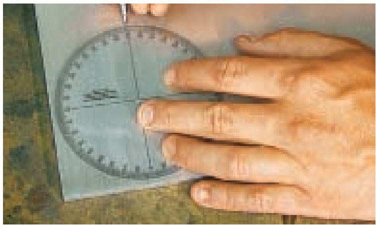
The gears are made by drilling holes around a circle, and then cutting material away so that the spaces between the holes become the teeth.

1a. Download patterns for the gears and all other project parts from makezine.com/21/candleholder. To calculate the radius of each gear's pitch circle, which runs through the center of the teeth, I used the formula:

$$r = s * n \,/\, \Pi$$

where *s* is the tooth size and *n* is the number of teeth. I used a ¼" drill, giving a ¼" tooth size, so for my 8-, 15-, and 24-tooth gears, I got pitch radii of 0.637", 1.194", and 1.910", respectively.

1b. Center-punch the center of each gear on the ¼" aluminum plate and use a protractor and scribe to mark the angle position of each tooth gap. The 8-tooth gear needs a mark every 45°, the 15-tooth gear every 24°, and the 24-tooth gear every 15°.



1c. For each gear, use a straightedge to scribe lines radiating from the center out to the angle marks. Set a drafting divider to the pitch radius (I did this with a caliper) and scribe the pitch circle. Similarly mark the outer circles. On the 2 larger gears, mark lines to position the connecting arm holes, at 0.687" radius for the 15-tooth gear and 1.125" for the 24-tooth.

1d. Wherever the pitch circle crosses the radiating lines, punch and drill a ¼" hole. Also drill the center with the ¼" bit.

The connecting arm holes need to be tapped for 10-24 threads, so punch then drill these with a #25 drill bit.

1e. Cut the gear out as much as you can on a band saw.

CAUTION: Aluminum dust is very harmful. Wear a respirator and work in a well-ventilated space.

1f. Finish the teeth by filing them until they are semicircular and even-looking.

1g. Test-mount the gears onto a wood board using ¼" bolts or rod. Leave a tiny bit of room, or "slop," between the gears to decrease the chance of binding. Turn them, and mark any problem areas for more filing.

1h. To tap the holes for the connecting arms, clamp the gear so the hole location is off the edge of a table. Secure the 10-24 tap into the handle, put a couple drops of tapping oil on the tap, and screw it slowly into the hole. Apply light pressure, and turn back every quarter turn to break off the curls of metal. Go all the way through the hole before backing the tap out. Clean the hole, and screw in one of the 10-24 shoulder bolts to test the threads.

2. MAKE THE BODY

2a. These gears are not precise, so you need to lay them out and adjust their relative distances before you machine the body pieces that they mount to. However, the distances to the arm pivot points are fixed and must be accurate. Follow the vertical and diagonal measurements on the pattern at makezine.com/21/candleholder, and within these constraints tweak the gears' relative horizontal positions so that they mesh effectively. Center-punch your marks, but hold off on drilling yet.

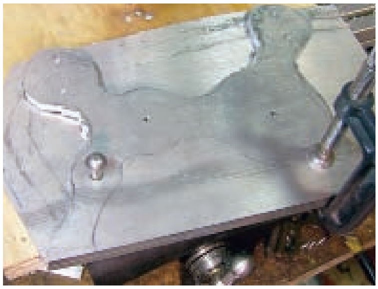
TIP: Use a combination square and a divider to mark vertical lines and distances from the bottom edge of the plate.

2b. Follow the pattern to outline the body. Use your center marks to create the outline, scribing circles and connecting them with "necks." I used an oval drafting template to make smooth curves.

For the 2 feet, mark two ⅞"-diameter half-circles at the bottom. In the upper corners, mark ⅞"-radius circles (1¾" diameter) that encompass both arm pivot holes. Make the central circles small enough to show off the mechanism inside. The resulting outline will be fun and reminiscent of old machines.

2c. Roughly cut the back panel of the body on a band saw and drill the holes. The 11/64" holes in the corners are for 8-32 machine screws that hold 1½" threaded standoffs between the 2 panels.

2d. Use the back panel as a template to mark the front panel. To improve visibility of the gears, make the middle area of the front panel a little smaller. Clamp the panels together and redrill the ¼" holes for the pinion (the smallest gear) and the 11/64" arm holes through the back and front panel together. These are the only holes in the front panel.



2e. Tap the holes for the larger gears on the back panel the same way you tapped the gears in Step 1h.

2f. For the pinion axle, which will connect to the knob, cut a 1" piece of ¼" steel rod. Put one end through the center of the pinion and slip a clamp-on shaft collar on top. To join the collar and pinion, drill a 1/16" hole down through both, off to one side, and use a small hammer to drive in a 1/16" tension pin.

2g. Make the knob the same way you made the gears, as a 5-tooth gear with ½" teeth (pitch radius = 0.796", marks every 72°). Drill and attach the knob to a shaft collar with a tension pin, the way you did the pinion in Step 2f.

2h. For the feet, cut two 4" lengths of ⅞" aluminum rod. They need 2 slots cut halfway through them, ¼" wide and 1½" apart. Put the feet in a vise and use a hacksaw to cut each side of the slot, and then saw diagonally across both to clear out material in between. Finish clearing out the slots with a coarse file until the body panels fit in them. You'll attach these feet with epoxy later.

3. CUT THE ARMS

Each of the larger gears drives an arm that moves 2 parallel levers up and down. The other ends of these levers hold the candle bracket, forming a 4-bar parallelogram linkage that keeps the candle upright. All the holes need to be placed accurately for the movement to work.

3a. Cut the arms. Refer to the connecting arms pattern at makezine.com/21/candleholder. All measurements are based on the centers of the holes, so add some extra length for the ends, and grind or file the corners round.

3b. Drill the holes. Some need to be ¼" while others are 13⁄64". The connecting arms attach to the gears with ¼"-diameter shoulder bolts and the parallel arms pivot on ¼" threaded standoffs. The arm parts attach to each other and to the candle brackets using 13⁄64" binding posts.

3c. Cut the spacers. Ten spacers of varying lengths hold the arms and gears at the correct distances between the front and back panels. Referring to the spacer plan online, cut the 2" unthreaded aluminum spacers down to the lengths needed with a hacksaw. Cut them a bit long and then file them down to a hair short, to allow for free movement.

4. MAKE THE CANDLE BRACKETS

4a. Cut two 2"-diameter discs out of the thinner (⅛" or 3⁄16") aluminum plate. Drill four 9⁄64" holes in each, following the bracket pattern online.

4b. Cut four 2" lengths of the ½"×⅛" aluminum bar, round the bottom corners, and cut and drill per the pattern. Each short length of bar needs 2 posts cut out of the top to fit into the holes in the disks. Use a file to round the corners of each post, and insert the bars into the disks.

4c. To fully test-assemble the brackets, I cut and drilled an extra bar to sit in between the others, then secured them together with the ⅜" binding posts. The posts should be snug and stick out about 1⁄16".

4d. To stake down the posts, clamp the bracket in a vise, then position your center punch in the middle of each post and use a small hammer to drive it in gently, spreading out the aluminum slightly, like a rivet.

TIP: **The aluminum will crack if pushed too far, so be gentle.**

4e. Use ⅜" binding posts to join the brackets to the parallel arms, then finish the holders by using epoxy to attach glass drip rings on top of the disks.

5. FINAL ASSEMBLY AND FINISH

5a. Before putting everything together, go back and finish the parts individually. File and sand the edges of the panels, the ends of the feet and bars, etc. Soften the edges of the panels, gears, candle disks, and knob. Make a final pass with Scotch-Brite pads or steel wool.

5b. Install the 8-tooth drive gear, axle, and knob. To hold the axle in place behind the back panel, slip a couple of wave spring washers over the end and secure it with the third clamp-on collar. You can adjust tension on the axle by pinching the spring washers between the collar and the panel.

5c. Use a grinder or file to trim ⅛" off the end of each shoulder bolt so they won't stick out through the holes in the ¼"-thick gears or panel. (The threaded ends of the bolts are ⅜" long.)

5d. Attach the large gears to the holes tapped in the back plate with 5⁄16" shoulder bolts, adding wave springs or fiber washers on each side for tension so that the candle arms won't fall down. I added 2 fiber washers behind and 3 spring washers in front of each gear.

5e. Attach the connecting arm for the 15-tooth gear with a ⅜" shoulder bolt through a ¼" spacer. Attach the arm for the 24-tooth gear with a ⅝" bolt through a ½" spacer.

5f. Referring to the spacer plan, add the front panel and the 4 pivot arms, connecting the long pivots to the connector arms with ¼" binding posts. The arms pivot around 4 standoffs secured to the panels by 8 button-head machine screws, and are laterally positioned by matched-length pairs of unthreaded spacers slipped over the standoffs.

5g. Attach the candleholders, and seat the panels in the feet. When all this is put together, the arms should be between the body panels, and secure but not tight on the gears. You may have to tweak the washer combinations; try several to find what works best. When you put the machine together for the last time, add some thread locker to the gear bolts and the binding posts to prevent them from coming undone.

5h. Use epoxy to permanently attach the feet to the body. You're done. Congratulations!

This is not a simple project, and doing it mostly with hand tools is especially challenging, but the sleek look and smooth mechanical action of the finished product should be very satisfying. I hope this piece will not only provide a fun project for the home but also be a catalyst for more experimentation in mechanics. For additional information and photos, go to twentysevengears.com/gearedcandleholder.

FINISH X **NOW GO USE IT »**

USE IT.

CRANK UP THE ATMOSPHERE

This candleholder makes an excellent centerpiece at the dinner table; being transformable means it can change to fit the occasion. Lots of big serving bowls on the table? Lift the candles up high so they shine down on all the delicious food!

Given the time and craftsmanship that goes into its creation, this project also makes a wonderful gift. I gave a similar candleholder to friends of mine at their wedding, and they told me it was the most beautiful object they own.

VARIATIONS

The dimensions and materials for this project are quite variable. You can use steel, plywood, or acrylic for the parts without a problem, except for tapping threaded holes. For plastic or wood, try threaded inserts such as McMaster-Carr part #99362A500.

The body shape and arm length can change to suit your desires. Just make sure the candle cups don't collide and the connecting arms don't hit the axle. If you're not sure whether your adaptation will work, make a cardboard mock-up and try it out.

The design is also expandable: imagine a whole row of candles, each rising and falling at different speeds!

BECOME A GEARHEAD

Once you understand the way this type of mechanism works, you can adapt it to an infinite number of projects. Being able to make your own gears and levers allows you to create exactly the movement you want, whether it's for a walking robot or a machine that brushes your teeth and ties your shoes!

Check out the resources to the right to add to your mechanical vocabulary and inspire your inner kinetic sculptor.

RESOURCES

Flash animations showing how different movements and mechanisms work: flying-pig.co.uk/mechanisms

Useful animations and explanations of mechanisms: technologystudent.com/cams/camdex.htm

My website, with images and video of many mechanical sculptures, as well as links to other kinetic sculptors and resources: twentysevengears.com

507 Mechanical Movements: Mechanisms and Devices by Henry T. Brown (Dover, 2005) is a classic book of ideas for creating movements.

Illustrated Sourcebook of Mechanical Components by Robert O. Parmley (McGraw-Hill, 2000) is a compendium of ideas for mechanical inventors.

Reaction Timer

By Charles Platt

How fast are your reflexes? Find out with a millisecond-accurate timer based on the 555 timer chip, in this experiment from *Make: Electronics*.

Make: Electronics is an electronics primer for the early 21st century. It's written for the absolute beginner and all those who've wanted to learn electronics. Those who've wanted to build all the cool kits out there, or to try their hand at programming microcontrollers, but who've found themselves intimidated by existing books and online resources that seem to be written by deep geeks for deep geeks.

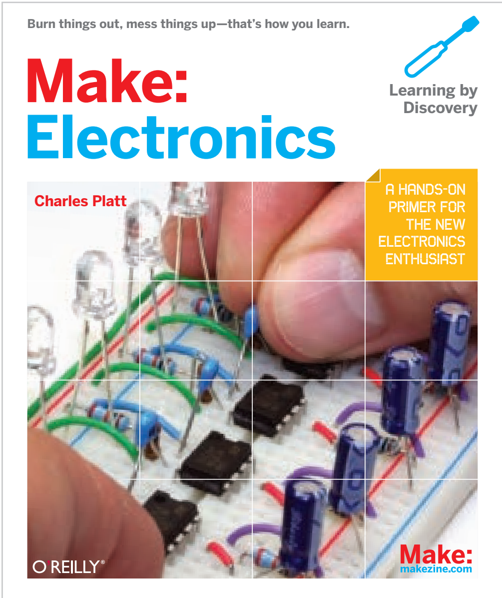
Make: Electronics is written in a fun, clear-spoken, graphical style. It includes 36 experiments and projects, plus dozens of sidebars on the science, history, and personalities behind electronics. And it's brimming with hundreds of photos, illustrations, diagrams, schematics, even cartoons, all done by Charles Platt!

It was Platt's beginner electronics guide and 555 timer projects in MAKE, Volume 10 that made us realize he might be the man to pull off the book we desired. So it's fitting that we've chosen this new 555 timer project to present here.

It occurs midway through the book, as Experiment 18, so it's a bit advanced for the beginner (don't worry, the book starts off with very easy fare), but if you follow the instructions carefully, you'll be fine. And one of the core lessons of the book is to not be afraid of failure, so if it takes you a few tries, that's fine too.

Be patient and learn from your mistakes. (If you're new to electronics you might want to read Platt's "Your Electronics Workbench" and do the projects in "The Biggest Little Chip," both in Volume 10, before tackling this project.)

We hope you enjoy this peek at *Make: Electronics*, and pick up a copy for yourself, a friend, or a family member. They're probably tired of seeing you having all the geeky fun, but are too embarrassed to let you in on their ignorance. We know they're out there.



Maker Media has just handed out the virtual cigars on the birth of our latest baby, *Make: Electronics*, by Charles Platt. To celebrate the blessed event, we thought we'd share a project from the book.

When we announced the book on Make: Online (makezine.com), we started getting "confessional" posts from readers. One wrote: "Prepare yourselves. You're going to sell one BILLION of these books. This is exactly what I've been looking for, for over a decade." Thanks. We made this book for you. (And we'll settle for a million.)

—Gareth Branwyn

Photography and Illustrations by Charles Platt

START

Time: An Evening **Complexity:** Moderate

Because the 555 timer chip can easily run at thousands of cycles per second, we can use it to measure human reactions. You can compete with friends to see who has the fastest response — and note how your response changes depending on your mood, the time of day, or how much sleep you got last night.

Before going any further, I have to warn you that this circuit requires a lot of wiring, and will only just fit on a breadboard that has 63 rows of holes. Still, we can build it in a series of phases, which should help you to detect any wiring errors as you go.

Step 1: Display

You can use three separate LED numerals for this project, but I suggest that you buy the Kingbright BC56-11EWA, which contains three numerals in one big package.

You should be able to plug it into your breadboard, straddling the center channel. Put it all the way down at the bottom of the breadboard, as shown in Figure A. Don't put any other components on the breadboard yet.

Now set your power supply to 9 volts (or use a 9-volt battery), and apply the negative side of it to the row of holes running up the breadboard on the right-hand side. Insert a 1K resistor between that negative supply and each of pins 18, 19, and 26 of the Kingbright display, which are the "common cathode," meaning the negative connection shared by each set of LED segments in the display. (The pin numbers of the chip are shown in Figure C on the following page. If you're using another model of display, you'll have to consult a data sheet to find which pin(s) are designed to receive negative voltage.)

Switch on the power supply and touch the free end of the positive wire to each row of holes serving the display on its left and right sides. You should see each segment light up, as shown in Figure A.

Each numeral from 0 to 9 is represented by a group of these segments. The segments are always identified with lowercase letters *a* through *g*, as shown in Figure B. In addition, there is often

MATERIALS

Good sources for some or all of these components include RadioShack (retail locations and radioshack.com), Mouser Electronics (mouser.com), Digi-Key (digikey.com), Newark Online (newark.com), and AllElectronics Corporation (allelectronics.com).

4026 Decade Counter chips (4) Really you need only 3, but get another one in case you damage the others.

555 timer chips (3) Do not get a CMOS or any high-precision versions.

Tactile (SPST momentary) switches (3)

3-digit LED display, such as the Kingbright BC56-11EWA. Or three numeric LEDs

Breadboard with at least 63 rows

Multimeter

Resistors: 1KΩ (6), 10KΩ, 330KΩ, 2.2KΩ or higher

Capacitors: 0.1μF (3), 1μF, 10μF (2), 68μF, 100μF

10K trim potentiometer

Low-current LED, 1mA

16-pin DIP IC sockets (3)

Jumper wires, 22-gauge solid-core insulated

9V DC power supply or 9V battery

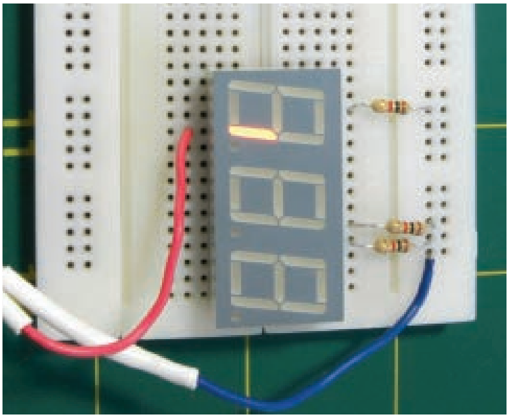


Fig. A: **After putting a 1K resistor between the common cathode of the display and the negative supply voltage, you can use positive voltage to illuminate each segment. Here, applying voltage to pin 4 lights segment 1c.**

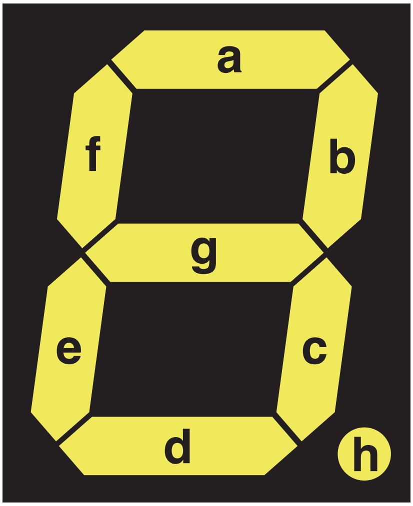


Fig. B: The most basic and common digital numeral consists of seven LED segments identified by letters, as shown here, plus an optional decimal point.

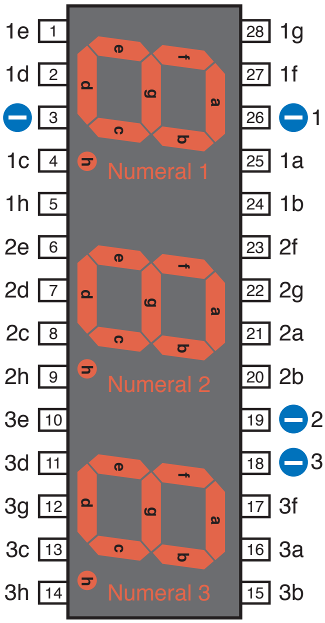


Fig. C: This Kingbright unit incorporates three 7-segment numeric displays in one package, and can be driven by three chained 4026 decade counters. The pin numbers are shown close to the chip. Segments *a* through *g* of numeral 1 are identified as 1a through 1g. Segments *a* through *g* of numeral 2 are identified as 2a through 2g. Segments *a* through *g* of numeral 3 are identified as 3a through 3g.

a decimal point, and although we won't be using it, I've identified it with the letter *h*.

Check Figure C showing the Kingbright display, and you'll see I have annotated each pin with its function. You can step down the display with the positive wire from your power supply, making sure that each pin lights an appropriate segment.

Incidentally, this display has two pins, numbered 3 and 26, both labeled to receive negative voltage for the first of the digits.

Why two pins instead of one? I don't know. You need to use only one, and as this is a passive chip, it doesn't matter if you leave the unused one unconnected. Just take care not to apply positive voltage to it, which would create a short circuit.

A numeric display has no power or intelligence of its own. It's just a bunch of light-emitting diodes. It's not much use, really, until we can figure out a way to illuminate the LEDs in appropriate groups — which will be the next step.

Step 2: Counting

Fortunately, we have a chip known as the 4026, which receives pulses, counts them, and creates an output designed to work with a seven-segment display so that it shows numbers 0–9. The only problem is that the 4026 is a rather old-fashioned CMOS chip (meaning, Complementary Metal Oxide Semiconductor) and is thus sensitive to static electricity.

Switch off your power supply and connect its wires to the top of the breadboard, noting that for this experiment, we're going to need positive and negative power on both sides. See Figure D for details. If your breadboard doesn't already have the columns of holes color-coded, I suggest you use Sharpie markers to identify them, to avoid polarity errors that can fry your components.

The 4026 counter chip is barely powerful enough to drive the LEDs in our display when powered by 9 volts. Make sure you have the chip the right way up, and insert it into the breadboard immediately above your three-digit display, leaving just one row of holes between them empty.

The schematic in Figure E shows how the pins of the 4026 chip should be connected. The arrows tell you which pins on the display should be connected with pins on the counter.

Figure F (page 100) shows the "pinouts" (i.e., the functions of each pin) of a 4026 chip. You should compare this with the schematic in Figure E.

Include a tactile switch between the positive supply and pin 1 of the 4026 counter, with a 10K resistor to keep the input to the 4026 counter negative until the button is pressed. Make sure all your positives and negatives are correct, and turn on the power.

You should find that when you tap the tactile switch lightly, the counter advances the numeric display from 0 through 9 and then begins all over again from 0. You may also find that the chip sometimes misinterprets your button-presses, and counts two or even three digits at a time. I'll deal with this problem a little later on.

The LED segments won't be glowing very brightly, because the 1K series resistors deprive them of the power they would really like to receive. Those resistors are necessary to avoid overloading the outputs from the counter.

Assuming that you succeed in getting your counter to drive the numeric display, you're ready to add two more counters, which will control the remaining two numerals. The first counter will count in ones, the second in tens, and the third in hundreds.

In Figure G (following page), I've used arrows and numbers to tell you which pins of the counters should be connected to which pins of the numeric display. Otherwise, the schematic would be a confusing tangle of wires crossing each other.

At this point, you can give up in dismay at the number of connections — but really, using a breadboard, it shouldn't take you more than half an hour to complete this phase of the project. I suggest you give it a try, because there's something magical about seeing a display count from 000 through 999 "all by itself," and I chose this project because it also has a lot of instructional value.

S1 is attached to the "clock disable" pin of IC1, so that when you hold down this button, it should stop that counter from counting. Because IC1 controls IC2, and IC2 controls IC3, if you freeze IC1, the other two will have to wait for it to resume. Therefore you won't need to make use of their "clock disable" features.

S2 is connected to the "reset" pins of all three counters, so that when you hold down this button, it should set them all to zero.

S3 sends positive pulses manually to the "clock input" pin of the first counter.

S1, S2, and S3 are all wired in parallel with 1K resistors connected to the negative side of the

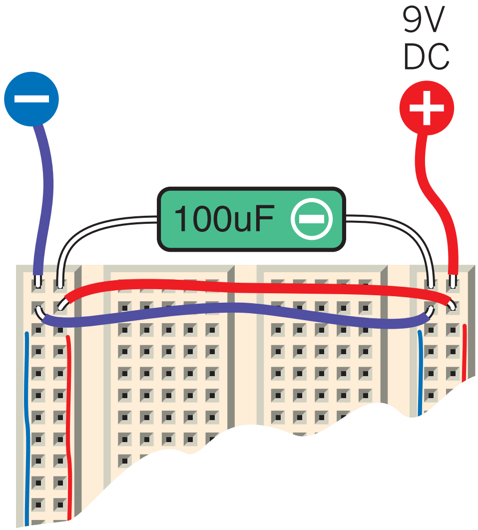


Fig. D: **When building circuits around chips, it's convenient to have a positive and negative power supply down each side of your breadboard. For the reaction timer circuit, a 9V supply with a 100µF smoothing capacitor can be set up like this. If your breadboard doesn't color-code the columns of holes on the left and right sides, I suggest you do that yourself with a permanent marker.**

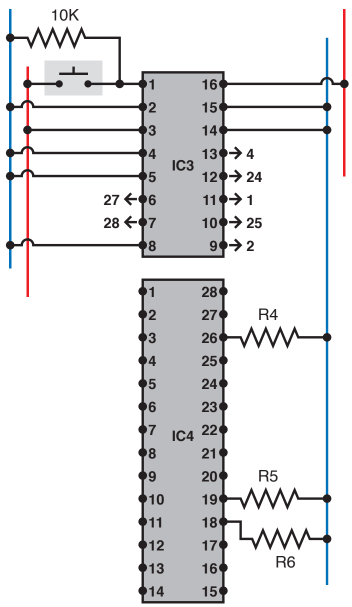


Fig. E: **IC3 is a 4026 counter. IC4 is a triple 7-segment display chip. The arrows tell you which pins on the LED display should be connected to the pins on the counter.**

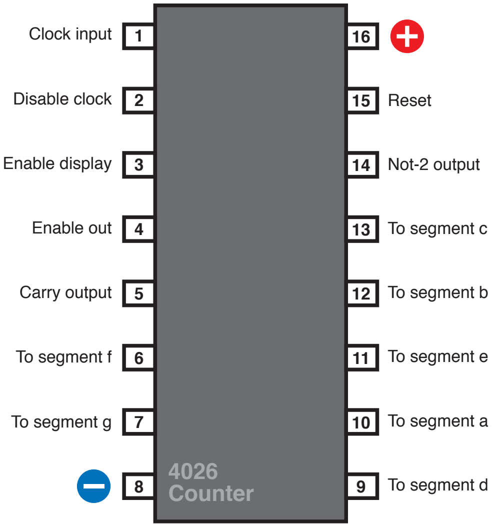


Fig. F: The 4026 decade counter is a CMOS chip that accepts clock pulses on pin 1, maintains a running total from 0 to 9, and outputs this total via pins designed to interface with a 7-segment LED numeric display.

power supply. The idea is that when the buttons are not being pressed, the "pull-down" resistors keep the pins near ground (zero) voltage. When you press one of the buttons, it connects positive voltage directly to the chip, and easily overwhelms the negative voltage. This way, the pins remain either in a definitely positive or definitely negative state.

If you disconnect one of these pull-down resistors you are likely to see the numeric display "flutter" erratically. (The numeric display chip has some unconnected pins, but this won't cause any problem, because it is a passive chip that is just a collection of LED segments.)

NOTE: Always connect input pins of a CMOS chip so that they are either positive or negative. **See the "No Floating Pins" warning on page 104.**

I suggest that you connect all the wires shown in the schematic first. Then cut lengths of 22-gauge wire to join the remaining pins of the sockets from IC1, IC2, and IC3 to IC4.

Switch on the power and press S2. You'll see three zeros in your numeric display.

Each time you press S3, the count should advance by 1. If you press S2, the count should reset to three zeros. If you hold down S1 while you press S3 repeatedly, the counters should remain frozen, ignoring the pulses from S3.

Grounding Yourself

To avoid the frustration that occurs when you power up a circuit and nothing happens, be sure to take these precautions when you use the older generation of CMOS chips (which often have part numbers from 4000 upward, such as 4002, 4020, and so on):

Chips are often shipped with their legs embedded in black foam. This is electrically conductive foam, and you should keep the chips embedded in it until you are ready to use them.

If the chips are supplied to you in plastic tubes, you can take them out and poke their legs into pieces of conductive foam or, if you don't have any, use aluminum foil. The idea is to avoid one pin on a chip acquiring an electric potential that is much higher than another pin.

While handling CMOS components, grounding yourself is important. I find that in dry weather, I accumulate a static charge merely by walking across a plastic floor-protecting mat in socks that contain some synthetic fibers. You can buy a wrist strap to keep yourself grounded, or simply touch a large metal object, such as a file cabinet, before you touch your circuit board. I am in the habit of working with my socked foot touching a file cabinet, which takes care of the problem.

Never solder a CMOS chip while there is power applied to it.

Grounding the tip of your soldering iron is a good idea.

Better still, don't solder CMOS chips at all. When you're ready to immortalize a project by moving it from a breadboard into perforated board, solder a socket into your perforated board, then push the chip into the socket. If there's a problem in the future, you can unplug the chip and plug in another.

Use a grounded, conductive surface on your workbench. The cheapest way to do this is to unroll some aluminum foil and ground it (with an alligator clip and a length of wire) to a radiator, a water pipe, or a large steel object. I like to use an area of conductive foam to cover my workbench — the same type of foam used for packaging chips. However, this foam is quite expensive.

Pulse Generation

A 555 timer is ideal for creating a stream of pulses that drive a counter chip. Figure H, page 103, shows how to connect these chips to the positive and negative rails on your breadboard. Also I'm showing the connection between pins 2 and 6 in the way that you're most likely to make it, via a wire that loops over the top of the chip.

For the current experiment, I'm suggesting initial component values that will generate only four pulses per second. Any faster than that, and you won't be able to verify that your counters are counting properly.

Install IC5 and its associated components on your

NOTE: In the course of researching the book, author Charles Platt ran across the home phone number of Hans Camenzind, inventor of the venerable 555 chip. On a lark, he decided to dial the number. You can read about what happened next at Make: Online (makezine.com/go/camenzind).

FUNDAMENTALS

Counters and Seven-Segment Displays

Most counters accept a stream of pulses and distribute them to a series of pins in sequence. The 4026 decade counter is unusual in that it applies power to its output pins in a pattern that is just right to illuminate the segments of a 7-segment numeric display.

Some counters create positive outputs (they "source" current) while others create negative outputs (they "sink" current). Some 7-segment displays require positive input to light up the numbers. These are known as "common cathode" displays. Others require negative input and are known as "common anode" displays. The 4026 delivers positive outputs and requires a common cathode display.

Check the data sheet for any counter chip to find out how much power it requires, and how much it can deliver. CMOS chips are becoming dated, but they are very useful to hobbyists, because they tolerate a wide range of supply voltage — from 5 to 15 volts in the case of the 4026. Other types of chips are much more limited.

Most counters can source or sink only a few milliamps of output power. When the 4026 is running on a 9-volt power supply, it can source about 4mA of power from each pin. This is barely enough to drive a 7-segment display.

You can insert a series resistor between each output pin of the counter and each input pin of the numeric display, but a simpler, quicker option is to use just one series resistor for each numeral, between the negative-power pin and ground. The experiment that I'm describing uses this shortcut. Its disadvantage is that digits that require only a couple of segments (such as numeral 1) will appear brighter than those that use many segments (such as numeral 8).

If you want your display to look bright and professional, you really need a transistor to drive each segment of each numeral. An alternative is to use a chip containing multiple "op amps" to amplify the current.

When a decade counter reaches 9 and rolls over to 0, it emits a pulse from its "carry" pin. This can drive another counter that will keep track of tens. The carry pin on that counter can be chained to a third counter that keeps track of hundreds, and so on. In addition to decade counters, there are hexadecimal counters (which count in 16s), octal counters (in 8s), and so on.

Why would you need to count in anything other than tens? Consider that the four numerals on a digital clock each count differently. The rightmost digit rolls over when it reaches 10. The next digit to the left counts in sixes. The first hours digit counts to 10, gives a carry signal, counts to 2, and gives another carry signal. The leftmost hours digit is either blank or 1, when displaying time in 12-hour format. Naturally there are counters specifically designed to do all this.

Counters have control pins such as "clock disable;" which tells the counter to ignore its input pulses and freeze the display; "enable display," which enables the output from the chip; and "reset," which resets the count to zero.

The 4026 requires a positive input to activate each control pin. When the pins are grounded, their features are suppressed.

To make the 4026 count and display its running total you must ground the "clock disable" and "reset" pins (to suppress their function) and apply positive voltage to the "enable display" pin (to activate the output). See Figure F to see these pins identified.

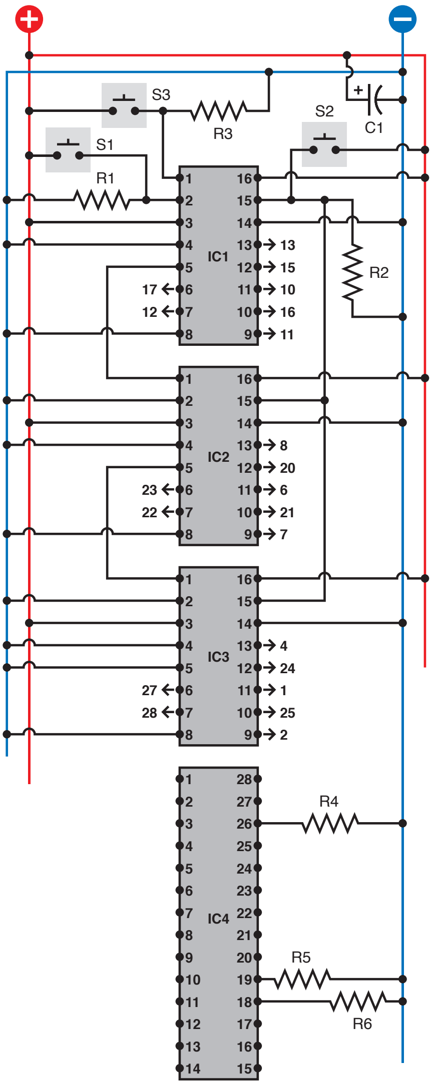


Fig. G: This test circuit, laid out as you would be likely to place it on a breadboard, allows you to trigger a counter manually to verify that the display increments from 000 upward to 999.

Component values:
All resistors are 1K.
S1, S2, S3: SPST tactile switches, normally open
IC1, IC2, IC3: 4026 decade counter chips
IC4: Kingbright 3-digit common-cathode display
C1: 100 µF (minimum) smoothing capacitor

Wire the output pins on IC1, IC2, and IC3 to the pins on IC4, according to the numbers preceded by arrows. The actual wires have been omitted for clarity. Check for the pinouts of IC4.

breadboard immediately above IC1. Don't leave any gap between the chips. Disconnect S3 and R3 and connect a wire directly between pin 3 (output) of IC5 and pin 1 (clock) of IC1, the topmost counter.

Power up again, and you should see the digits advancing rapidly in a smooth, regular fashion. Press S1, and while you hold it, the count should freeze. Release S1 and the count will resume. Press S2 and the counter should reset, even if you are pressing S1 at the same time.

Refinements

Now it's time to remember that what we really want this circuit to do is test a person's reflexes. When the user starts it, we want an initial delay, followed by a signal — probably an LED that comes on. The user responds to the signal by pressing a button as quickly as possible. During the time it takes for the person to respond, the counter will count milliseconds. When the person presses the button, the counter will stop. The display then remains frozen indefinitely, displaying the number of pulses that were counted before the person was able to react.

How to arrange this? I think we need a flip-flop. When the flip-flop gets a signal, it starts the counter running — and keeps it running. When the flip-flop gets another signal (from the user pressing a button), it stops the counter running, and keeps it stopped.

How do we build this flip-flop? Believe it or not, we can use yet another 555 timer, in a new manner known as *bistable* mode.

In bistable mode, the 555 has turned into one big flip-flop. To avoid any uncertainty, we keep pins 2 and 4 normally positive via pull-up resistors, but negative pulses on those pins can overwhelm them when we want to flip the 555 into its opposite state.

The schematic for running a 555 timer in bistable mode, controlled by two pushbuttons, is shown in Figure J, page 105. You can add this above your existing circuit. Because you're going to attach the output from IC6 to pin 2 of IC1, the topmost counter, you can disconnect S1 and R1 from that pin. See Figure K, page 106.

Now, power up the circuit again. You should find that it counts in the same way as before, but when you press S4, it freezes. This is because your bistable 555 timer is sending its positive output to the "clock disable" pin on the counter. The counter is still receiving a stream of pulses from the astable 555 timer, but as long as pin 2 is positive on the counter, the counter simply ignores the pulses.

Now press S5, which flips your bistable 555 back to delivering a negative output, at which point the count resumes. We're getting close to a final working circuit here. We can reset the count to zero (with S3), start the count (with S5), and wait for the user to stop the count (with S4). The only thing missing is a way to start the count unexpectedly.

The Delay

Suppose we set up yet another 555 in mono-stable mode. Trigger its pin 2 with a negative pulse, and the timer delivers a positive output that lasts for, say, 4 seconds. At the end of that time, its output goes back to being negative. Maybe we can hook that positive-to-negative transition to pin 4 of IC6. We can use this instead of switch S5, which you were pressing previously to start the count.

Check the new schematic in Figure K, which adds another 555 timer, IC7 above IC6. When the output from IC7 goes from positive to negative, it will trigger the reset of IC6, flipping its output negative, which allows the count to begin. So IC7 has taken the place of the start switch, S4. You can get rid of S4, but keep the pull-up resistor, R9, so that the reset of IC6 remains positive the rest of the time.

This arrangement works because I have used a capacitor, C4, to connect the output of IC7 to the reset of IC6. The capacitor communicates the sudden change from positive to negative, but the rest of the time it blocks the steady voltage from IC7 so that it won't interfere with IC6.

The final schematic in Figure K shows the three 555 timers all linked together, as you should insert them above the topmost counter, IC1. I also added an LED to signal the user. Figure L (on page 107) is a photograph of my working model of the circuit.

Because this circuit is complicated, I'll summarize the sequence of events when it's working. Refer to Figure K while following these steps:

1. User presses Start Delay button S4, which triggers IC7.

2. IC7 output goes high for a few seconds while C5 charges.

3. IC7 output drops back low.

4. IC7 communicates a pulse of low voltage through C4 to IC6, pin 4.

5. IC6 output flips to low and flops there.

6. Low output from IC6 sinks current through an LED and lights it.

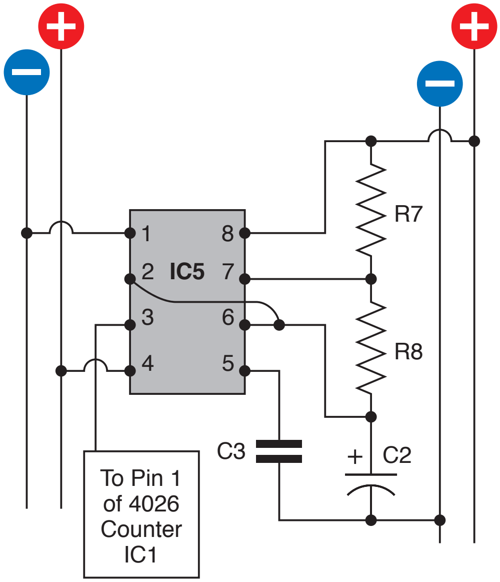


Fig. H: A basic astable circuit to drive the decade counter in the previous schematic. Output is approximately 4 pulses per second.

Component values:
R7: 1K
R8: 2K2
C2: 68 µF
C3: 0.1 µF
IC5: 555 timer

FUNDAMENTALS

Switch Bounce

When you hit S3, I think you'll find that the count sometimes increases by more than 1. This does not mean that there's something wrong with your circuit or your components; you're just observing a phenomenon known as "switch bounce."

On a microscopic level, the contacts inside a pushbutton switch do not close smoothly, firmly, and decisively. They vibrate for a few microseconds before settling; the counter chip detects this vibration as a series of pulses, not just one.

Various circuits are available to "debounce" a switch. The simplest option is to put a small capacitor in parallel with the switch, to absorb the fluctuations; but this is less than ideal. Switch bounce is not a concern in this circuit, because we're about to get rid of S3 and substitute a 555 timer that generates nice clean bounceless pulses.

No Floating Pins!

A CMOS chip is hypersensitive. Any pin that's not wired either to the supply voltage or to ground is said to be "floating" and may act like an antenna, sensitive to the smallest fluctuations in the world around it.

The 4026 counter chip has a pin labeled "clock disable." The manufacturer's data sheet helpfully tells you that if you give this pin a positive voltage, the chip stops counting and freezes its display. As you don't want to do that, you might just ignore that pin and leave it unconnected, at least while you test the chip. This is a very bad idea!

What the data sheet doesn't bother to tell you (presumably because "everyone knows" such things) is that if you want the clock to run normally, the clock-disable feature itself has to be disabled, by wiring it to negative (ground) voltage. If you leave the pin floating (and I speak from experience), the chip will behave erratically and uselessly.

All input pins must be either positively or negatively wired, unless otherwise specified.

7. Low output from IC6 also goes to pin 2 of IC1.
8. Low voltage on pin 2 of IC1 allows IC1 to start counting.
9. User presses S3, the "stop" button.
10. S3 connects pin 2 of IC6 to ground.
11. IC6 output flips to high and flops there.
12. High output from IC6 turns off the LED.
13. High output from IC6 also goes to pin 2 of IC1.
14. High voltage on pin 2 of IC1 stops it from counting.
15. After assessing the result, user presses S2.
16. S2 applies positive voltage to pin 15 of IC1, IC2, and IC3.
17. Positive voltage resets counters to zero.
18. The user can now try again.
19. Meanwhile, IC5 is running continuously.

In case you find a block diagram easier to understand, I've included that, too, in Figure M (on page 107).

Using the Reflex Tester

At this point, you should be able to fully test the circuit. When you first switch it on, it will start counting, which is slightly annoying, but easily fixed. Press

FUNDAMENTALS

The Bistable 555 Timer

Figure I shows the internal layout of a 555 timer, but the external components on the right-hand side have been eliminated. Instead, I'm applying a constant negative voltage to pin 6. Can you see the consequences?

Suppose you apply a negative pulse to the trigger (pin 2). Normally when you do this and the 555 starts running, it generates a positive output while charging a capacitor attached to pin 6. When the capacitor reaches ⅔ of the full supply voltage, this tells the 555 to end its positive output, and it flips back to negative.

Well, if there's no capacitor, there's nothing to stop the timer. Its positive output will just continue indefinitely. However, pin 4 (the reset) can still override everything, so if you apply negative voltage to pin 4, it flips the output to negative. After that, the output will stay negative indefinitely, as it usually does, until you trigger the timer by dropping the voltage to pin 2 again. This will flip the timer back to generating its positive output.

Here's a quick summary of the bistable configuration:

• A negative pulse to pin 2 turns the output positive.

• A negative pulse to pin 4 turns the output negative.

• The timer is stable in each of these states. Its run-time has become infinite.

It's OK to leave pins 5 and 7 of the timer unconnected, because we're pushing it into extreme states where any random signals from those pins will be ignored.

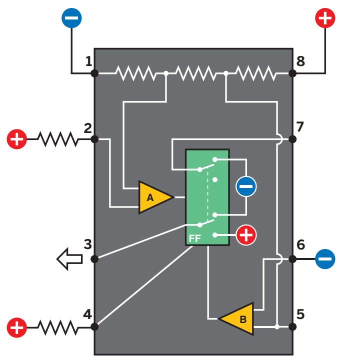


Fig. I: In the bistable configuration, pin 6 of a 555 timer is perpetually negative, so the timer cycle never ends, unless you force it to do so by applying a negative pulse to pin 4 (the reset).

S3 to stop the count. Press S2 to reset to zero.

Now press S4. Nothing seems to happen — but that's the whole idea. The delay cycle has begun in stealth mode. After a few seconds, the delay cycle ends, and the LED lights up. Simultaneously, the count begins. As quickly as possible, the user presses S3 to stop the count. The numerals freeze, showing how much time elapsed.

There's only one problem — the system hasn't yet been calibrated. It's still running in slow-motion mode. You need to change the resistor and capacitor attached to IC5 to make it generate 1,000 pulses per second instead of just three or four.

Substitute a 10K trimmer potentiometer for R8 and a 1µF capacitor for C2. This combination will generate about 690 pulses per second when the trimmer is presenting maximum resistance. When you turn the trimmer down to decrease its resistance, somewhere around its halfway mark the timer will be running at 1,000 pulses per second.

How will you know exactly where this point is? Ideally, you'd attach an oscilloscope probe to the output from IC5. But, most likely you don't have an oscilloscope, so here are a couple other suggestions.

First remove the 1µF capacitor at C2 and substitute a 10µF capacitor. Because you are multiplying the capacitance by 10, you'll reduce the speed by 10. The leftmost digit in your display should now count in seconds, reaching 9 and rolling over to 0 every 10 seconds. You can adjust your trimmer potentiometer while timing the display with a stopwatch. When you have it right, remove the 10µF capacitor and replace the 1µF capacitor at C2.

The only problem is, the values of capacitors may be off by as much as 10%. If you want to fine-tune your reflex timer, you can proceed as follows. Disconnect the wire from pin 5 of IC3, and substitute an LED with a 1K series resistor between pin 5 and ground. Pin 5 is the "carry" pin, which will emit a positive pulse whenever IC3 counts up to 9 and rolls over to start at 0 again. Because IC3 is counting tenths of a second, you want its carry output to occur once per second.

Now run the circuit for a full minute, using your stopwatch to see if the flashing LED drifts gradually faster or slower than once per second. If you have a camcorder that has a time display in its viewfinder, you can use that to observe the LED.

If the LED flashes too briefly to be easily visible, you can run a wire from pin 5 to another 555 timer

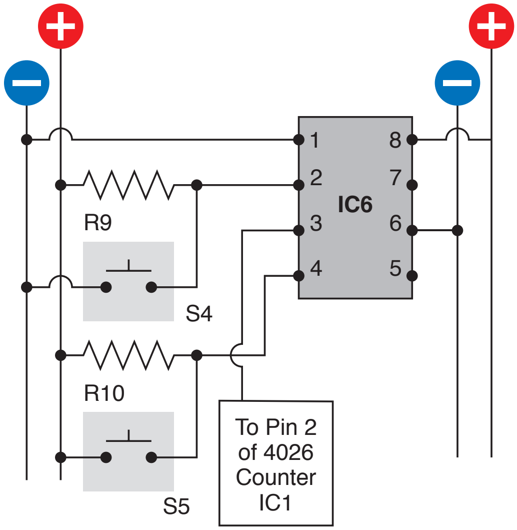


Fig. J: Adding a bistable 555 timer to the reflex tester will stop the counter with a touch of a button, and keep it stopped.

Component values:
R9, R10: 1K
IC6: 555 timer

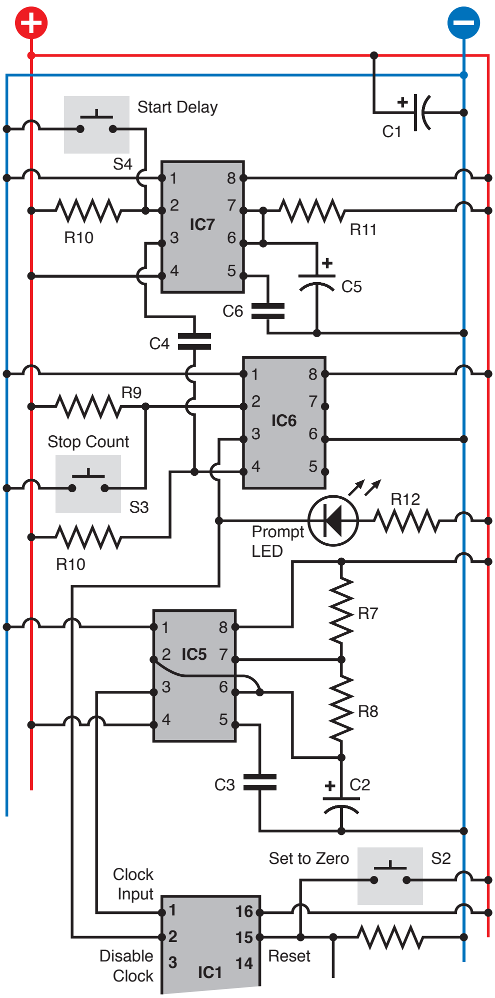


Fig. K: The completed control section of the circuit, to be added above these timers.

Component values:
R7, R9, R10, R12: 1K
R8: 2K2
R11: 330K
C1: 100 μF
C2: 68 μF
C3, C4, C6: 0.1 μF
C5: 10 μF
S1, S2, S3: tactile switches

that's set up in monostable mode to create an output lasting for around 1⁄10 of a second. The output from that timer can drive an LED.

Enhancements

It goes without saying that anytime you finish a project, you see some opportunities to improve it. Here are some suggestions:

1. No counting at power-up. It would be nice if the circuit begins in its "ready" state, rather than already counting. To achieve this you need to send a negative pulse to pin 2 of IC6, and maybe a positive pulse to pin 15 of IC1. Maybe an extra 555 timer could do this. I'm going to leave you to experiment with it.

2. Audible feedback when pressing the Start button. Currently, there's no confirmation that the Start button has done anything. All you need to do is buy a piezoelectric beeper and wire it between the right-hand side of the Start button and the positive side of the power supply.

3. A random delay interval before the count begins. Making electronic components behave randomly is very difficult, but one way to do it would be to require the user to hold his finger on a couple of metal contacts. The skin resistance of the finger would substitute for R11. Because the finger pressure wouldn't be exactly the same each time, the delay would vary. You'd have to adjust the value of C5.

Summing Up

This project demonstrated how a counter chip can be controlled, how counter chips can be chained together, and three different functions for 555 timers. It also showed you how chips can communicate with each other, and introduced you to the business of calibrating a circuit after you've finished building it.

Naturally, if you want to get some practical use from the circuit, you should build it into an enclosure with heavier-duty pushbuttons — especially the button that stops the count. You'll find that when people's reflexes are being tested, they are liable to hit the Stop button quite hard.

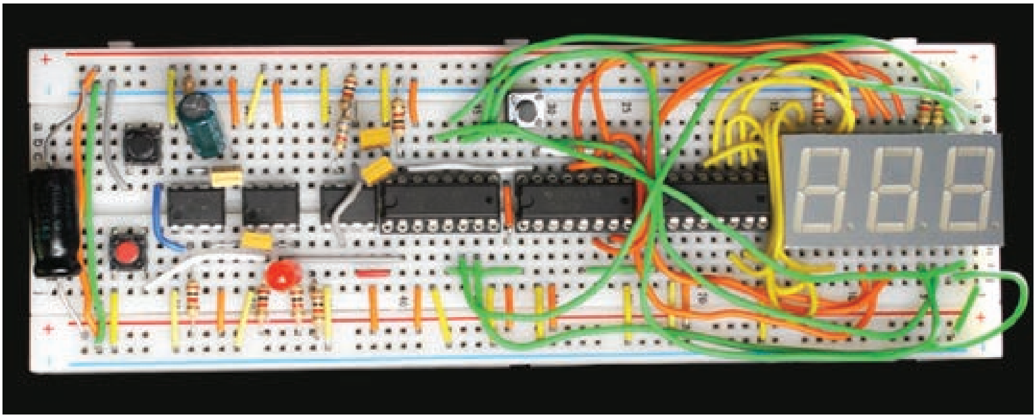


Fig. L: The complete reaction-timer circuit barely fits on a 63-row breadboard.

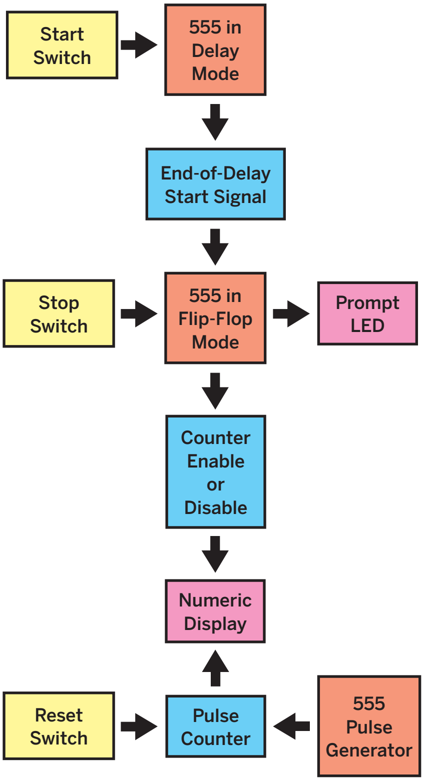


Fig. M: The functions of the reflex tester, summarized as a block diagram.

BUILD NOTES

Run a mini electric "punk bike" faster (and funnier) by powering it with a big, bad cordless drill.

The Drill Rod

BY RUSS BYRER

I HAVE A 25' CRUISING TUGBOAT IN FLORIDA, and I wanted a small, lightweight ride that I could keep onboard for making beer and ice runs when I pull into a marina. After seeing a short segment on TV about a cordless-drill-powered bike at a hardware convention, I decided to build my own.

Behold the result: the Drill Rod (Figure A). Equipped with a 36-volt drill, this brute accelerates from 0 to 10mph in just 2 seconds and is responsive enough to do tricks like standing on its back wheel.

As for styling, it's been said that when I'm on my Drill Rod, I look like a circus bear on a tricycle (duly note in Figure B). You will not attract potential romantic partners when riding this. Trust me.

When I started the project, I contacted the company that made the bike I saw on TV and asked if they could just sell me the right-angle gearbox that enables the center-mounted drill to drive the rear wheel. But they refused; they would only sell a finished bike.

I continued looking for ways to build my own. At a flea market, I found a tiny battery-powered bike for kids called the Electric Punk, made by Razor. I bought it for $60 and took it home. With its small battery and motor, I knew it was underpowered for what I needed, and its 7" rear wheel looked too small to support the weight of an adult.

On flat pavement, the Electric Punk only went 5mph, and it couldn't even pull me up my driveway slope. But its small frame was perfect for the project.

For the engine, I used a 36V Bosch Litheon drill, which was the most powerful cordless I could find. I bought it reconditioned through Amazon for $219. I also found a nice, small right-angle gearbox (1:1 ratio) made by Torque Transmission, model #RAB-1, which was rated at ⅓HP at the drill's maximum speed of 1,800rpm.

Beefing Up the Rear Wheel

I took the Electric Punk apart (Figure C) and went to work. I stripped the plastic shells, the battery, the motor, and the motor thumb trigger on the right handlebar. I threw the useless little motor in the trash.

First I replaced the 7" rear wheel with a larger rear wheel and sprocket assembly for the Razor Mini Chopper, which takes a 9" tire. This would carry weight more comfortably. I don't know if this was strictly necessary, but I knew I wanted it in order to make the bike look cooler.

To fit the 9" wheel onto the bike, I needed to relocate the axle farther back on the swing arm, so I drilled new axle holes about ¾" behind the original ones, and then moved the brake pads back to match (Figure D, page 111).

A

B

Photography by Russ Byrer (Fig. A); and courtesy of Russ Byrer (Fig. B)

Photograph by Ed Troxell

MATERIALS

Razor Electric Punk (aka E-Punk) mini bike **This has been discontinued by Razor; check flea markets and eBay (ebay.com).**

Right-angle gearbox, 1:1 ratio **part #RAB-1 from Torque Transmission (torquetrans.com), $89**

High-powered cordless drill **Make sure the chuck opens enough to accept the shaft of the gearbox. I used a Bosch 36-volt Litheon.**

Rear wheel assembly (wheel and sprocket) for Razor Mini Chopper **part #W15125090048 from Razorama (razorama.com), $26**

18-tooth sprocket for #25 chain, 3/8" bore **part #2737T121 from McMaster-Carr (mcmaster.com), $6**

Roller chain, #25, 3' **McMaster-Carr #6261K283, $10**

Connecting link for #25 chain **McMaster-Carr #6261K108**

Motorcycle twist grip throttle, to fit 3/4"-diameter handlebars **I bought mine on eBay for $20.**

Motorcycle throttle cable

Aluminum bar stock

3/8" metal rod, 5" length

1/2" square aluminum U-channel, 1/16" wall thickness, 14" length

5/16" threaded rod, 16" length

Hardwood scraps **for the kickstand extension and hinged platform. I used some old oak and a broken teak paper towel holder I found in the trash can at the marina.**

Black plastic knobs, 1/4-20 threaded

Ball plunger pin, 3/16"×3" long, threaded

Heavy-duty nylon zip ties **for kickstand extension**

Bicycle seat

Various screws, washers, and nuts

TOOLS

Milling machine **I used my Smithy (smithy.com) combination milling machine and lathe.**

Tap and die set, plus tapping oil

Marker

Drill **Use the one that will power the bike later!**

Drill bits **for metal**

Screwdrivers and Allen (hex) wrenches **common sizes**

Heavy pliers and file

Hammer and chisel, or router

Ruler

THE 10MPH BEAST

The Drill Rod's speed is determined by the speed of its drill, the size of its rear wheel, and its gear ratio. I made a spreadsheet that let me see the results, in miles per hour, of changing each of these variables. My calculations:

Gear ratio
= **wheel sprocket teeth / gearbox sprocket teeth**
= 66/18

Wheel rpm
= **drill rpm / gear ratio**
= 1,800rpm / (66/18)
= 463.6rpm

Wheel circumference
= **wheel diameter * Π**
= 9" * Π = 30.73"

Speed
= **wheel rpm * wheel circumference**
= 14,245" per minute
/ (63,360"/mile)
* (60 minutes/hour)
= 13.49mph

This speed is the absolute best case with no weight. With an adult rider, the bike's speed is closer to 10mph. You can use a bigger gearbox sprocket to make it faster, but 10mph is plenty fast for me on something this small.

Note that keeping the E-Punk's original 7" back wheel would have made the bike's top speed only 10.49mph (although the increased torque would mean less speed reduction from weight).

Note also that the original Electric Punk bike was made for kids, and is officially rated at 120lbs maximum weight for the rider.

I weigh 230lbs, and the Drill Rod handles my weight just fine. My son, who weighs more than I, also rides it successfully (his weight is being withheld for my safety and well-being).

Mounting the Right-Angle Gearbox

Next came the gearbox. I screwed an 18-tooth sprocket to the right side of the gearbox, and then mounted the box where the bike's original motor attached.

The original mount was a plate that slid up and down for adjusting the chain's tension, which meant that I couldn't just drill holes through and bolt the gearbox on with nuts on the other side. So I made my own mounting plate that screwed into the original motor's holes, with blind-tapped holes for the gearbox mounting screws to sink into (Figure E).

I used Google SketchUp (sketchup.google.com) to design the mounting plate, as well as the throttle mechanism and seat post hinge mechanisms that I added later. Visit makezine.com/21/build_notes for links to these designs, which include dimensions.

I used a straightedge to make sure the gearbox sprocket lined up accurately with the wheel sprocket (Figure F). This is important because if the sprockets don't line up, the chain may slip off. Then I cut the chain to length and connected the 2 ends with a connecting link.

The larger wheel makes the bike's kickstand too short, so I made an extension out of scrap oak. To secure it, I chiseled out a groove that fit the curved lower part of the original kickstand, then drilled the wood and strapped it on with heavy-duty nylon zip ties (Figure G).

Mounting the Throttle

I attached the drill to the gearbox shaft directly, just the way you would put a drill bit in it. The problem was, the drill had so much torque that the chuck just slipped around the shaft and quickly chewed it up. I found this out the hard way, so I had to make a replacement shaft.

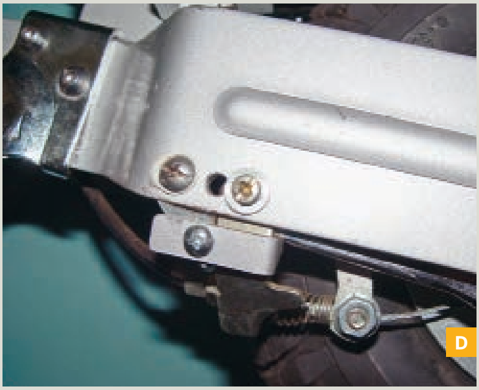
The original gearbox shaft was ⅜" in diameter, but I made the new one ½" thick and then machined 3 equally spaced flats around its sides, giving it a rounded triangle shape. The resulting shaft was beefier and easier for the drill chuck to clamp down on (Figure H).

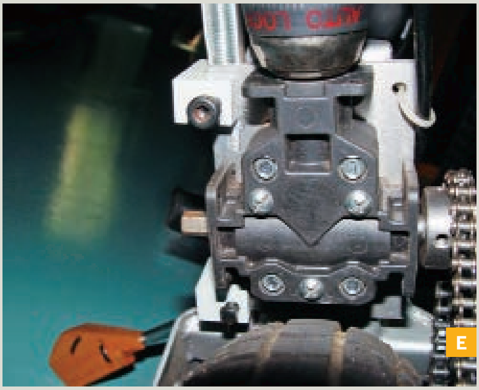
The Razor came with a thumb-operated switch that simply turned the motor full on or off. I replaced this with a motorcycle-style handlebar twist grip that pulls a throttle cable (Figure I).

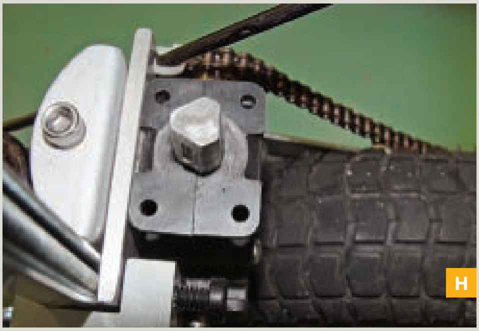
This was easy; you just take off the old hand grip, slip the new one over the handlebar, and tighten the screws. The throttle cable's other end attaches to a small lever that pulls the drill's trigger, just like you would with your finger. This speed control method is about as basic as it can get, but it works!

I machined the throttle mechanism out of aluminum. The small lever that pulls the drill's trigger pivots around a 3" threaded ball plunger pin, where it passes through a hole in the middle of a 6" vertical plate (Figure J). The plate, in turn, extends down from the platform that holds the back of the drill.

At the bottom of the plate, a smaller plate has a guide hole that carries the throttle cable to the







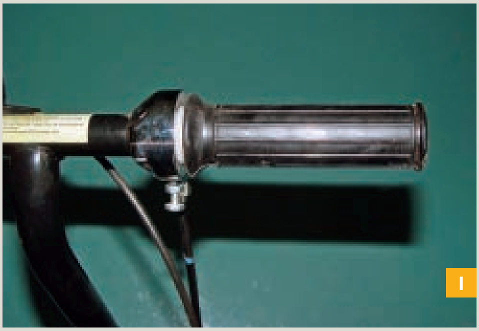


Fig. D: Rear axle and brake moved back on the swing arm to accommodate a larger rear wheel. Fig. E: Right-angle gearbox mounted to a custom tapped plate that's screwed to the original motor mount. Fig. F: Aligning the sprockets. Fig. G: Wooden kickstand extension. Fig. H: Gearbox shaft milled into a triangular shape, for a stronger hold from the drill chuck. Fig. I: Handlebar twist-grip for throttle cable. Fig. J: Throttle mechanism, cable side.

BUILD NOTES

The Drill Rod

opposite end of the trigger lever. I filed the lever end round so its edges wouldn't mar the plastic trigger (Figure K).

Mounting the Drill

The bike's rear wheel has a spring shock absorber (Figure L), so I needed to mount the drill in a way that would allow it to move up and down along with the bike's swing arm. (The alternative would be to tighten the rear shock spring all the way down, disabling it — but this would make the ride extremely uncomfortable.)

To accomplish this, I designed a hinged platform that connects to the bike's seat post. Designing and making this flexible connection was the hardest part of the project.

The platform has 2 parts: a front bracket that clamps to the seat post, and the main platform that holds the drill. The bracket has a flat slot in back, and the platform has an axle that passes through the slot. The rod is contained by the slot but is free to move inside, creating a combination slip joint and hinge (Figure M). This supports the platform while giving it 2 degrees of freedom: up-down tilt (pitch) and forward-back translation (surge).

I machined the front bracket out of aluminum stock using my Smithy and made the axle out of some ⅜" rod, turning the ends with a threaded die and screwing matching knobs onto each end. I pieced together the platform out of some scrap teak wood from a paper towel holder that I dumpster-dove at a marina. See design sketches for the hinge and platform at makezine.com/21/build_notes.

The rear part of the platform has a metal tongue for the bottom of the drill to hook onto, and 2 pegs that cradle the drill on either side. The pegs are small lengths of dowel that I beveled with a file and glued into holes (Figure N).

A separate curved piece of teak fits on top of the platform and swings around to cradle the back end of the drill, where it protrudes through the hole in the platform (Figure O).

A support pillar connects the main platform down to the motor mounting plate. It's a 16" length of threaded rod tucked inside a slightly shorter length of square aluminum U-channel. At the top, the U-channel butts up against the underside of the platform. The rod sticks up through holes in the platform and swing piece, and then threads through the washer, nut, and wing nut that tighten it down (Figure P).

I attached the bottom of the support pillar to the gearbox mounting plate using 2 U-shaped clamps that I cut out of steel. The clamps fit around the plate and U-channel, with a socket head cap screw to tighten them down together (Figure Q). The bottom end of the threaded rod rests on the topside of the bike's swing arm.

Riding the Drill Rod

One last modification: the seat that comes on the E-Punk is very small, so I installed a larger, spring-loaded seat. The Drill Rod was complete, ready to rev up and ride (Figure R).

So how does it handle? I have cruised with the Drill Rod several miles so far, and it works just fine. Several friends have also tried it, and it always puts a big smile on their faces. I like to think this is because they're having fun, but perhaps embarrassment is involved. My son and son-in-law also both love riding the Drill Rod. Like me, they have no shame.

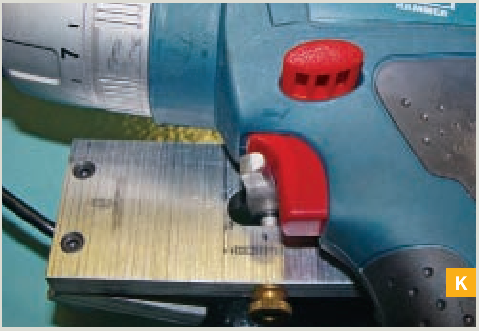
One day I was cutting tree limbs hanging over a fence on my property, and a limb fell onto the neighbor's side of the fence. The way our homes are configured, I had to go halfway around the block to get to where I could pick up the limb, and I decided to ride the Drill Rod. On the way back home, I passed a city maintenance truck. The guy inside just stared and shook his head as if to say, "You know that people can see you, don't you?"

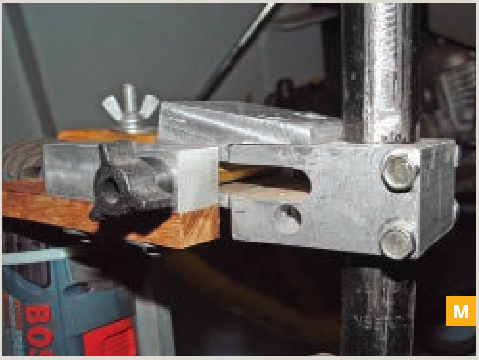
The Drill Rod weighs 37lbs, including the weight of an extra battery, which fits easily in the frame where the original battery pack went. The little bike takes me 2 miles per fully charged battery. If you carry extra batteries, you increase your range 2 miles per battery. I did the math.

Admittedly, the brakes that come on the E-Punk are terrible, and are inadequate for the Drill Rod. But between using the brakes and dragging your feet, you can get stopped. That being said, if you build one and run it into a tree, consider yourself forewarned.

Meanwhile, I'm thinking about building a drill-powered dinghy.

Russ Byrer is a retired engineer for Delphi Automotive Systems who, among other things, did technical support for the CART Indy Car Racing Series.





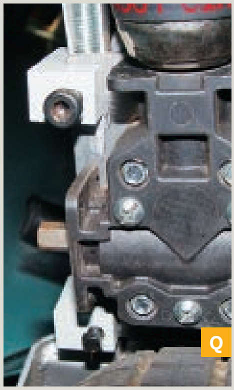


Fig. K: Drill trigger side of throttle mechanism, showing lever rounded at the contact point. Fig. L: Rear wheel shock absorber. Fig. M: Hinged slip-joint connection between the drill support platform and the seat post. Fig. N: Support plate with hook for holding bottom end of the drill. Fig. O: Back end of drill, shown being steadied by the swing arm. Fig. P: Support pillar between the main support platform and the gearbox mounting plate. Fig. Q: Bracket securing the bottom end of the support pillar. Fig. R: Completed Drill Rod, in all its glory, equipped with a spare battery pack in the frame.

1+2+3 Safe Bamboo Swords

By David Battino

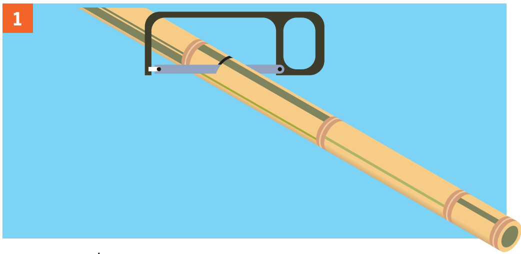
At an outdoor festival, my sons and I saw a group of teens play-fighting with padded swords. That looked like a lot of fun, so we tried making our own. It was remarkably easy and inexpensive — each sword costs about $4.

YOU WILL NEED

Bamboo poles about 1" in diameter by 6' long
Foam pipe insulation The kind with a slit along one side is best.
Duct tape
X-Acto knife to trim foam
Saw (optional) to cut bamboo

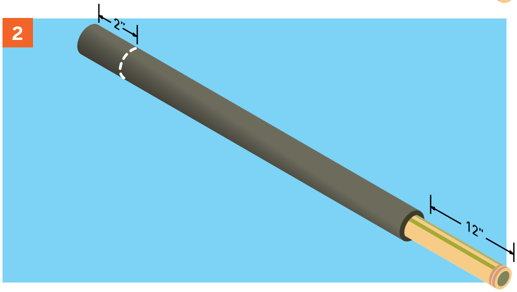
1. Cut the bamboo (if desired).

Six-foot swords are great, but we also made two 3-footers.



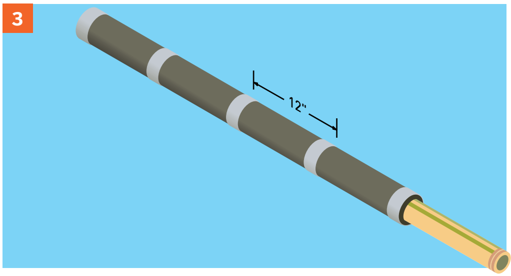
2. Wrap it in foam.

Squeeze the foam around the pole, leaving about 12" uncovered for the handle. Allow the foam to extend 1"–2" beyond the other end of the pole so the tip is padded.



3. Add duct tape for strength.

The foam we chose has adhesive along the slit, but a few wraps of duct tape every foot or so will ensure that it doesn't split open. Some people wrap the whole thing in duct tape. Covering the handle with duct tape is also an option.



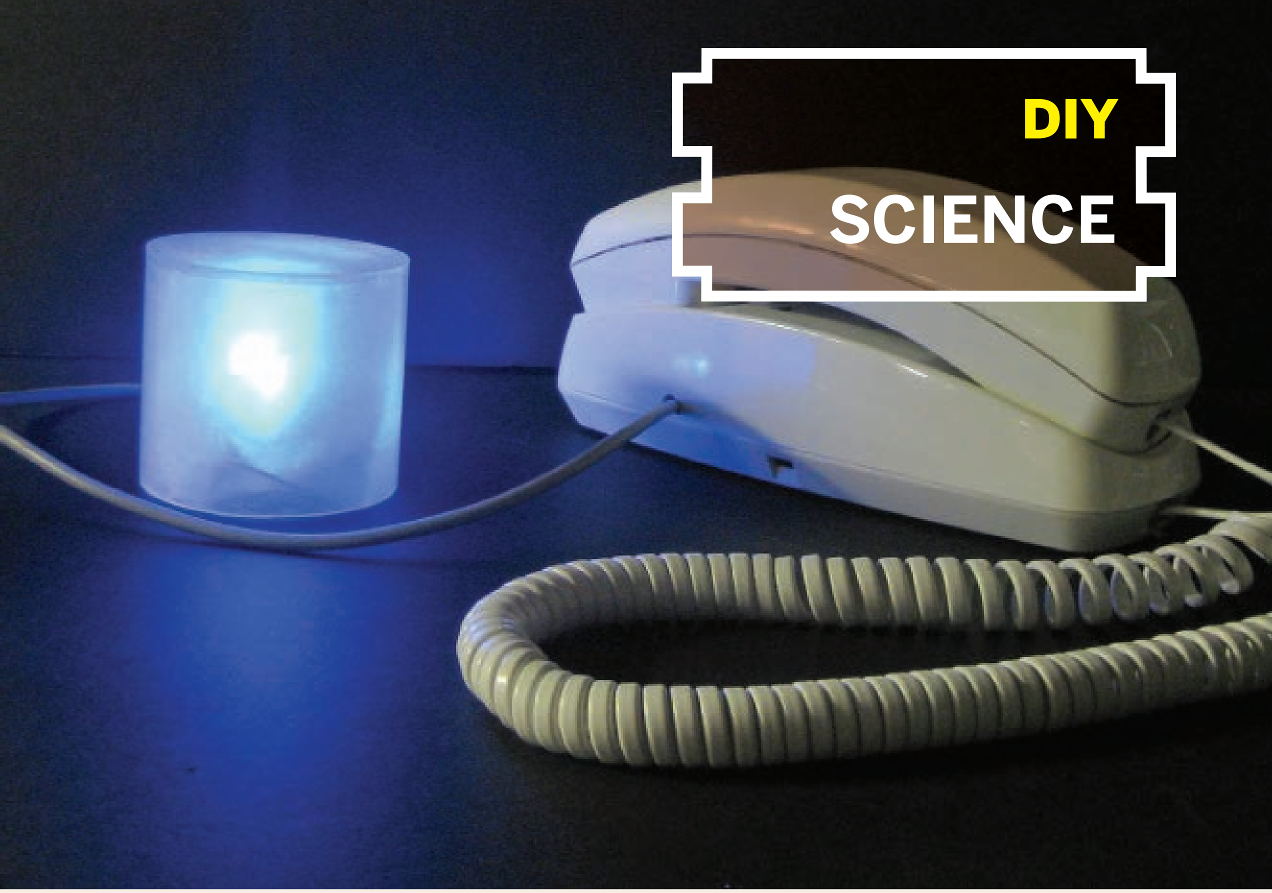
Use It.

We battle using Monty Python's "Black Knight" rules: a chop to your opponent's arm or leg disables it; keep fighting until one of you has no limbs left. In the photo below, Sir Christopher has lost both legs and King Toma has lost an arm.

It's great, silly fun to fight while hopping on one leg or gripping the sword between your knees because you've lost both arms. Plus, the low mass of the poles and the thick padding make sparring fairly safe.

Illustrations by Julian Honoré/p4rse.com; photograph by David Battino

David Battino makes music (batmosphere.com) and Japanese storycards (storycardtheater.com).



ESP/PSI TESTING LAMP

Watch the universe play dice, by detecting random radiation. By John Iovine

Albert Einstein once wrote that God does not play dice with the universe. To which Niels Bohr (or Enrico Fermi) reportedly replied, "Stop telling God what to do with his dice."

Here's a mood lamp that expresses these dice as 4 multicolored cubes that blink randomly, with true randomness — not the deterministic, pseudo-random chaos that computers and other closed, logic-based systems produce, but real, nonreplicable randomness, triggered by background radiation from across the universe.

I designed this lamp for testing ESP (extrasensory perception), although it has other fun and interesting applications. At the heart of the device is a mini Geiger counter that detects ionizing radiation from 3 main sources: cosmic radiation from the sun and stars; terrestrial radiation from radioactive elements in the soil, air, and water; and radioactive isotopes in living organisms' bodies, such as potassium-40, carbon-14, and lead-210.

To produce the random numbers, a microcontroller constantly runs through a loop counting from 1 to 4. Whenever the Geiger counter detects a particle, the loop is interrupted and the last number counted indexes to one of the 4 LED cubes. This new cube is lighted, and the counting resumes until the next detection. The algorithm resembles a fast-spinning carnival wheel that's stopped occasionally to read the pointer position, then spun again.

As a result, a new cube on the lamp switches on about once or twice a minute, under normal circumstances. If the same cube lights again, it momentarily blinks off in between. For logging and other uses, the random numbers are also sent to a serial port as TTL data (0V low, 5V high) that can be read by a PC.

Photography by John Iovine

MATERIALS

All parts (materials) are available as a kit from my company, Images SI, at imagesco.com/esp.html. I also sell separately the Geiger tube, PCB, case, step-up transformer, and a preprogrammed microcontroller.

Mini Geiger-Müller tube
PIC 16F84 microcontroller, 20MHz
Circuit boards The kit has custom PCBs, or you can use 2 plain 2"×6" breadboards and insulated hookup wire.
Plastic case The kit includes a transparent cylinder case that fits the PCBs.
Mini step-up transformer
16MHz crystal oscillator
4049 hex inverter chip
Chip sockets: 16-pin and 18-pin for PIC and inverter chips
SPST (on/off) switch
Capacitors: 22pF (2), 0.0047µf, 100–330µF (2)
High-voltage capacitors, 1kV, 0.01µf (4)
Diodes: 1N914, 1N4007 (3), 1N5281B 200V Zener (2), 5.1V Zener
Bridge rectifier, 1 amp
LEDs: red, green, blue, yellow (1 each)
Resistors, ¼ watt: 33Ω (4), 1kΩ, 4.3kΩ, 4.7kΩ, 5.6kΩ, 10kΩ, 15kΩ, 330kΩ, 3.3MΩ
Transistors: 2N3904 (5), IRF830 power MOSFET
7805 voltage regulator
¼" copper foil tape, about 2" length
⅛" 2-conductor jack for data out
6V–9V DC "wall wart" transformer and 2.5mm power jack, and/or 9V battery and battery snap

TOOLS

Clear silicone adhesive
Soldering equipment and solder
Vise
Small saw
Drill press or drill and bits: ¼", ⅜"
Sandpaper and wire brush (optional) for decorative texturing
PIC programmer and PC (optional) if you don't buy the preprogrammed microcontroller

Circuit Overview

The circuit draws power from a 6V–9V DC transformer or a 9V battery. See makezine.com/21/diyscience_esp for a schematic. On the logic side of the circuit, a voltage regulator produces 5V DC to supply the chips and LEDs. The other part of the circuit, the detector side, steps the voltage up to the 400V DC needed to power the Geiger tube. A 4049 hex inverter chip is set up to generate a square wave, which drives an IRF830 power MOSFET to switch the current on and off to a mini step-up transformer.

The transformer's AC output then feeds into a voltage doubler, consisting of 2 high-voltage diodes and 2 high-voltage capacitors, which produces the 400V DC that connects to the anode of the Geiger tube.

The Geiger tube's cathode connects to ground through a 330kΩ resistor, and a 5.1V Zener diode spans the resistor to limit the tube's pulse output. The output feeds into the base of a 2N3904 transistor, which boosts it and routes it through 2 inverting gates. The inverters momentarily buffer the signal without reversing its polarity, before it continues to the microcontroller's interrupt pin and halts the spinning carnival wheel.

I built my lamp to run off a wall-wart, but you can also make a portable version that takes a 9V battery, or a lamp that runs both ways. See the schematic notes for details.

Building the Circuit

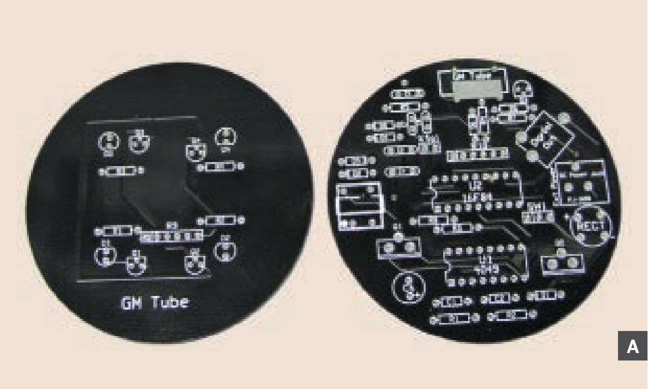
You can build the ESP Lamp circuit on my kit PCB, which is printed to show which components go where (Figure A), or else use plain breadboard and follow the online schematic. Either way, assemble 2 different boards: a small display board carrying the LEDs, their paired resistors, and the transistors that drive them (Figure C), and a main circuit board with everything else (Figure B). Connect the 2 boards temporarily just for testing; they'll be stacked in close proximity in the completed lamp, so you may want to shorten the connections later.

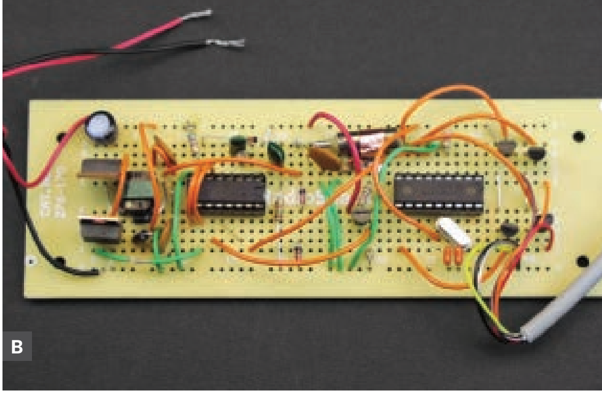
To prepare the Geiger tube's cathode before connection, wrap copper foil tape around the body of the tube (Figure D). This foil solders to the 330kΩ grounding resistor. Solder the sockets in for the PIC microprocessor and 4049 inverter chips so that they can be easily removed — this is especially important for programming the PIC.

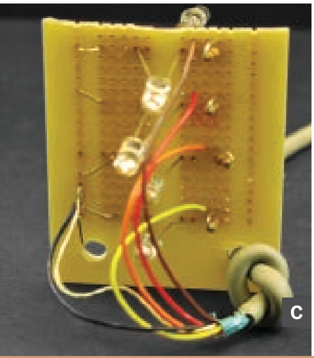
After assembling the electronics, download the hex file from makezine.com/21/diyscience_esp and use a PIC programmer to burn it onto the microprocessor. Plug in the chip, switch on the power, and watch. When the lamp turns on, it does a self-test, lighting the 4 LEDs in sequence. Then all the LEDs are turned off until the first radioactive particle is detected. If it all works, you're ready to build the case.

Making the Case

Before gluing the lamp together, test-fit the case pieces and circuit boards. With the kit case, the small ring piece fits inside the main tube and supports the







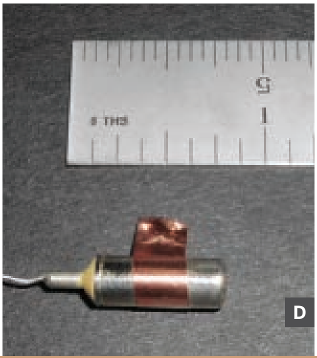


Fig. A: The ESP Lamp project kit PCBs for the display board and main board. Fig. B: Main board for a plain breadboard circuit. Fig. C: Small display board for a plain breadboard circuit.

Fig. D: The mini Geiger-Müller tube wrapped with copper foil. Fig. E: Holes drilled in the main tube for power and data connections.

main PCB. Mark positions and drill ⅜" holes for the power plug and data port, if used, leading to their locations on the PCB. You can insert dummy plugs into the jacks to confirm that the holes fit (Figure E).

Use a small saw to cut 3 arcs, about 60° each, out of the medium-sized ring. Arrange these arcs as curved spacers around the perimeter of the main board (Figure F, following page), and stack the display board on top.

Solder the final connections between the 2 boards if you haven't already, making them short and flexible enough to fit.

Drill each cube halfway through with a ¼" bit, for an LED to fit into. The kit case pieces are made from clear plastic and you can leave them transparent, but I created a frosted effect by texturing the cubes and the surfaces below them with sandpaper and a wire brush (Figure G).

The lamp is ready to be glued together. Using clear silicone adhesive, glue the cubes over the LEDs on the display board (Figure H). Glue the main board platform into the main tube and then glue in the board. Glue the spacers to the inside of the tube, and the display board on top. Finally, fit the clear plastic top disk over the cubes, finishing off the lamp.

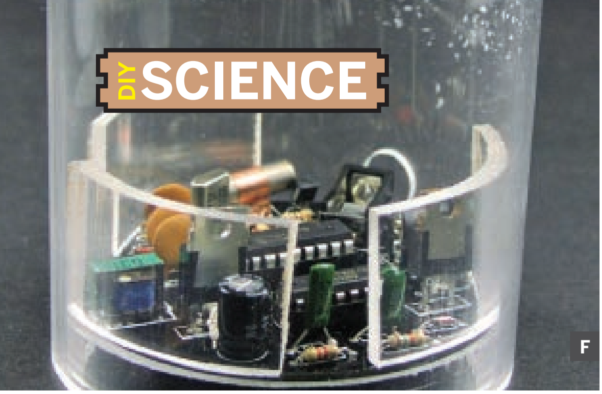
Applications — Radioactivity and Party Games

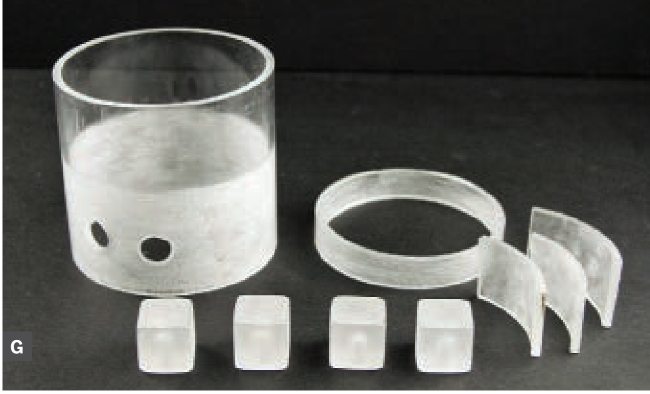
True random numbers are useful for data encryption, statistical mechanics, probability, gaming, neural networks, and disorder systems, to name a few. Here are some specific applications for the ESP Lamp.

Mood Lamp The lamp's output is unpredictable in both time and color. You can see it as a sophisticated mood lamp, a window into the ramblings of the universe at large, or maybe an example of God talking (if anyone is listening).

Radioactive Fallout Detector Excessive radiation, such as from radioactive fallout, would make the LEDs blink rapidly. Using this same principle, if you wanted to generate random numbers more rapidly than the lamp typically outputs, you could hold a small piece of uranium ore close to the Geiger tube. This will also cause the lamp to blink rapidly and output random numbers.

Precognition Testing Predict the color of the next LED that will light, and track the results. For example, write down what you think the next 60 LED colors will be. Chance alone will average 15 correct hits out of 60 calls, but any number of hits between 9 and 21 hits (2 standard deviations from chance) is not considered significant. Hit counts above (or below)





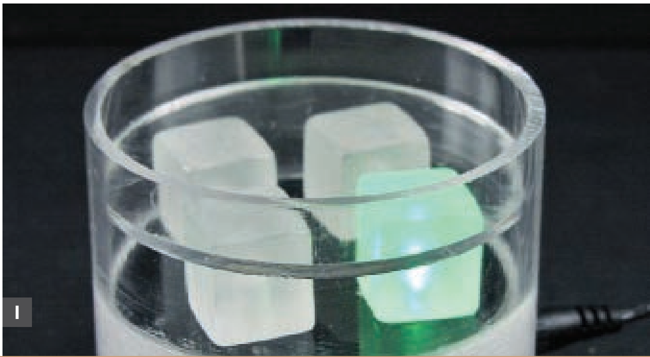


Fig. F: The display board support spacers arranged around the parimeter of the main board. Fig. G: The case pieces cut, frosted, drilled, and ready for assembly.

Fig. H: The "dice" cubes glued over the LEDs on the display board. Fig. I: Random radiation or psychokinesis at work?

this range may be showing ESP/psi activity.

Psychokinesis (PK)/Intention Testing Choose a single color to "intend" and write down the next 60 LED colors while mentally trying to get your color to come out. As with precog testing, anything above or below the range 9 to 21 suggests activity. It has been suggested that groups of people all intending the same color have a higher influence rate than individuals, so this could be a game to try at your next party.

Telepathy Testing Two people sit in separate rooms; a sender observes the ESP Lamp and tries to transmit the color changes to the receiver as they occur. The receiver tries to receive the impression from the transmitter and writes down the colors and times.

Telephone to God Use the ESP Lamp as a Magic 8-Ball type of device. Assign values to the colors, like green for yes, red for no, and so on. Ask a question and wait for the reply from the next lit LED. Matthew 10:29 reads, "Not even a sparrow falls to earth without God's knowing it." If so, God would know of this telephone and could communicate through it.

Global Consciousness Signal The Global Consciousness Project (see Resources) analyzes randomly generated numbers for significant deviations from randomness, which they reportedly observed during Lady Diana's funeral and after the 9/11 attacks. The ESP Lamp has a TTL output that can be read by a PC, so software can be written to check whether its output becomes less random, signaling an event, global or local.

Resources

Here are 3 research sites that use statistical tools and random events to assess possible ESP/psi abilities of the human mind:

» **Psi Arcade:** An online intuition game from the Institute of Noetic Sciences (IONS) psiarcade.com

» **Global Consciousness Project:** Featured in MAKE, Volume 09, page 62 noosphere.princeton.edu

» **International Consciousness Research Laboratories (ICRL):** Extending the discontinued Princeton Engineering Anomalies Research (PEAR) program icrl.org

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John Iovine is a science and electronics tinkerer who has published a few books and articles, owns and operates Images SI Inc., a small science company, and resides in Staten Island, N.Y., with his wife and two children, their dog, Chansey, and a newly rescued tabby kitten.

SLOW DOWN TO SPEED UP

A smart, cheap setup for shooting long-duration time-lapse movies. By Ken Murphy

We've all seen time-lapse movies that seem to speed up the world around us. The effect is very compelling, making processes that normally occur at a rate too slow to perceive unfold before our eyes, such as the blooming of a flower.

I'm working on a time-lapse movie that captures the dynamics of weather and clouds, and the patterns of sunrise and sunset for an entire year. I need a setup to capture a large number of images. I need to collect these images without interrupting the image-capture process, and to access the system remotely. I want to do it on the cheap, without sacrificing quality.

Here's the solution I came up with: I'm putting a dusty old PC back into service, installing Linux and gPhoto image capture software, and connecting it to my old 4-megapixel Canon A520 camera via USB. The camera will be mounted in an improvised (yet sturdy) outdoor enclosure. With this setup, the images can be continually captured directly to disk, around the clock, and I'm able to log in remotely to control the camera. I can also compile the images into movies on the same system.

1. Install Linux.

Note that installing Linux will wipe out any data on your PC. You can download the Ubuntu installer for free (ubuntu.com), or buy the DVD from Amazon. The installation tools will walk you through the entire process, asking you to select various application packages.

You'll likely want an OpenSSH server so you can remotely and securely log in, a web server such as Apache so you can view your images remotely, and any scripting languages you may find useful, such as Python or Perl.

Photograph by Ken Murphy

MATERIALS AND TOOLS

Digital camera Free gPhoto software supports hundreds of cameras; check their website (gphoto.org) to see if yours is on the list. Even older digital cameras can take high-quality pictures, and a 4-megapixel camera exceeds the resolution required to make an HD movie.

Wide-angle conversion lens (optional) I want to capture as much of the sky as possible, so I bought a wide-angle conversion lens online for about $30. It fits right over the camera's existing lens and doubles the angle of view.

AC adapter Don't expect the USB connection from your computer to supply power to your compact digital camera! I found a cheap off-brand power supply online that's compatible with my camera.

PC A minimal installation of Linux, along with the gPhoto software, will not place great demands on your system; an old 600MHz Pentium III, for example, has more than enough horsepower.

USB active extension cables (optional) I picked up a couple for about $16 each. These can be daisy-chained together to reach distances of 60–80 feet (according to manufacturers' claims).

Enclosure I used a 6"×6"×6" steel enclosure made by Hoffman (hoffmanonline.com), part #A6R66NK.

Picture frame glass for the enclosure window. My local frame shop cut a 5"×5" piece for a few bucks.

Slotted angle (optional) for mounting the enclosure. I used two 6' lengths. The mounting hardware you require may vary.

Miscellaneous hardware You'll need a handful of ¼-20 machine screws or hex bolts, washers, nuts, and/or wing nuts, for putting it all together. If you need to fit your camera with a power-on setscrew (see Step 4), you'll also need a 3" aluminum mending brace, a 1" #8 machine screw, and a couple of matching nuts.

Dremel or your favorite metal cutting tool to modify the enclosure. There are many ways to cut sheet metal, but I used a rotary tool with a tungsten carbide cutting bit.

Silicone caulk

5-minute epoxy (optional) for attaching the setscrew bracket (again, see Step 4)

Uninterruptible power supply, aka UPS (optional) I want my system to survive short-term power outages, so I purchased an inexpensive UPS designed for desktop computers.

Software I used open source gPhoto software (gphoto.org), which runs on Unix-Linux operating systems. My flavor of choice is Ubuntu (ubuntu.com), which is about as easy to install as Linux gets. If you're not quite ready to jump into the Linux universe, there are great image capture and time-lapse programs for other operating systems. For Windows, there's GBTimelapse shareware (granitebaysoftware.com); it works only with Canon cameras.

Pliers and vise-grips

2. Install additional software.

The easiest way to install software on Ubuntu is using its package manager system. To install gPhoto, log in and enter the command:

```
sudo apt-get install gphoto2
```

Likewise, you can install FFmpeg (which you'll use to assemble your images into a movie) like so:

```
sudo apt-get install ffmpeg
```

It's likely that you'll want a video player to view your creation. For Linux, there is VLC:

```
sudo apt-get install vlc
```

You may also choose to install other programs or libraries. For example, ImageMagick includes a number of line-command tools for manipulating images, and Image::EXIF is a Perl module for extracting EXIF data embedded in your image files.

3. Test your camera.

Before putting your camera in its enclosure, see how it works with the software. Connect your camera to the PC with its USB cable, and power it on. Log into your Linux box and enter the command:

```
gphoto2 --list-config
```

GPhoto will attempt to auto-detect your camera. If successful, it will output a list of configuration parameters. For many supported cameras, you can manipulate all the camera's settings just as if you were operating it by hand. For example, to set the image capture size to the lowest resolution:

```
gphoto2 --set-config imgsize=small
```

Some cameras may need to be identified explicitly, for example:

```
gphoto2 --camera "Canon PowerShot A520 (PTP mode)"
  --port usb: --list-config
```

Before capturing an image, Canon cameras must first extract the lens with the command:

```
gphoto2 --set-config capture=on
```

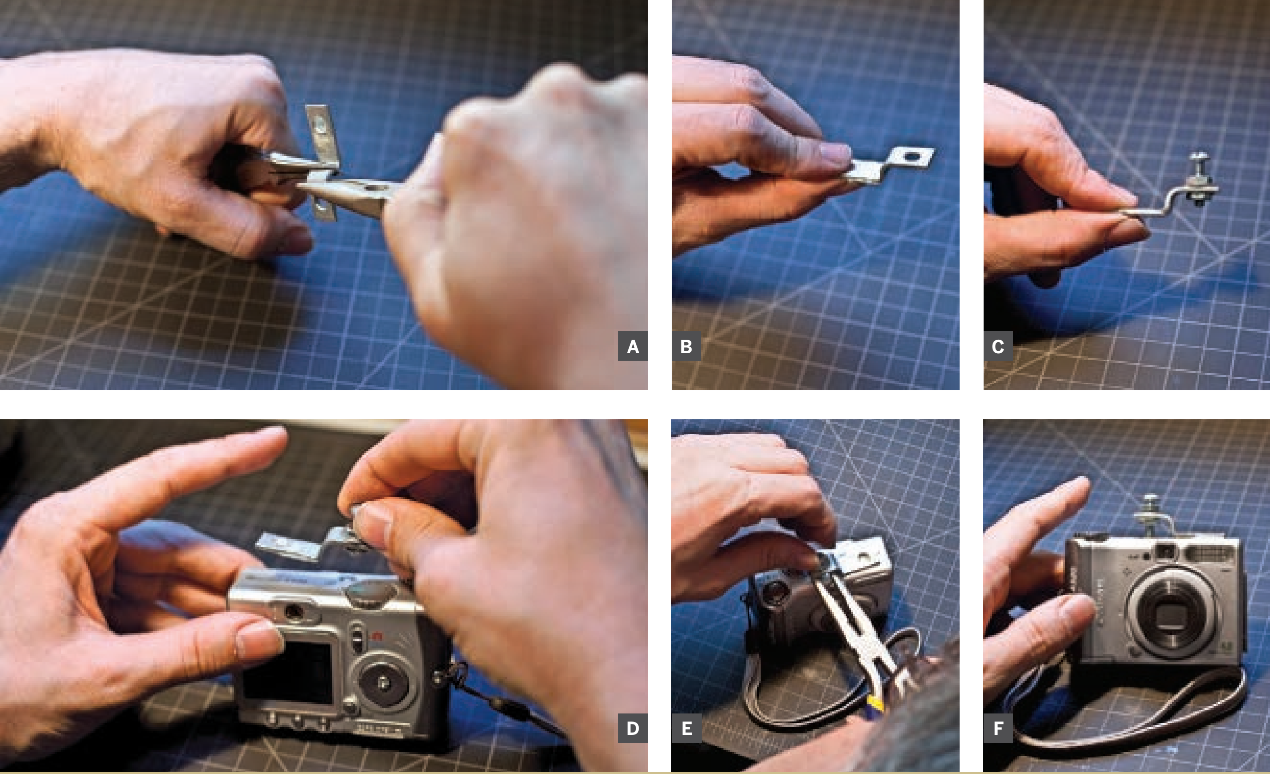
To capture 3 images at 10-second intervals, enter the command:

```
gphoto2 -F 3 -I 10 --capture-image-and-download
```

This will capture and download 3 image files into your current directory: *capt0000.jpg*, *capt0001.jpg*, and *capt0002.jpg*. If you have problems, the gPhoto site has good documentation.

4. Fix the power-up problem.

One problem I ran into with my Canon A520 was the fact that when its power supply is momentarily interrupted, restoring the power will not automatically turn the camera back on. Fortunately, I found that



KEEPING THE POWER BUTTON PRESSED ON: Figs. A and B: Use pliers to bend a 3" aluminum mending brace. Fig. C: Attach a #8 screw onto the bracket with 2 nuts. Fig. D: Position the screw directly over the power button and glue it in place with 5-minute epoxy. Fig. E: Turn the screw by hand until it begins to tighten against the power button. Fig. F: Tighten the top nut against the brace to lock the setscrew in place.

my camera will switch on upon power-up if its power button is held in the depressed position. To do this, I fashion a simple bracket and setscrew. I bent a 3" aluminum mending brace as shown in Figures A and B.

Now thread one nut partway down the #8 screw, insert it in a bracket hole, and thread the other nut on the other side, so that it looks like Figure C. Then, positioning the screw directly over the power button, glue it in place with 5-minute epoxy as in Figure D. Hold onto the nut between the brace and the camera, and turn the machine screw by hand until it begins to tighten against the power button (Figure E).

You should feel some resistance, and the camera should turn on. Don't overtighten, as this could damage the camera. Tighten the top nut against the brace to lock the setscrew in place (Figure F).

Note that with the power button held down, you may not be able to operate the camera manually, as its buttons will be unresponsive. You will, however, be able to operate it remotely using the gPhoto software.

5. Install the enclosure window.

I removed the front cover of the enclosure, cut a 4"×4" window, and sealed the glass into place with the silicone adhesive (Figures G and H, following page).

6. Assemble and install the camera mount.

Camera tripod sockets accept a ¼-20 bolt, which makes it easy to improvise a mount with a single bolt, mounted through the floor of the enclosure. Use a hex nut to tighten a large washer against the bottom of the camera.

I want my camera pitched upward within the enclosure, to capture more of the sky, so my mount includes an L-bracket bent down to about 45° using a couple of pairs of vise-grips (Figure I). The camera is attached to the bracket using a ¼-20×1" machine screw, a big 1½" washer, and a nut. The other leg of the bracket is mounted to the enclosure floor.

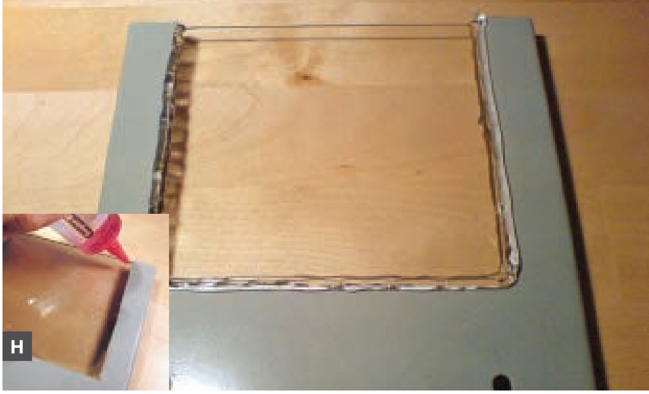
If your enclosure has knockouts, you may want to use them for bringing your power cords and USB cables into the box; I just cut a notch at the front of the box floor for easy access with the enclosure cover door removed (Figure J).

7. Put it all together.

After assembling the enclosure outside, I plugged my PC and the extension cord into the UPS power supply, and ran the power and USB cables out my window. I made sure the setscrew was properly set to ensure that the power is on, then plugged in the

Photography by Alexander Tarrant

G



H

I

J

K

BUILDING THE ENCLOSURE: Fig. G: Remove the front cover of the enclosure and cut out a 4"×4" window. Fig. H: Seal the glass into place with silicone adhesive. Fig. I: Make a camera mount from a bent L-bracket, washer, screw, and bolt. Fig. J: Cut a notch at the front of the box floor for the USB cable. Fig. K: Adjust the set-screw to ensure that the power is on, then plug in the AC adapter and stuff it and the camera inside the enclosure.

AC adapter and stuffed it, along with anything else that might need protection from weather, inside the enclosure (Figure K). Then I mounted the enclosure on my roof.

8. Make time-lapse movies!

Hopefully you've pointed your camera at something interesting. To capture an image every 10 seconds for 1 hour, log into your Linux box (or open a terminal window), and enter the following command:

```
gphoto2 -F 360 -I 10 --capture-image
```

When it completes, you'll see that the current directory is filled with image files. Enter the command:

```
ffmpeg -f image2 -i capt%04d.jpg -sameq
  FirstMovie.mpg
```

This will assemble the images into an MPEG movie file. To view it, open it with VLC:

```
vlc FirstMovie.mpg
```

At the default 24 frames per second, this gives you a whopping 15 seconds! Of course with this setup you'll be able to make movies *much* longer than that. To tell gPhoto to run indefinitely until you interrupt it (using control-C), simply set the -F flag to 0:

```
gphoto2 -F 0 -I 10 --capture-image
```

This just scratches the surface. The gPhoto and FFmpeg programs are extremely powerful, and the possibilities are endless for creating beautiful time-lapse movies that span days, months, or even years.

Resources

» **CHDK** — Replacement firmware for some Canon cameras: chdk.wikia.com

» **gPhoto** — Library and applications for Unix-like operating systems: gphoto.org

» **GBTimelapse** — Windows shareware, for Canon cameras only: granitebaysoftware.com

» **iStopMotion** — Mac shareware: boinx.com/istopmotion

» **FFmpeg** — Versatile image, audio, and video processing software: ffmpeg.org

+ For additional online resources, go to makezine.com/21/diyimaging_timelapse.

+ Follow the progress of Ken Murphy's year-long time-lapse movie of the sky at murphlab.com/hsky.

Ken Murphy (ken@blinkybug.com) is a programmer, musician, and tinkerer living in San Francisco. He is the creator of Blinkybugs, simple, electronic insects that respond to their environment by blinking their LED eyes.

Photography by Ken Murphy

ELEMENTAL KNOWLEDGE

Think you've mastered fire? Make and use a bow drill. By Wendy Tremayne

While visiting New York's Berkshire Mountains region last winter I happened upon a crew of girls who are grounded in Earth knowledge. They study with naturalist Michelle Apland at the Flying Deer Nature Center. The group's treasure chest of skills includes how to make bone tools, identify plants and insects, build shelter, create a natural spring, distill water, and whip up a bow drill to make fire without a match.

On a below-freezing day in March, the girls and I traversed a frozen pond. Midway across, the sound of cracking froze me in place. A 12-year-old turned her head over her shoulder to assure me that cracking is no sign of weakness in the pond's ice sheet.

Later, all the girls unexpectantly dropped to their bellies, extended their limbs to disperse their weight on the ice, and reached out for cattails growing beyond the watery edge — the booty of the exploration.

MATERIALS AND TOOLS

Branches
String
Knife
Handsaw (optional)

After the harvest, the formation was uniformly reversed and we set out for a fort that the girls had built earlier that day.

Here awaited a tinder bundle, a bow drill, and an ice half-wall. The wall surrounded a fire pit that was easily lit, without matches, immediately providing warmth.

I hoofed my way out of the woods feeling entirely pooped while the girls remained to carry out an impressive list of things they were going to do before sundown. I took with me this gem of a DIY.

Photography by Talya Phelps

Fig. A: Gather wood, string, and a knife. Fig. B: Whittle a spindle with semi-pointy ends. Fig. C: Notch the handhold to seat the spindle. Fig. D: Tie a thick string to the bow ends. Fig. E: Drilling stance (righty): left foot on the fireboard, right knee on the ground, bow with your right arm, and brace left arm around left knee. Figs. F and G: Drill a scorched pit into the fireboard, V-notch it, and drill again to make a hot coal. Fire!

Make a Bow Drill

A bow drill has 4 parts: the *bow*, the *spindle*, the *fireboard*, and the *handhold*.

1. Choose and whittle your wood.
For your fireboard, find or whittle a flat board as thick as your thumb and bigger than 3" wide and 3" long.

For your spindle, choose a straight-grained branch that's a thumb knuckle in diameter and 8" in length. Whittle into a dowel shape, removing the bark (Figure B), with a semi-sharp point at each end.

For your handhold, find a 5"-long piece of wood (slightly narrower in width), semi-flat on one side. To make the handhold notch, whittle a ½"-deep hole sloping at 45° to its center (Figure C).

2. Make the bow.
Pick a bow from a live branch that's the thickness of your index finger and a few inches longer than your arm. Choose a string thicker than a shoelace and 5" longer than your bow. Using a clove hitch or square knot, tie it at each end of the branch (Figure D).

Use a Bow Drill to Make Fire

1. Drill a pit into the fireboard.
Loop the bowstring once around the spindle. With one end of the spindle on the fireboard and the other in the notch of the handhold, apply firm downward pressure to the handhold while bowing back and forth so the bow turns the spindle in both directions (Figure E). Increase the speed. Stop when you've burned a pit into the fireboard that's the diameter of the spindle, and dark with charred wood dust.

2. Make a notch in the fireboard.
On your fireboard, cut a pie-shaped V-notch that reaches the center of the pit you just drilled. This is easiest if you've drilled your pit near the edge of the fireboard. (You can see the V-notch in Figure G.)

3. Spin a hot coal.
Place the fireboard on a surface that will catch the black sawdust, which creates a hot ember or coal. Look for smoke and a red glow as you use the bow to spin the spindle (Figure F). When the dust reaches 800°F, it will create a glowing coal (Figure G) that can be placed in a tinder bundle or kindling teepee to create a matchless fire.

Wendy Tremayne is an event producer, conceptual artist, and yoga teacher. She created Swap-O-Rama-Rama as an alternative to consumerism. gaiatreehouse.com

Photography by Jessica Reed (E, F, G)

COMBO SNOW GUN

Make snow with a pro-style gun for about $90. By Steven Lemos

Photograph by James Moss (makesnow.net)

So it doesn't snow enough where you live? Fear not — if it gets cold, you can cover that front lawn in white, fluffy snow with a homemade snow gun. All you need are a few items from your local hardware store, some quality spray nozzles, and access to a pressure washer and an air compressor.

This snow gun is based on an internal-mixing "combo" design I found at snowguns.com. It mixes pressurized air and water internally and sprays them out through 2 types of nozzles that work together cleverly. Just wrap teflon plumber's tape on all the pipe threads, then twist it together tightly as you see it in the photograph on the following page.

To understand how it works, remember high school chemistry: the smaller a particle is, the more surface area it has relative to its volume. Generally, that makes it easier to freeze. This is the job of the nucleation nozzle; it breaks the water into very small particles, making it possible for them to "nucleate," or freeze quickly around their own impurities, thus generating a spray of superfine ice crystals.

This "ice mist" then crosses the spray from the 2 bulk nozzles, which supply the bulk of the water for our snowmaking. Droplets from the bulk spray freeze to the nucleated ice crystals, creating fluffy snow.

Nozzle Knowledge

Nozzles are the most important purchase for your snow gun. To make an effective snow gun you have to match the bulk nozzles to the nucleation nozzles, and match both to the characteristics of your compressor and pressure washer.

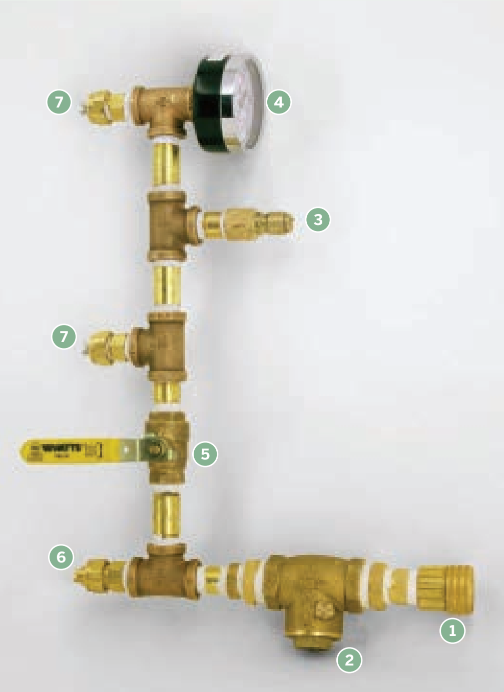
A good brand is TeeJet; they make spray nozzles for agricultural use and these work great for snow guns. TeeJet nozzles are numbered by their output; on their face is a 4 or 5 digit number whose first

MATERIALS

⅜" IPS (⅝" OD) brass tee pipe fittings (4)
⅜" IPS brass ball valve
⅜" IPS brass pipe nipples, 1½" (3), 2" (3)
You can vary these lengths, but you need at least 4" between the nucleation nozzle and the first bulk nozzle.
Brass nozzle tips, flat spray, 80° (1) and 50° or 65° (2) TeeJet/Spraying Systems parts #TP8010 and #TP5004 or #TP6504. These are available from agriculture equipment suppliers; look online or see teejet.com for a list of dealers.
⅜" brass nozzle bodies (3) and nozzle caps (3) TeeJet type 3/8TT, parts #CP1324 and #CP1325
Brass garden hose fitting with ⅜" IPS adapter for air line
Brass fitting with ⅜" adapter to attach your water line; some are ¼" or ⅜" quick-disconnect, some are threaded.
1,000psi pressure gauge (optional but recommended)
⅜" brass pipe plug if not using pressure gauge
Check valve, ⅜" IPS thread if you can find one. I used a ¾" valve with two ⅜" reducers.
Garden hose for air line
High-pressure water line like the hose that comes with a pressure washer
Pressure washer or other water pump capable of at least 300psi
Air compressor, oil-cooled capable of 6 cubic feet per minute (cfm) at 40psi

TOOLS

Pipe wrench
Teflon tape
Outdoor thermometer and humidity gauge



ASSEMBLY: The air line uses a garden hose fitting (1) to reduce freeze-ups, and a check valve (2) to protect the compressor. The water line's fitting (3) depends on your high-pressure hose. The gauge (4) displays overall pressure. The ball valve (5) lets pressurized water mix with air for the nucleation nozzle (6), which must be at least 4" from the bulk water nozzles (7).

Photograph by Ed Troxell

2–3 digits represent spray angle, and whose last 2 represent flow at 40 pounds per square inch (psi), measured in gallons per hour (gph). For example, nozzle 8005 translates to an 80° spray angle and 0.5gph flow at 40psi.

The trick to matching your bulk nozzles to your nucleation nozzles is that the nucleation spray must engulf the bulk spray, or else the bulk spray will have wet edges (spraying non-snow, just water). But you don't want the nuc spray overly wide, or you'll lose efficiency.

Here are some good angles to use: 40° bulk and 65° nucleation, or 50° bulk and 80° nuc. (I used 65°/80° here because that's what was in stock.)

For a list of nozzle volumes (gpm) at various pressures (psi), go to makezine.com/21/diyoutdoors_snowgun.

Pipe and Pressure

This snow gun uses ⅜" ID pipe made for home use. I used a garden hose connection for the air line, because quick-disconnect fittings are more prone to freeze-ups, but the water line is high-pressure hose so you'll need to use a quick-disconnect or a specific threaded fitting there.

Pipe material is another concern. Typical galvanized steel pipe is rated for 150psi–300psi; it's possible to run it close to 600psi, but anything over 700psi and the chances of pipe bursts are greater. Brass is better, with a pressure rating from 125psi–400psi. Stainless steel is the safest, rated for 3,000psi, but I don't think people want to spend $15 per ⅜" tee fitting.

It's a good idea to have a pressure gauge that reads to 1,000psi, to control how much pressure is going into the gun. I run my brass gun at 450psi–700psi, but keep in mind, higher pressure will wear more on your nozzles, pipe, and pump, and you exceed the ratings at your own risk.

The ball valve is in place to adjust the water pressure going to the nucleation nozzle, and this takes some playing around with to get it right. If the water pressure's too high, you'll get a misty fog and puny snow production. If it's too low, you'll get big droplets that won't freeze before reaching the bulk spray, and you'll be making very wet snow.

Compressor and Pressure Washer

The snow gun runs on 40psi–70psi from the air compressor. It is highly recommended that you use an oil-lubricated compressor; this will allow hours of operation without any trouble. A good compressor should be able to output 6cfm at 40psi.

A good pressure washer will feed about 2 gallons per minute (gpm) at 450psi.

Snowmaking 101

To make snow, you don't necessarily need temperatures below 32°F — you just need them below freezing on the wet bulb temperature chart (makezine.com/go/wetbulb), which takes into account the relative humidity of your location. For example, at 95% humidity you need temperatures 27°F or colder, but at 10% humidity you can start making snow at just 39°F.

First, close the ball valve, so you don't flood your compressor. Turn on the water supply — but not the pressure washer yet — and make sure water's coming out of the bulk nozzles. Make sure there's no ice in your pressure washer — ice could destroy the unit or hurt someone — then turn on the pressure washer. Turn on the air compressor, letting the pressure reach 40psi or more. Now start to open the ball valve just a little, so you get a superfine mist from the nucleation nozzle. Check the compressor and make sure the air pressure is above 60psi. You should be making snow!

To check your snow's quality, put your coat sleeve in front of the spray; the snow should bounce right off. Check the gun periodically, making sure your nucleation nozzle isn't freezing up; if it is, open the ball valve a bit more.

Elevating the gun gives the snow more time to freeze before hitting the ground; you can use a ladder or make a stand out of wood or PVC pipe.

Output and Precautions

So I'm sure you're wondering, "How much snow can I actually make with this thing?" The answer depends on how much water you're flowing, and this depends on the water pressure and air pressure. The more water you're able to flow through the gun, the more snow you'll have piling up. Expect 2"–5" per hour, at 2gpm flow. Some advice to keep in mind:

1. Don't shoot snow against the wind. You'll get freeze-ups. Go with the wind to make life easier.
2. Install a check valve between your compressor and the snow gun; this will prevent flooding of your compressor.
3. Air compressors are loud, so if you plan to make snow overnight or in the early morning, be considerate of neighbors.
4. Your snow gun will hiss like a gas leak, so inform your neighbors that it's nothing to be afraid of.
5. Wear plenty of warm clothing when you're making snow, because it will be cold outside, and when you're working with water and metal pipe it will seem a lot colder. Wear good waterproof gloves.
6. Don't leave your hose outside with water in it, or it will freeze and possibly split. Bring it inside. If it does freeze, throw it in a bathtub of warm water.
7. Last but not least, have fun!

Special thanks to the contributors to snowguns.com, where much of this information came from.

Steven Lemos is a mechanical engineering student at CSU Chico, and has an infatuation with the odd and bizarre. A former intern at MAKE, he still shares his interests with us.

Make: TIPS!

Mixing Epoxy Without Bubbles

To avoid whipping in a lot of air bubbles, use a bent palette knife when you mix up a small batch of epoxy. You can stir up down and around thoroughly without letting the bent section break the surface, so you'll be able to get a nice clear bubble-free mix.

—*Frank Ford*, frets.com/homeshoptech

Find more tools-n-tips at makezine.com/tnt.

GOURD LANTERNS

Drill patterns into hard-shell gourds and let the light shine through. By Diane Gilleland

Hard-shell gourds, sometimes called calabash gourds, are some of the world's first cultivated plants. They are harvested from their vines in the fall and then air-dried for several months. When a gourd is fully dry inside and out, it forms a woody shell that can be cut with simple tools.

Cultures all over the world fashion hard-shell gourds into vessels or musical instruments. Here, we've turned them into festive outdoor lanterns, using a drill to create patterns for light to shine through.

NOTE: This project is fairly messy, making it a good outdoor build.

MATERIALS

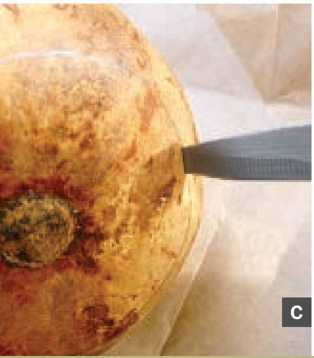
- **Hard-shell gourd** A good source online is welburngourdfarm.com.
- **Bucket of water**
- **Scrubbing sponge**
- **Newspaper**
- **Surgical mask (optional)**
- **Pencil**
- **Small paring knife**
- **Pumpkin-carving tool kit** yankeeharvest.com
- **Handheld drill with various drill bits**
- **Large spoon**
- **Mineral oil (optional)**
- **String of Christmas lights (25–50)**

1. Clean the gourd.

Hard-shell gourds develop a coating of dirt and mold as they dry out. You can buy them already cleaned, but you'll save a lot of money by cleaning them yourself.

Begin by soaking the gourd in a bucket of water

Photography by Diane Gilleland



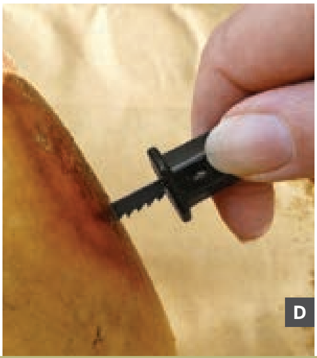


Fig. A: Soak the gourd in water before cleaning.
Fig. B: Scrub surface dirt away with an abrasive sponge.
Fig. C: Pierce the gourd shell with a paring knife.
Fig. D: Cut a 6" hole in the base of the gourd with a pumpkin-carving saw. Cut with the part of the blade nearest the handle for better safety and stability.
Fig. E: Clean the pulp and seeds out of the gourd. Gourd seeds are finicky, so planting them probably won't work.

for about 10 minutes (Figure A). The gourd will want to float, so turn it occasionally to keep all sides wet. Then, use a scrubbing sponge to remove the grime (Figure B). It should rub off with medium pressure. If you find an area that's difficult to scrub clean, try letting it soak a bit longer. If your gourd has a stem, you can scrub the grime from it as well.

Allow the gourd to air-dry.

NOTE: The gourd will have some natural discoloration even after cleaning.

2. Cut off the base.

Cover your work surface with paper. Use a pencil to draw about a 6" circle around the bottom of the gourd. When you cut out this circle, it will give the gourd a flat, stable base to sit on.

Begin the cut by using a paring knife to poke a hole through the gourd shell. Use medium pressure and gently rock the blade back and forth until it penetrates the shell (Figure C).

Insert a pumpkin-carving saw into this cut and carefully saw along your pencil line. Use the part of the blade closest to the handle for sawing (Figure D); this will keep the blade from bending.

NOTE: Some people are allergic to gourd dust, so do this next step outdoors and wear a surgical mask if you have this sensitivity.

3. Clean out the inside.

Remove the base of the gourd and dump all the loose seeds and dried pulp from inside it (Figure E). Gourds vary widely; some will have very little material on the inner walls and others will have a thick layer of flaky dried pulp (Figure F, following page). If the material is thick, scrape out as much as you can with a large spoon. Discard the pulp and seeds.

4. Draw some guidelines.

Draw a design on the gourd in pencil. You can trace a template or draw freehand. These lines will serve as cutting guides and can be easily removed with an eraser later.

5. Drill or cut out your design.

You can always cut a design into the gourd using the pumpkin carving saw, but I've decided to use a drill here. With a drill, you can build all kinds of patterns from holes of various sizes.

Position the drill bit so it's perpendicular to the gourd's surface, and drill straight into the gourd

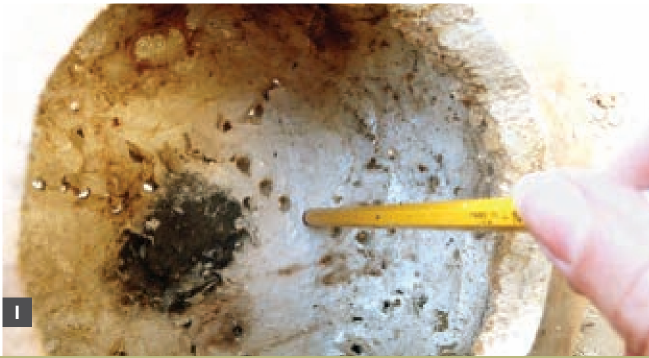


Fig. F: Gourds vary; some have thin walls, while others have thick, pulp-covered walls. Fig. G: Drill into the gourd wall with care, keeping hands away from the drill bit. Change drill bits to vary the sizes of the holes in the pattern. Fig. H: Remove pencil marks from the shell with an eraser. Fig. I: Poke through the drilled holes from the inside to remove pulp that may be clogging them.

with medium pressure (Figure G). The drilled holes should be at least ¼" apart to keep the surface of the gourd from breaking. Vary your patterns by switching to drill bits of different sizes.

CAUTION: Be very careful when drilling a gourd, as the drill bit can slide on the curved surface and cause injury. Always steady the gourd against your work surface, and keep your hands far away from the bit. Be especially careful when drilling scarred areas of the shell, as they can be much harder than the surrounding shell and can cause the bit to slip.

6. Clean up your design.

When you've finished drilling your pattern into the gourd, clean your pencil lines off the shell with an eraser (Figure H).

Inspect the gourd from the inside. That pulpy material on the walls sometimes clogs up the drilled holes. Poke the holes from the inside with a pencil or bamboo skewer to clear them (Figure I).

7. Finish your gourd.

You can leave your gourd unfinished, or rub a little mineral oil into the surface with a soft cloth. The oil will give the gourd a subtle shine and help it resist moisture.

Alternatively, you can use a polyurethane spray varnish for maximum protection, but to my mind, it looks rather unnatural.

8. Light it up.

First and foremost, never place a lit candle inside a gourd lantern! The inside walls are highly flammable.

Instead, stuff a string of tiny Christmas lights inside the gourd — they won't fall out — or use a small LED lantern.

Diane Gilleland produces CraftyPod (craftypod.com), a blog and podcast about making stuff.

Make: TIPS!

Plastic Bag Thread Protection for Jars
If you store leftover shellac, lacquer, or similar material, just screw the lid down over a piece of plastic bag. That way the stuff won't glue the lid on, and you can visit the contents any time with ease.

—*Frank Ford*, frets.com/homeshoptech

Find more tools-n-tips at makezine.com/tnt.

BETTER LEATHER

Embellish leather using a woodburning technique. By Betz White

When I was in college for fashion design, we were assigned to create a garment using leather and suede. Working with animal skins presents certain challenges — you can't buy continuous yardage, only hides; ripping out a seam leaves holes; it can't be ironed. I decided to come up with a way to make the plain cowhide a little more exciting as a "fabric."

That's when I had the inspiration to get my hands on a woodburning tool and brand a design into the suede. Woodburning, or *pyrography*, is the process of drawing on wood by burning lines into its surface with a soldering iron-type tool.

I was recently inspired to try the technique again, this time on a leather bag. By using this tool on leather or suede, you can decorate and personalize anything from belts to wallets to shoes. Swap out different tips to create a variety of detailed lines, or experiment with traditional drawing techniques such as shading, crosshatching, and stippling. You'll be surprised how much detail can be achieved and how addictive this technique can become!

CAUTION: The woodburning tool gets very hot. Never leave it unattended, and unplug it if you walk away. Work in a well-ventilated area, and keep a dish with ice water nearby. If you burn yourself, cool your fingers in the water.

1. Do some natural selection.

Select an item, such as a purse or other piece of leather, you'd like to woodburn. You can pick up something secondhand or use an item you already have. Keep in mind that it's best to use vegetable-tanned leather and/or suede with a natural, unfinished surface. Lighter colors produce a higher contrast when burned, allowing for a more visible image.

Photography by Betz White

2. Draw inspiration.

Whether it's doodled line art or shaded dimensional shapes, draw whatever suits your style and the item you'll be woodburning. Fluid, organic forms tend to work best, rather than precise lines and geometrics.

When you've settled on a design, sketch it onto a piece of tracing paper. Overlay the paper onto your leather to find the best placement of your design.

3. Plan ahead.

A dimensional item like a bag or purse should be stuffed with paper or fabric to give you a stable surface to work on.

Now, roughly sketch your design onto the item. With leather, you can lightly sketch by scratching the surface with a straight pin (Figure A). If you're working with suede, try using a chalk wheel used for marking on fabric. Making a few indications of your design will help keep you on track once you start burning.

4. Practice plenty.

Plug in the woodburning tool and let it heat up. Get a feel for the tool by practicing on some scrap leather or suede (Figure B). If you don't have any scraps, do a trial on an old pair of leather shoes you're planning to donate to charity. Top-grain leather reacts differently than suede leather, and light colors differently than dark. Experiment with an assortment of tips to figure out which is best suited for your design.

After you've practiced, try out the woodburning tool on your selected item by making a small mark in an inconspicuous area such as a seam allowance or underside of a strap. If you like how it looks, proceed to the next step.

5. Burn, baby, burn!

Start out slowly, burning on your basic lines and elements (Figure C). Gradually build up the line weight and add detail. Keep your hand relaxed. Turn your work as needed for ease of drawing, resting the heel of your hand on the item to keep it steady.

6. Finish and protect.

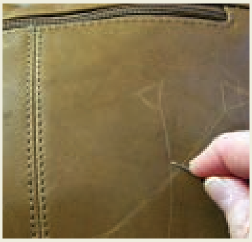
When you're happy with the outcome, unplug the tool and admire your work. You can leave your leather project as-is, or protect it with a moisture-resistant finish made for leathers.

Betz White is a designer and author of the recycled felting book *Warm Fuzzies*, and of *Sewing Green*. betzwhite.com

MATERIALS

Leather item such as a purse or belt; not "pleather"
Woodburning tool available at craft stores and woodworking shops (woodcraft.com, rockler.com) in a range of types and prices. For under $20, I bought a basic model with interchangeable tips. Fancier versions with heat regulators can cost upward of $40. Kits at tandyleatherfactory.com.
Tracing paper
Paper or fabric to stuff the purse for stability
Straight pin or pen-type chalk wheel for doing a rough sketch of your design on the leather
Leather scraps for practicing (brettunsvillage.com)
Moisture-resistant leather finish (optional) for sealing
Design Sketch out a few design ideas on paper, or use my floral motifs (below), provided at makezine.com/21/diyhome_leather.


A




B


C

Fig. A: Draw your design on paper, then roughly sketch the design on the leather. Fig. B: Practice, practice, practice! Use the tool on scrap pieces of leather and suede to get a feel for how it works. Try different tips and different patterns. Fig. C: Keep your hand relaxed and work slowly, gradually building up the line weight.

Photograph by Jeremy Kerfs

INTRO TO SCRATCH

Make your own games and animations, free and easy. By Jeremy Kerfs

The big video game companies create best-selling titles every year, but for the rest of us, bringing our own unique game ideas from wishful thinking into reality is notoriously difficult.

Creating even the simplest functionality can take tens of thousands of lines of code. Luckily, the MIT Media Lab has created free software, Scratch (scratch.mit.edu), that lets kids create their own games or interactive stories using an easy drag-and-drop interface and some elementary programming.

Download, install, and launch Scratch, and soon you'll be creating simple "side-scrollers" — games like Super Mario Bros., where characters navigate obstacles left-to-right. You can also make your characters communicate via speech balloons, like an animated cartoon. Scratch makes no distinction between games and animations; it's all in your programming.

How Scratch Works

In software parlance, Scratch is an *object-oriented*, *event-driven*, *visual programming environment*. Let's take those terms separately.

Object-oriented means that you design each character in your game (each *sprite*) by putting together scripts that dictate its behavior. Then when you run the game, the sprites all just do their own thing. To influence each other, the sprites pass coded messages called *broadcasts*.

Event-driven means that every script you assemble for each sprite runs in reaction to some triggering event, like when the player clicks on the sprite, or hits one of the keyboard keys, or when another sprite broadcasts a message.

Visual programming environment means that blocks on the screen represent basic programming elements, and you assemble a series of instructions by dragging-and-dropping the blocks together into stacks. The blocks are color-coded and shaped so they only fit together in ways that make sense programmatically: the triggering events look like folder tabs, and the subsequent steps fit together like jigsaw puzzle pieces. Numbers fit into round holes, text strings fit into rectangular text boxes, and conditionals fit into diamond-sided holes that look like decision points in a flowchart.

Familiarizing the Screen

Scratch's main screen (Figure A) has 3 columns:

1. The *program blocks* are on the left, organized into menus by type.

2. The middle column is where you stack the blocks into a sprite's *scripts*. Tabs at the top also let you customize the sprite's *costumes* (the different ways it can appear) and the sounds it can make. You can select costumes (Figure B) from a native library of animals, things, and people, or else design your own using the Paint Editor pane (Figure C). Similarly, you can select sounds from a library of effects, or record your own by clicking the Record button.

3. The right column contains the stage, where the game's action takes place. When you first open the program, the stage is a white rectangle containing one sprite, the orange cat that's Scratch's icon. To run and stop your game, you click the green flag or the stop-sign button above the stage.

Below the stage, you see thumbnails of all the sprites in your game. This is where you manage your cast of characters, creating new sprites and selecting the one you're working on. There's also a thumbnail for the stage itself, because it works as a special sprite; you can control its appearance, to paint backdrops, for example, but you can't make it move around.

Walking the Cat

To illustrate Scratch programming technique, here's how you can make the cat move with the arrow keys. To start a program, open the Control program blocks on the left and drag the first block, `when (green flag) clicked`, into the center of the Scripts pane. This block instructs the program to start this script as soon as the program is started.

The Control tab contains blocks that trigger scripts and blocks that determine their flow, such as loops and `if` statements. Add a `forever` block under the green flag block; this sets up an endless listen-respond loop. Next, drag 4 `if` blocks into the `forever` loop. We'll use these to check for the 4 different arrow keys.

Look under the Sensing tab and drag a `key [space] pressed?` block into one of the `if` block slots. In this game, we want to know if the arrow keys are pressed, not the space bar, so click the box in the block and change `space` to one of the arrow keys. Fill the other 3 `if` blocks to sense the other 3 arrows.

Under the Motion category, move a `change x by 10` block into the `if` blocks for the right and left arrows, and a `change y by 10` into the up/down blocks. To correct the directions for left and down, put a minus sign (–) in front of the 10.

Your program should look like Figure D. Click the green flag, and you should be able to maneuver the cat around the screen. You can see that the `if` statements inside the `forever` loop evaluate as true if the key is pressed and false if not. The movement blocks then adjust the position of the cat accordingly.

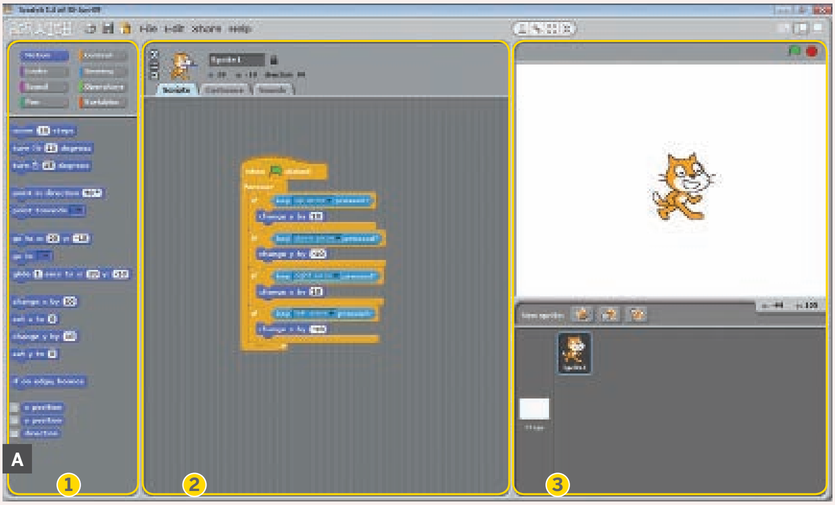
Adding Complexity

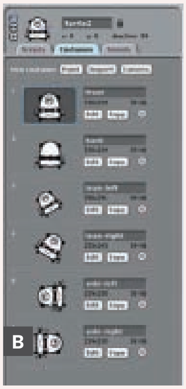
This program is very simple, but complex programs can be difficult to follow. To help with this, Scratch has a Single Stepping mode that lights up each block as it evaluates during runtime. To turn it on, go to the Edit menu and select Start Single Stepping.

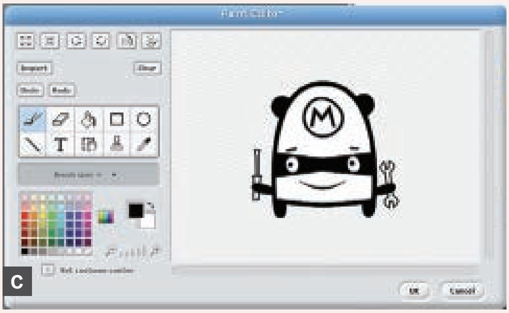
To expand your program, you can add blocks to your current scripts or start new scripts. To create a new script, go to the Control category and drag over a new `when` block. This technique of creating different scripts that run in parallel allows you to separate the movement functionality, for example, from that of any weapons or jumping.

There are other types of code blocks besides Control, Sensing, and Motion: Variables blocks let you use global variables to store things like speeds or the number of lives or bullets left; Operators blocks perform simple arithmetical, logical, and text string functions; Pen blocks let sprites draw lines; and Looks blocks control a sprite's costumes, speech balloons, and other aspects of its appearance.

You can use costumes to create the illusion that a sprite is moving. Click the Costumes tab, and you see that the orange cat has 2 different costumes. Use Looks blocks in a script to alternate between these, and the cat will appear to walk. Timing is important here; to avoid a too-fast blur, put a `wait`







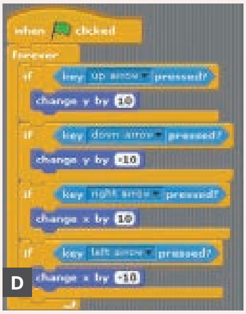


Fig. A: Scratch's main screen has 3 columns (called out in yellow). Fig. B: Costumes let sprites change their appearance. Fig. C: The Paint Editor pane lets you draw or modify costumes. Fig. D: This simple script lets the player move a sprite with the 4 arrow keys.

Control block after each costume change. You can also use costumes to give a character a shield, and program a sprite to take up a shield when a certain key is pressed.

Sounds and music add a lot to a game, and Scratch makes adding these easy as well. Sound blocks let scripts play and modify sounds, and the Sounds tab over the scripts area lets you import and record your own.

References and Community

Scratch is well documented at info.scratch.mit.edu/support, which has a good How to Get Started document and a Reference Guide that documents all of the blocks. With these resources, you should have no trouble creating your projects. And if you want some inspiration for coming up with ideas, the Scratch website also boasts more than 500,000 projects you can view and play online. To explore what others are doing with Scratch, go to scratch.mit.edu/channel/recent.

The Scratch community lets you share your projects and comment on others. To join, go to scratch.mit.edu/signup. Sharing your project is as easy as clicking Share at the top of the Scratch window and then choosing "Share this program online." If you like someone else's project, you can download and change it yourself, which is a great way to learn. But if you gain inspiration (or code) from other people's projects, make sure you credit them.

For people to play your Scratch games directly, they need to have Scratch installed on their own machines. But there are also ways of converting Scratch projects into *.exe* executable files that will run on any Windows machine.

+ Visit makezine.com/21/diykids_scratch for links to Scratch resources.

Jeremy Kerfs is a high school student who likes programming and computers. In his spare time he also enjoys reading and running.

DIY
OFFICE

MAGIC PHOTO CUBE

Make a fun, folding desktop photo display for about a buck. By Ken Wade

Sometimes something comes along that snaps you out of the blur of even the most mind-numbing meeting. I was at this stage when the speaker passed around a demo of the newest training tool — a "magic story cube" that pulls kids into the learning process.

The speaker's words didn't grab my attention but the remarkable object in my hands sure did. This was cool. I had to make one.

The magic photo cube (the easy half of a Yoshimoto Cube, a truly impressive object invented in 1971) is made by the clever hinging of 8 smaller, identical, and perfect cubic blocks. I had our local woodshop make 40 nearly identical cubic blocks from scrap. After mixing and matching, I was able to make 4 magic photo cubes, each consisting of 8 blocks.

The size of the cubic block doesn't make any difference for the project. The sides of mine are about 5cm, the perfect size for 48mm-wide clear packing tape.

The magic is all in the hinges. Use strong, clear packing tape for hinges, taping the front and back of each joint. Rub the tape down with a "bone" — that's what my dad called whatever smooth steel thing he used to make tape stick — such as a socket out of the tool chest.

MATERIALS

Cubic wooden blocks (8) about 15¢ each; I had 40 made for $6.
Clear packing tape free; always around somewhere
Photos fresh off the computer printer free, using my daughter's photo paper
Glue stick

» TOTAL PRICE: $1.20

Photography by Nattanan

Fig. A: Stack together 8 identical blocks to form a cube. Fig. B: Tape the blocks together as indicated to form the hinges. Use clear tape (black tape was used here to make it easier to see where the tape goes).

1. Stack the 8 cubic wooden blocks into a larger cube; 4 for the base and 4 on top (Figure A). Keep them nice and tight.

2. Carefully tape the blocks together as indicated in Figure B. The clear packing tape is nearly invisible, so I've used black duct tape to clearly show which 2 blocks to tape together to make each all-important hinge. Your packing tape should cover the whole joint between blocks, unlike my duct tape here.

2a. Tape a hinge connecting 2 bottom blocks to make the front face of the magic photo cube. Tape a hinge on the back face connecting its bottom 2 blocks the same way. The front and back faces of the magic photo cube should be identical.

2b. Tape 2 hinges connecting the top and bottom blocks to make the left face of the magic photo cube. Tape 2 hinges on the right face connecting the top and bottom blocks the same way. The left and right faces should be identical.

2c. Tape 2 hinges connecting the front and back blocks to make the top face. There are no hinges on the bottom face.

3. Rub the tape on each individual cubic wooden block with the bone. Carefully open the magic photo cube and reinforce the backside of each hinge with another strip of clear packing tape.

4. Now you've got to play with this thing. There are 6 faces on the magic photo cube, and after manipulating it you'll discover you can turn it inside out showing 6 totally new faces. Along the way you'll discover other orientations of different dimensions.

Do the math. There are 8 cubic blocks in the magic photo cube and each has 6 faces, totaling 48 faces. The full magic photo cube has 6 faces, each made of 4 faces from the cubic blocks. So, the full photo cube shows 24 of the possible 48 cubic block faces.

When you completely turn the magic photo cube inside out, the other 24 cubic block faces are visible on the 6 new magic photo cube faces. The surfaces of the intermediate orientations combine the 48 cubic block faces in different ways.

5. Only after manipulating the magic photo cube and thinking about your prize pictures are you ready to measure, print, and apply the pictures.

Cut each picture into the required number of little wooden squares for the selected surface. If the blocks aren't perfect, measure each cut.

6. Apply the pictures to one surface of the magic photo cube at a time using a good glue stick.

7. Adjust the picture portions to allow a smidgen of room for the hinges to bend in each direction.

TIP: Glue can really mess up your pictures. Watch their edges, as they tend to shave off bits of glue that stick to something later.

Video showing a real Yoshimoto Cube in action: makezine.com/go/yoshimoto

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Ken Wade is a volunteer engineer and project manager serving kids and families at risk in Southeast Asia. He's married and has three children; two are in college in the United States.

"GLENGARRY" BRASS BALLS

This totemic desk toy assembles in 2 minutes. By Paul Spinrad

My friend Ed and I love quoting from the movie *Glengarry Glen Ross*, especially the plot-inciting speech by Alec Baldwin's character, in which he informs a veteran sales team that they will now compete against each other to keep their jobs ("Third prize: you're fired.")

Toward the end of his harangue, he reverently reaches into his attaché case and produces two brass balls on a cord, saying, "It takes brass balls to sell real estate."

It's a memorable image, and I've always wondered why SkyMall doesn't sell high-quality brass balls as a desktop "executive toy" or motivational prize. Maybe they feel it would be in poor taste or politically incorrect, or maybe they're afraid of lawsuits over something that could so easily crush a skull (brass balls are heavy). But to my mind, these considerations just make the object more appealing.

I decided to replicate the balls, and once I figured out how to securely connect the cord, it was simple. You can put these together in 2 minutes with no tools other than scissors to cut the cord and a flame to singe the ends.

To make them, cut about 2' of cord, thread a setscrew on each end, tie a knot, and screw it into the ball. You can use epoxy or threadlocker to make the connection permanent. The balls I ordered already had brass setscrews that reduced their original bores to ¼-20, and the knot probably wouldn't slip out of those, but adding the smaller setscrews makes the connection neater and more secure. I used a white cord for authenticity, but I think a black one would add a nice formal touch for evening occasions.

I gave the brass balls to Ed and he got a kick out of them. He works in management at a large, sales-driven company, so I hope he puts them on his desk.

Check the new Makers Market (makersmarket.com) for a kit to make your own desktop brass balls. No real estate license required!

Paul Spinrad is projects editor for MAKE.

MATERIALS

1½"-diameter brass balls, tapped blind with ¼-20 thread (2) part #BAL154 from Liberty Brass (libertybrass.com), $13

Setscrews, ¼-20 threaded (2) part #91318A410 from McMaster-Carr (mcmaster.com)

3mm nylon satin cord, 2' length Try your local craft store or part #SCN3Y-N2 from The Satin Cord Store (satincord.com).

Epoxy or threadlocker (optional)

Glengarry Glen Ross image compliments New Line Cinema/ Artisan Entertainment; photograph by Paul Spinrad

AUTOMATED FAN SPEED CONTROLLER

Steady temperatures in a server room, using the MAKE Controller. By Duane Wessels

Photography by Duane Wessels

When our house was built, I put a server room next to my office. Unfortunately, it had only a small bathroom-style fan with a 4" duct leading outside, and during the summer I had to leave the door open, which made my office hot and loud.

So I installed a larger fan, along with an 8" duct that dumps the waste heat into our basement during winter and outside during the summer. The new fan works well, but also draws a lot of power — almost 300 watts. To reduce energy usage, I installed a manual speed control, but this made the temperature vary too much.

Finally, I built a control system that automatically adjusts the fan speed to maintain a constant temperature in the room. I was already using a serial-port temperature sensor connected to a computer to monitor and plot the server room temperature, so I closed the control loop using a MAKE Controller, a stepper motor, and some Lego Technic gears to turn the manual speed control knob.

I considered getting a different temperature sensor that would connect to the MAKE Controller directly. This would allow the system to stand alone without the computer. But in the end I chose to extend my existing setup and simply use the controller as an interface to the motor.

Assembly

I mounted all the hardware onto a scrap of board. I screwed an outlet box onto one corner for the

MATERIALS AND TOOLS

Temperature sensor with serial interface I used a Hot Little Therm from Spiderplant (spiderplant.com) that's unfortunately no longer being sold. You can also wire an LM35 temperature sensor chip directly to the MAKE Controller (and tweak my Perl code to read the temperature from the controller, rather than executing the "term" program).
Electronic variable-speed fan control Broan model #72W (broan.com)
MAKE Controller Kit v2.0 with Application Board product #MKMT3 from Maker Shed (makershed.com), $120
Stepper motor such as All Electronics part #SMT-116, #SMT-113, or #SMT-119 (allelectronics.com)
Wall-wart power supplies (2) to power the MAKE Controller and stepper motor separately
Lego Technic parts sets: beams, bushes, cross axles, and gear wheels Lego sets #10072-1, #10073-1, #10074-1, and #10076-1 (peeron.com)
Deep electrical outlet box such as Wiremold/ Legrand #B3
Host computer with Ethernet adapter The computer will need to be on all the time, but if you're cooling a server room (like me) there should be no shortage of computers.
Ethernet cable
Scrap of board or plywood, about 1' square
Metal bracket for the end of a 2×4 such as Simpson Strong-Tie #FB24
Screws and standoffs (4) for mounting the controller board to wood; I salvaged some from various ATX computer cases.
Small weight tied to a string
Wire strippers
Drill and drill bits
Screwdriver
Glue gun and hot glue

2 power supplies, and drilled the wood to let the 115V AC wiring enter through the back. I mounted the MAKE Controller in another corner using some hex screw standoffs, and I secured the stepper motor in a bracket sized to hold 2×4 studs (Figure A).

Next came the connections. From the controller's Application Board, Main Power connects to DC (I used a 10V DC, 0.3A wall wart), and an Ethernet cable connects to the PC. The motor has 5 wires; 4 connect to Digital Outs Bank 1 on the Application Board and 1 connects to ground. I figured out which went where by trial and error.

The best part of the project was figuring out how to connect the stepper motor to the fan speed control. One of the Lego gears fit over the stepper motor's shaft (Figure B), but the speed control's knob shaft was recessed below a plate and harder to access. So I left its knob on, cut a hole in a Lego gear, and hot-glued the knob inside (Figure C).

Lego gears span the distance between the motor and the knob, all attached to a long beam with short axle pins. I'd like to say I designed the system of gears using algebra, but it was just trial and error. Additional beams and axles comprise a frame that wraps behind the speed control so the gears don't slide front-to-back (Figure D). A small hanging weight keeps the last gear on the beam pressed down against the knob gear.

One problem was handling the situation when the stepper motor tries to turn the knob beyond its range. I wanted to keep the software stateless, so that it wouldn't have to care when the knob reached its maximum or minimum position. This was particularly important with my speed control, since turning it just past the maximum shuts the fan off.

After some experimentation, I found the solution: I used a separate, weaker power supply (an old cellphone charger) for the stepper motor, which was strong enough to turn the knob through its On range, but not strong enough to click it over to Off. This works wonderfully and was simple to do on the MAKE Controller. I just connected the power supply to External Power 1 and set the jumper to VExt.

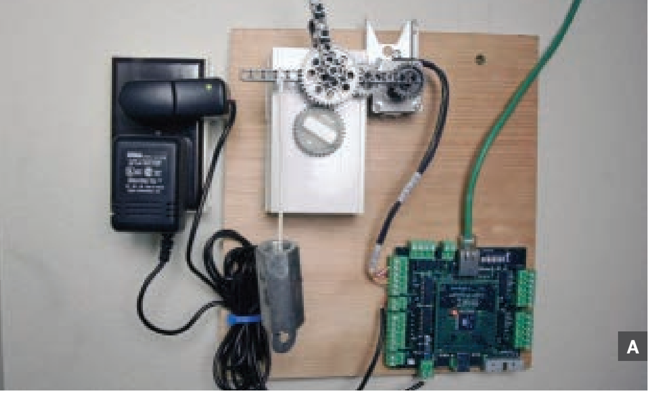
Software

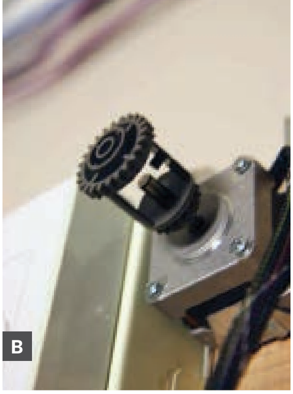
I wrote the fan speed control code in Perl using the OpenSoundControl (OSC) module, which lets Perl talk to the MAKE Controller over either Ethernet or USB. If your computer runs BSD, Linux, or Mac OS X, you probably have Perl installed. Download the OSC module from opensoundcontrol.org. You can download my project code at makezine.com/21/diyworkshop_fan.

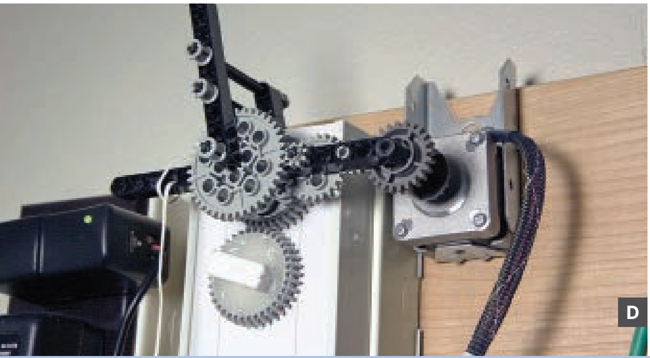
I configured OSC to use Ethernet rather than USB because it doesn't require any special drivers. The MAKE Controller gets an IP address for the computer via DHCP and listens for OSC commands to move the motor on port 10000.

The stepper motor is controlled by 4 digital output pins that correspond to the motor's 4 coils. To nudge the motor a step in either direction, the controller changes the outputs to energize different coils.

For continuous motion, the code needs a delay between steps to give the motor shaft time to find its new position. Welcome to the world of stepper motors, which behave very differently from servos.







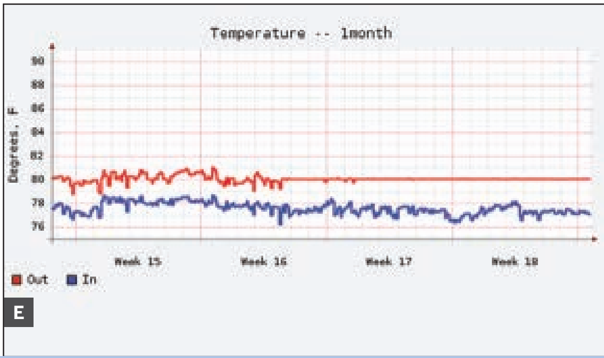


Fig. A: Hardware mounted to board, powered by wall-warts. Fig. B: Lego gear connection to stepper motor. Fig. C: Lego gear glued around fan speed control knob.

Fig. D: Gear assembly linking stepper motor to speed control. Fig. E: Incoming and outgoing air temperatures before and after system installation.

Obviously if the temperature is high the fan speed should be increased, and vice versa. But for programmed control, the question is how frequently should adjustments be made, and by what amount?

I found that it works well to step the motor some number of ticks based on the logarithm of the difference between the measured and desired temperature. If the two are close, then no adjustment is made, 95% of the time. For the few other times, the system turns down the fan speed by one tick, so that it finds the minimum speed necessary to maintain the target temperature.

To run the program, *fanspeed.pl*, you need your controller's IP address. You can find this using the mchelper app, downloadable from the controller's maker, Making Things (makingthings.com). Then run the Perl script in a terminal window, like this:

```
$ perl fanspeed.pl [desired-temperature] - [ip-address]
```

where `desired-temperature` is in degrees Fahrenheit and `ip-address` is the address of the MAKE Controller. Running the script to keep the temperature at 80°F, for example, would look like like this:

```
$ perl fanspeed.pl 80 - 10.0.0.9
```

The program will then periodically log the temperature and stepper commands in the terminal window.

I use the open source data logging and graphing system RRDtool (oss.oetiker.ch/rrdtool) to track air temperatures inside and outside my server room. Figure E shows the month I placed the speed controller into service. Note how the red line — air coming out of the room — went nice and flat.

Conclusion

I had a lot of fun with this project. It taught me about microcontrollers and stepper motors, and even gave me an excuse to play with Lego. This was my first project using the MAKE Controller, which I was eager to try, and I'm already looking forward to my next "MAKE Controlled" project. Meanwhile, the fan control system has been very reliable during its 20-plus months of service.

+ For project code and links to stepper motor control resources, visit makezine.com/21/diyworkshop_fan.

Duane Wessels (wessels@packet-pushers.com) is the author of three O'Reilly books and is a big-time Unix/internet geek. He has too many computers but not enough Lego.


PRIMER

ELECTRO-LUMINESCENT (EL) WIRE

It's easy to work with flexible strands of light.

By Louis M. Brill and Steve Boverie

An electric field can excite phosphorescent materials to glow; that's the principle of electroluminescence. Since the mid-1970s, this cool form of illumination has back-lit flat panels for gauges and small displays, and in the 1990s a company called Elam found a way to create the same glow from bendable, shapeable wire.

Electroluminescent wire, aka EL wire or lightwire, soon became a favorite medium for creative electronics projects that light up at night. The wire's flexibility and length let you draw and animate on a grand scale. Its durability withstands harsh treatment and environments. It stays cool and draws far less power than neon or rope lights or even LEDs. And its otherworldly color can lend its creations an almost hallucinatory look.

This article describes how lightwire works and how you can bend it to your will.

Photograph by Sam Murphy

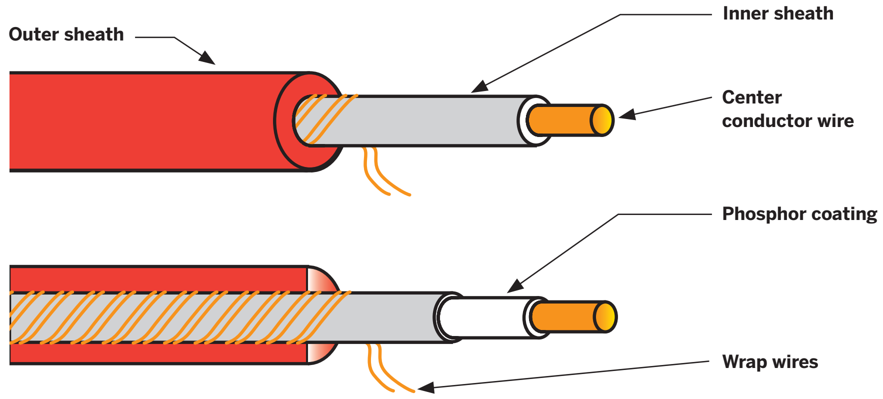
ANATOMY OF LIGHTWIRE

Lightwire consists of a **copper conductor** or **core wire** coated with a layer of electroluminescent **phosphor** material and wrapped with a coil or mesh of fine **outer** or **wrap wires** that's thin enough to let light through (Figure A). When you connect high-voltage, high-frequency AC power between the core and outer wires, the phosphor layer in between glows.

Covering this coaxial sandwich are one or two **vinyl sheaths** that protect the outer wires and filter the light to create different colors.

Lightwire comes in diameters ranging from superfine 0.9mm to 5mm, and also in non-round cross sections such as D-type for application to flat surfaces or T-type for stitching onto textiles.

Other flavors include outdoor wire with UV protection, marine wire with greater water resistance, twin-core wire, high-brightness wire, and Lumiflex, an industrial-strength lightwire cable for robust, professional applications.



A

COLORS, VOLTAGES, AND FREQUENCIES

Lightwire now comes in 11 colors, including green, blue, aqua, white, yellow, pink, red, lime green, orange, and purple. Originally, all colors used the same aqua-glowing phosphor material inside, but white wire now uses a pinkish phosphor and an aqua coating, which comes out as a brighter white.

You typically run lightwire at 100V–120V AC, with a frequency between 400Hz–2,000Hz. Increasing the frequency changes the aqua phospor's glow color from green to blue, with a brightness peak at around 2,000Hz (cyan). Running lightwire at 3,000Hz will even turn it purple, although the glow is dim. At peak frequency, increasing the voltage will make the wire glow brighter, but also shorten its lifespan; lightwire slowly fades with use.

Lightwire is shaped like other wires, but you don't connect each end and run current through it. Instead, the two connections are made to the center conductor wire and the outer wrap wire at the same end.

The far end of the lightwire is left unconnected. In component terms, a lightwire connects and behaves like a capacitor, with its capacitance proportional to its length.

Illustrations by Gerry Arrington

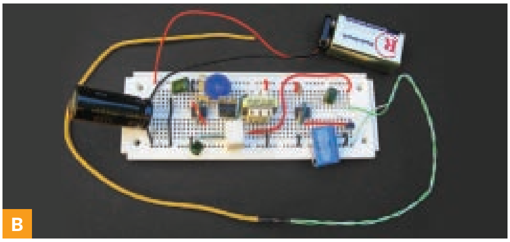
DRIVERS AND SEQUENCERS

Most lightwire projects run on battery power, which lets you take them out at night. To convert the battery's DC to high-voltage (but low-amperage) AC, you need a **driver**. A mini industry of inexpensive lightwire driver boxes has emerged, and these are what most people use; the boxes are small, cheap, and easy.

There's currently a range of drivers, each designed to illuminate specific lengths of lightwire, from just 1' on up to 330' of a single strand, or several separate strands that total 330'. If the length to be illuminated exceeds the limit of a driver, a more powerful driver must be used.

You can also build your own driver to fine-tune the AC, giving you more control over the lightwire's appearance. Figure B shows a simple lightwire driver and strobe circuit based on two 555 dual-timer chips (or one 556), a TIP120 Darlington transistor, and a small transformer. This circuit will power about 10' of wire. The left side of the circuit, the driver, has a potentiometer knob that sets the AC frequency, which changes the wire's brightness and color.

The right side is a simple strobe that switches the wire on and off. As with other 555 flashers, connecting a pot to Pin 7 of the chip or a trim cap to Pin 2 will let you adjust the blink rate. For a schematic and a components list, visit makezine.com/21/primer.


B

By lighting up multiple strands of lightwire in sequences or other patterns, you can create animations and other visual effects. You can also buy mini **sequencers** for lightwire that act like switchboards, taking the driver output and routing it to multiple channels in a series of patterns, like the way some Christmas tree light controllers operate.

Fancier boxes, such as the CAT-09 sequencer used in the Annie's Blinking Eye project on the next page, have a driver built in and do tricks like letting you program and switch between multiple patterns.

For ultimate control, you can program a **microcontroller** to switch lightwires on and off, using **triacs**. The triac, a component that's like a transistor or relay for AC, switches the AC between each microcontroller output pin and the lightwire strand it controls; the triac's gate pin connects to the microcontroller, and its other 2 pins connect the lightwire to voltage or ground.

LIGHTWIRE VS. LEDS

In lighting design for costumes, signage, theater sets, or other projects, one of the first questions to answer is whether to use lightwire or light-emitting diodes (LEDs). The decision is mainly a matter of aesthetics and what reads best design-wise. Here's a comparison.

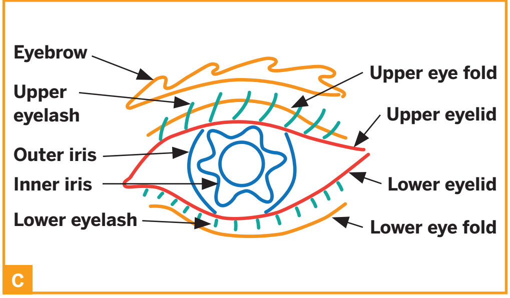
	Lightwire	LEDs
Pluses	Creates smooth, clear contours; off-the-shelf drivers and sequencers run many effects (strobes, blinks, sequences); flexible to apply, and easy to remove	Less complicated to achieve fading, blinking color, and color-mixing effects; less expensive, lower energy consumption, more illumination per area; can project light over a distance (with a lens)
Minuses	Does not color blend; fades over time; if you cut the wire too short, you have to start over	Tedious to attach multitudes (100s) of LEDs into a single circuit; control circuitry needs to be custom built

Photography by Paul Spinrad

LIGHTWIRE ANIMATION PROJECT

ANNIE'S BLINKING EYE

Here's a project that illustrates the steps and considerations for using lightwire to create a successful animated image: in this case, a large, blinking eye.



C

1. Make a full-sized drawing.

First, sketch out the object you want to animate. We've seen running horses, jumping kangaroos, flying saucers, and leaping dolphins. The best designs can be understood from just a few contours.

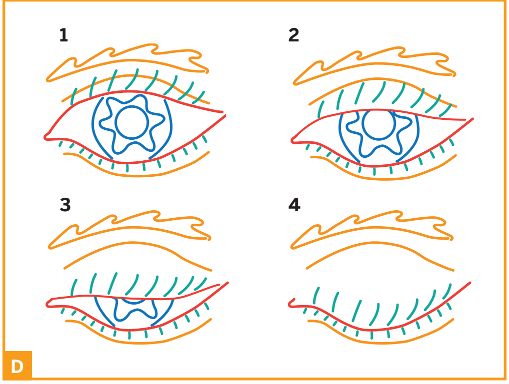
Once you've refined your idea, draw it at full size on one or more sheets of paper. You need to figure out which elements are always on — the common frame — and which will be animation frames.

In our case, the common frame included the eyebrow, the folds above and below the eye, and the eye's bottom edge and eyelashes. The animation consisted of 4 frames (Figure D) that showed the eyelid and lashes, iris, and pupil in various stages of open- and closed-ness. To distinguish the various parts and make the animation easier to view, we decided to use yellow for the eyebrow and folds, green for the lashes, pink for the eyelid, and blue for the iris and pupil.

We made a full-sized master drawing of the fully opened eye (the common frame plus frame 1) and then 3 more drawings for frames 2–4. To make the movement of the upper lashes appear smoother, we drew them on a separate piece of tracing paper and simply translated them downward for frames 2–4 without foreshortening the lashes' length. This allows successive lash segments to overlap from frame to frame, which helps the viewer follow them and see them as the same thing. The animated movement reads better this way, even though real lashes don't stay upright.

MATERIALS AND TOOLS

- 2.5mm lightwire, "High Brightness Standard" in yellow, pink, blue, and green, 6' lengths of each **$1.40/ft from Light 'N Wire (lightnwire.com)**
- Standard driver (cube driver) for lightwire **Light 'N Wire part #CB-SD01, $8**
- 10-channel sequencer for lightwire **Light 'N Wire #SQ-XC01, $75**
- Heat-shrink tubing, various diameters
- Foamcore board, 2'×3'×¼" thick
- Copper tape **available at stained glass supply stores**
- Steel wire, 28 gauge, uninsulated
- Network cable, 8-conductor, 24-gauge twisted pair wire, 3' long
- Snap connector leads, lightwire side (5) **Light 'N Wire #SNR-LSC02, $1 each (1 included with each lightwire order)**
- Small zip ties
- Duct tape
- 12V DC battery holder, 8×AA "brick" **Light 'N Wire #PS-BB01, $2**
- AA batteries (8)
- 9V battery snap
- Colored pencils and paper
- Scissors
- Wire cutter/stripper
- Heat gun
- X-Acto knife
- Needlenose pliers
- "Helping hand" mini workstand
- Alligator clips (2)
- Paper or masking tape **for labeling wires**
- Palm drill and small bits
- Lightwire stripper (optional) **Light 'N Wire part #AC-WS01, $5**
- Soldering iron and solder



D

2. Transfer the drawing to the mounting medium.

You can attach lightwire to almost anything. We mounted our eye to a sheet of foamcore board. To transfer the drawings, we taped them onto the board, then followed along each line with a stylus, making an indentation by pushing down into the board. Then we filled in the indented lines with different colored pencils for each frame.

3. Measure and cut the lightwire.

For each eye image segment, hold the corresponding color of lightwire along its line to measure out the proper length, then cut it to size, adding about 6" of extra length. Label each segment with tape to identify it, for example, "eyelash/frame 1." Group the cut segments together by frame: common or 1–4.

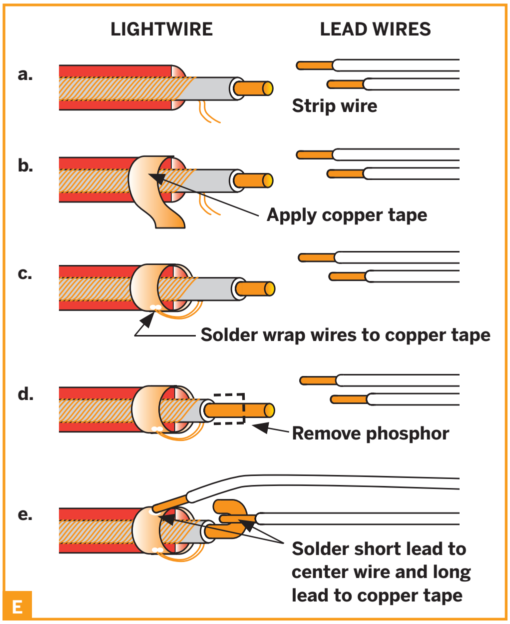
For elements like the eyelashes, which are laced in and out of the board, follow the wire's path back and forth with a piece of string, holding it along the way with bits of masking tape. Then measure the lightwire against the string and cut it to length plus 6".

NOTE: Lightwire can't be folded or bent too tightly. For corners, use separate segments or thread a single segment out the back, loop it, and bring it back to the front at a new angle through an adjacent hole. To black out short sections, cover the wire with tape or heat-shrink.

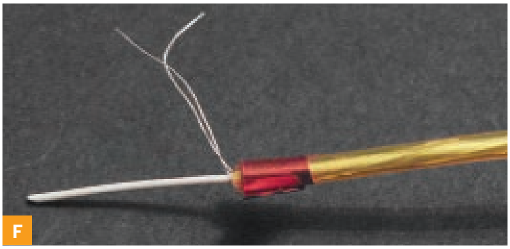
4. Attach the leads.

Before mounting, each segment needs to be connected to its 2 lead wires (Figure E). Our leads came from cutting open a network cable, which contains matched pairs of wires in 4 colors. This is helpful for color-coding our 4 animation frames. (Five colors would be even better, to include the common frame.) Here's how to connect each segment to its leads:

» Strip off about ¾" of the lightwire's outer vinyl sheath(s) at one end.
» Tease away the tiny wrap wires, then stick a cuff of copper tape around the sheath, right behind where you began stripping (Figure F).
» Bend the wrap wires back over the copper tape and solder them to the copper tape.
» Scrape off the phosphor layer to completely expose about ⅜" of the tip of the core conductor wire (Figure G).



E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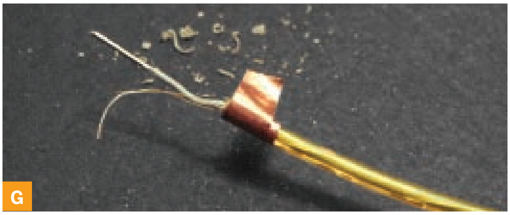
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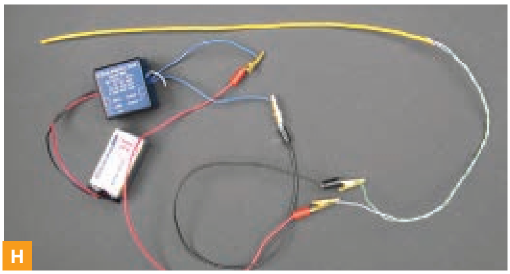
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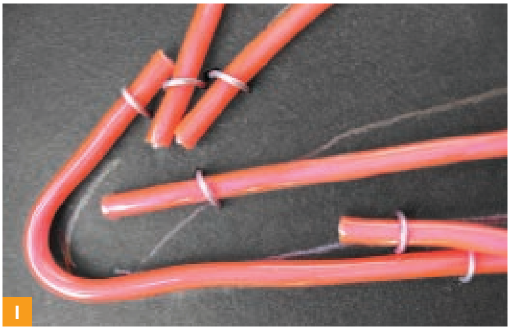

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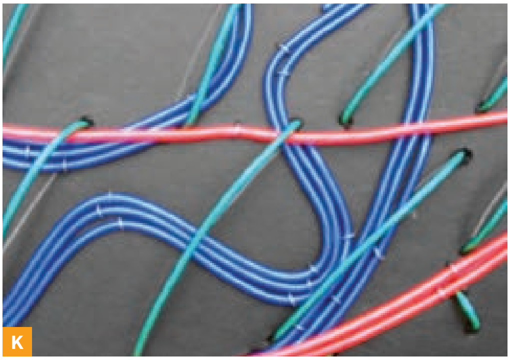

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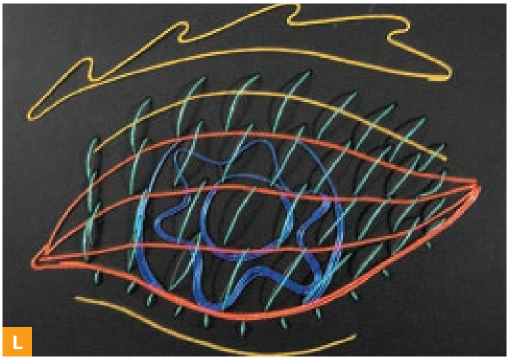


L

» Cut and strip 2 leads about 12" long. Solder one to the bare core conductor and the other to the copper tape. Use the proper color leads to designate the frame (but stripe vs. solid can go either way).

» Test the segment by connecting it to a working driver (Figure H, previous page). If it lights up, cover the joint with a piece of heat-shrink tubing.

5. Mount the segments, frame by frame.

Starting with the common frame, attach all the segments for each frame to the front of the board, following the drawing and running the leads out the back. To minimize the spaghetti in back, pick one side of the board to carry the leads, and drill pilot holes on that side where each segment starts.

To hold the segments down and guide them around curves, we made "staples" out of 28-gauge steel wire. Drill pilot holes where you want the staples to sit, run each end of the staple through the holes, then fit the staple snugly around the lightwire and fold its ends flat on the backside using needle-nose pliers (Figures I and J).

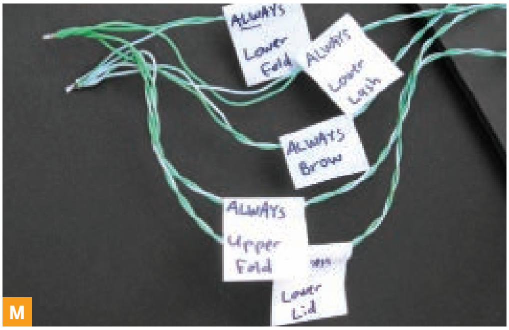
The blinking eyelid covers different amounts of the blue iris and pupil, so frames A–C all include iris and pupil segments, even though these elements don't move. Where the frames' segments represent the same lines in the original drawing, we mounted them side by side so they wouldn't block each other (Figure K).

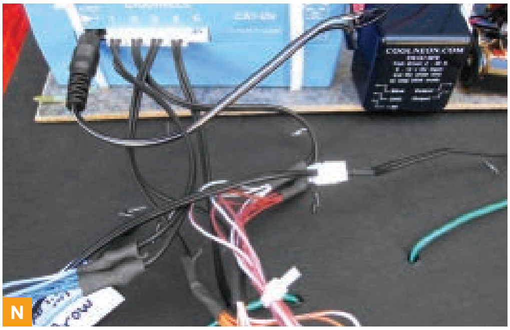
After mounting all the segments for each frame (Figure L), bundle the leads together in back and label them for final connection later.

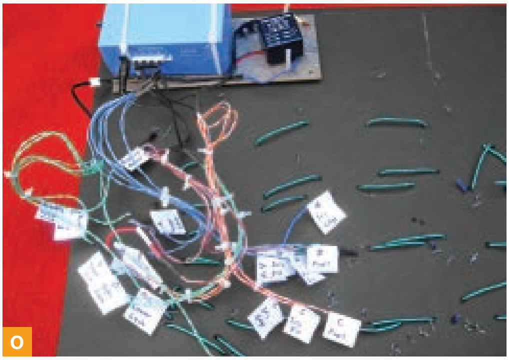
6. Connect the frames to the driver and sequencer.

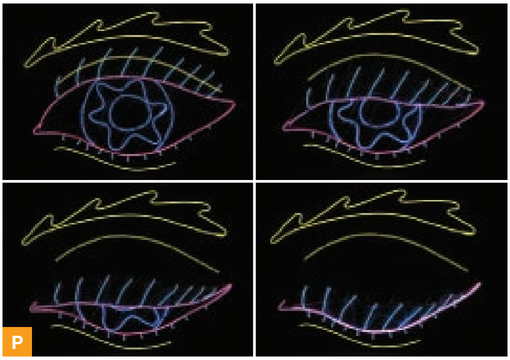
The 10-channel sequencer can switch from frame 1 to frame 4, but it doesn't include an always-on output, so we connect the common frame leads to a different box, a cube driver.

Test each lightwire strand again by alligator-clipping its leads to a driver. Although we tested them before, the soldered connections can break when the strands are mounted, and it's easier to identify and repair individual elements before they're connected together.









For the wires in each frame, bundle all of their leads together and separate the solid and striped wire pairs. Twist the solid leads and the striped leads together into 2 pigtail connections for each frame (Figure M), then solder the 2 masses to a snap connector. You should wind up with 5 snap connector plugs, each of which connects in parallel across all the segments in a single frame and plugs into the sequencer or cube driver (Figure N).

7. Final assembly.

The sequencer and driver both run off the same 12V battery brick. Each has a battery snap that plugs into the brick's 9V-style terminals, so you need to solder an additional 9V battery snap to connect it to both boxes. Then mount the brick, sequencer, and driver together on the back of the board near the lead bundles. We just stuck them on with cardboard, metal fasteners, and zip ties, and then neatened up the wires in back with more zip ties (Figure O).

Finally, plug the frame 1 connector into the sequencer's channel 1 port, frame 2 to channel 2, 3 to 3, and 4 to 4. Plug the common frame connector into the cube driver. Choose the sequencer pattern that makes sense for the project; in this case, "1-2-3-4-3-2-1" gives the illusion of the eye opening and closing (Figure P). You're done!

RESOURCES

- **Animated image of Annie's Blinking Eye:** makezine.com/go/blink
- » **Elam EL Industries** LyTec lightwire manufacturer's site, with product datasheets: elam.co.il
- » **Instructables** How to add EL wire to a coat or other garment: makezine.com/go/elwirecoat
- » **ePlaya** Burning Man Community Discussion Board: eplaya.burningman.com
- » **Light 'N Wire Productions** for lightwire, drivers, sequencers, and more: lightnwire.com

Louis M. Brill ("Louie Lights") and Steve Boverie ("Dr. Glowire") are co-founders of Light 'N Wire Productions, (lightnwire.com), an art-technology resource center dedicated to EL wire. They teach classes on EL wire at The Crucible in Oakland, Calif., and via touring "Tupperwire" seminars.

By Lee D. Zlotoff

Water Landing!

The Scenario: You've had a long and crappy day at work. What's more, it's raining. Hard. You pile into the front seat of your car with your umbrella, waterproof storm coat, and briefcase, comforted only by the sight of a zip-lock plastic bag with homemade cookies. You plug in your cellphone, secure it to the hands-free mount on the dashboard, start the engine, and hit the road.

Traffic sucks, so you decide to get off the highway onto a winding, back-road shortcut that runs along the nearby river. Which would've been fine, until a deer suddenly darts across the road, causing you to swerve, skid, and go bounding down the embankment to crash-land in the river.

The Challenge: When you recover from the initial shock enough to utter a few choice expletives, you notice the airbag has deployed — protecting your upper body from the crash — but your legs and ankles really hurt, and might very well be broken. What's more, the river water is rapidly rising into the passenger compartment from below. Fortunately, the door latch seems to work, the river's current isn't too swift, and you're a pretty strong swimmer. But it's dark, raining, and you're miles off the beaten track. What are you going to do now?

What You've Got: In addition to the aforementioned items, there's a small flashlight and a Swiss Army knife or Leatherman tool in the glove box, plus the typical work-related items in your briefcase. Talk about needing a bailout ... good luck!

Photograph by Jen Siska

Send a detailed description of your MakeShift solution with sketches and/or photos to makeshift@makezine.com by May 28, 2010. If duplicate solutions are submitted, the winner will be determined by the quality of the explanation and presentation. The most plausible and most creative solutions will each win a MAKE T-shirt and a *MAKE Pocket Ref*. Think positive and include your shirt size and contact information with your solution. Good luck! For readers' solutions to previous MakeShift challenges, visit makezine.com/makeshift.

Lee David Zlotoff is a writer/producer/director among whose numerous credits is creator of *MacGyver*. He is also president of Custom Image Concepts (customimageconcepts.com).

A simply great calculator, laundry alternatives, a look at music, and the 3D camera you've been waiting for.

TOOLBOX

Epilog Zing 16 Laser Cutter

$8,000 epiloglaser.com/zing_16.htm

Before Epilog sent their new Zing 16 laser cutter to review, I'd never considered building things one slice at a time. Soon thereafter, I felt like an Ikea flat-pack design ninja. This 40-watt CO_2 laser system makes quick work of cutting through wood and acrylic up to ¼" thick, translating my digital designs into real-world objects.

Think of a laser cutter as a USB printer with superpowers. First, create your design with a vector drawing program, such as Rhino, Illustrator, or CorelDraw. Then send the design to "print" on the Zing. Instead of ink issuing from a print head, you get a focused laser beam cutting a path through your material. My biggest complaint is that the official drivers are Windows-only. Third-party drivers for OS X and Linux exist, but I haven't tried them.

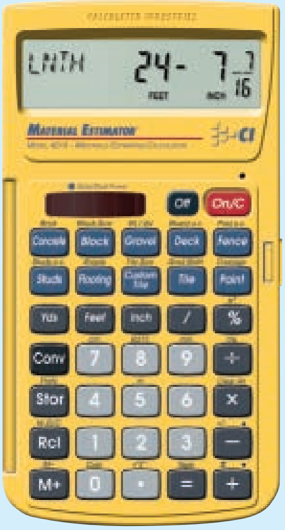
I learned some laser cutting rules of thumb: Square edge notches make for flush fits. Right angles are the norm. Too much power leads to charred edges.

After you get the hang of it, you can create precise parts to solve your problems. For me, these included solenoid brackets for a train project, Arduino prototyping enclosures, and tiny geared robots. With the Zing's work area of 16"×12", I never needed more space.

Small and reasonably priced (compared to previous-generation systems), the Zing series represents a new breed of desktop laser cutters. The Zing 16 is an amazing tool, just the thing for a hackerspace or tool collective. Fire up the laser!

—John Edgar Park

» **Want more? Check out our searchable online database of tips and tools at makezine.com/tnt. Have a tool worth keeping in your toolbox? Let us know at toolbox@makezine.com.**



DIY Project Calculator

$25 calculated.com

The ProjectCalc Plus tool gets a place of honor above my heart, in the chest pocket of my Carhartt bibs. I use it daily at work to switch between feet and inches with the touch of a button, as well as decimal measurements to fractions down to 32nds (it also converts to metric measurements and back). It has numerous additional shortcuts to estimate quantities of everything from tile, studs, and plywood, to yards of gravel or bags of concrete. Fancier versions have trig functions; I prefer the basic, cheaper version with its protective folding cover.

—Sam Mason

OpenIt

$12 enjoyzibra.com/openit

I was skeptical at first glance, thinking the OpenIt tool from Zibra was just a fancy pair of scissors and not the wunderkind packaging Houdini it claimed to be. But when I saw the way it handled our kids' packaged Christmas presents with ease, the OpenIt earned a permanent place in our utility drawer.

The tool is heavy-duty enough to cut through the most stubborn plastic. The right-angled blades slip easily under tie wraps and provide better access for cutting through those annoying clamshell packages.

The OpenIt also has a retractable utility knife in one handle and a tiny screwdriver in the other, perfect for opening those little battery doors on toys. And, as if they read this Santa's mind, there's even a bottle opener.

—Bruce Stewart

Fujifilm 3D Camera

$600 fujifilm.com/products/3d

Stereo photographers have an excuse for going digital now that Fujifilm's FinePix 3D camera has arrived. It has many of the features they've always wanted, all packed into a sleek and compact camera that does exactly what good stereo requires. The camera takes two matched 10MP pictures from vantage points separated by 77mm. It also has synchronized shutters, auto focus, auto exposure, zoom, and nearly all the features one expects in a compact digital camera.

Fuji promotes its $500 autostereoscopic viewing frame to see the pictures in 3D. You don't need it. The free software StereoPhoto Maker (stereo.jpn.org/eng/stphmkr) reads the camera's MPO format, extracts the two left/right JPEG pictures, and then converts them for any viewing method.

The camera is difficult to hold without getting one's fingers over one of the lenses. This is easily prevented by using an old flash bracket with handgrip (see photo). (*For a detailed review, see makezine.com/go/fuji3d.*)

—Donald Simanek

Fujifilm 3D Camera photograph by Donald Simanek

KITS FROM THE MAKER SHED

Explore these and more at makershed.com. By Marc de Vinck

Getting Started with Arduino Kit

$70 **Maker Shed #MSGSA**

Bridging the gap between the "real world" and your computer, this kit is your starting point into the world of physical computing. You get the Arduino Duemilanove microcontroller and other electronic parts, along with our best-selling *Getting Started with Arduino* book by Massimo Banzi, the co-founder of Arduino. And soon you'll be ready to join the tens of thousands of engineers, designers, artists, and hobbyists who have discovered this incredible and educational prototyping platform.

Electronics Workshop 1 Kit

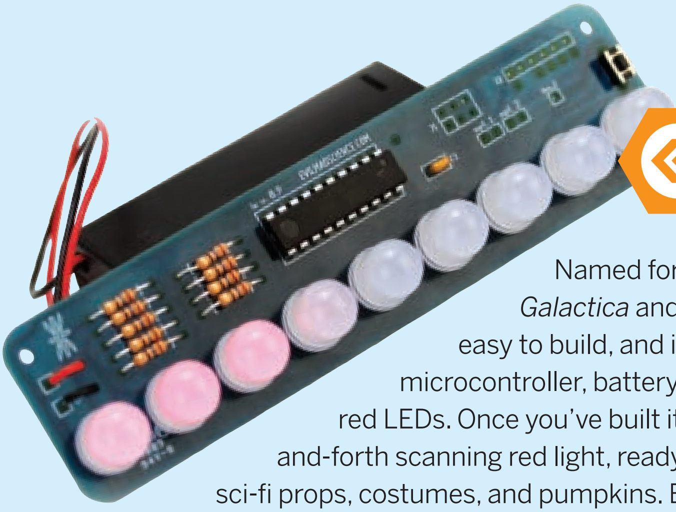
$110 **Maker Shed #MKTK15**

Discover the digital world with this unique introduction to electronics. Follow the story of Robert M-3, a young robot in the year 2069, who is beginning his education in electronics with an apprenticeship to Sirius Armstrong, the chief electrical engineer on an enormous space station orbiting Earth. As you read about robot Robert's lessons in electronics, you'll conduct experiments alongside him using your Electronics Workshop console and the beautifully illustrated, full-color, 68-page manual.

DIY Design Electronics Kit

$50 **Maker Shed #MKSL1**

Harness the power of the electron to create games, toys, and contraptions with the fundamental electronic components. Follow the easy instructions to make a light detector, LED flasher, noisemaker, and more. Everything you need to get started is right in the box, including switches, buttons, diodes, capacitors, transistors, and regulators. You'll learn the amazing concepts of resistance, capacitance, voltage, and current with the step-by-step project manual. Soon you'll be the electronics wizard! It's a great introduction to electronics for all ages.



Larson Scanner Kit

$13 **Maker Shed #MKEMS7**

Named for the creator of *Battlestar Galactica* and *Knight Rider*, this kit is very easy to build, and includes a preprogrammed microcontroller, battery holder, and nine ultrabright red LEDs. Once you've built it, you'll have a beautiful back-and-forth scanning red light, ready for incorporation into various sci-fi props, costumes, and pumpkins. By your command!

MotorShield for Arduino Kit

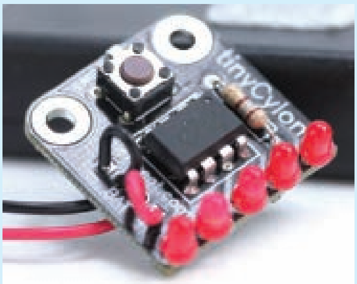
$20 **Maker Shed #MKAD7**

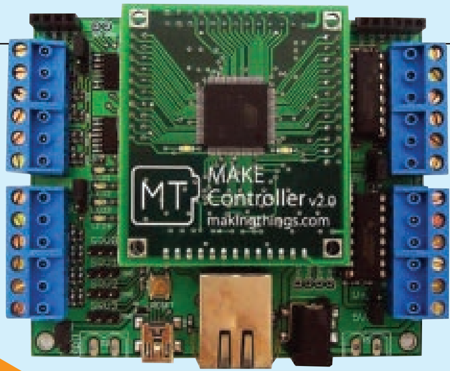
The MotorShield kit is a full-featured motor board that can power many simple to medium-complexity projects for your Arduino. Power up and control your servos, bidirectional DC motors, and stepper motors in all kinds of combinations. Kit comes with all parts necessary. Soldering required. Arduino not included.

tinyCylon

$10 **Maker Shed #MKDW1**

The tinyCylon kit is a great first project for anyone wanting to learn to solder. It comes preprogrammed with several different light displays, or you can hack it to create any pattern that you want! Available assembled or as a kit. Batteries not included.





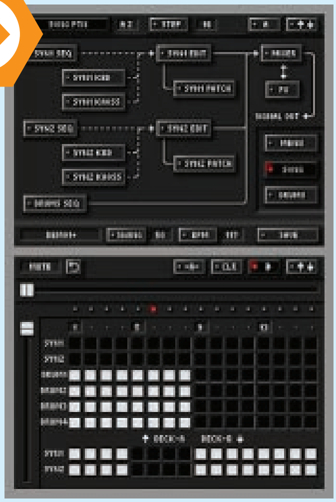
MAKE Controller Kit v2.0

$120 **Maker Shed #MKMT3**

The MAKE Controller Kit is an open source hardware platform for projects requiring high-performance control, feedback, connectivity, and ease of use. It can be programmed to run autonomously or it can be used as a peripheral for desktop/laptop applications via the popular OSC protocol. The MAKE Controller is supported by great open source software tools. (*Check out a MAKE Controller project on page 139 of this issue.*)

Korg Synth for Nintendo DS

$20 korgds10synthesizer.com



When I first saw this synth program, I thought it would be an interesting game. I was way off: it turned out to be a complete synthesizer with surprisingly good sound quality. It holds up to 21 different sessions, and each session has up to 16 patterns of 16 steps. It has two "oscillators," each with its own virtual Keyboard, KAOSS Pad, Sequencer, Patch screen, and Edit screen. It comes with sound presets, but you can modify them or make your own. It also has four customizable drums. You can either write a song using the sequencer or you can record yourself playing it on the Keyboard, KAOSS Pad, or Drum Pad.

After you record your song, the DS-10 will turn it into a pattern on the Sequencer screen. You can even use the wireless connectivity to create a shared session. It isn't a Moog, but for $20, it's an excellent portable music machine. *—Adam Zeloof*

Boss RC-20XL Loop Station

$260 makezine.com/go/loopstation

Despite its daunting name, the Boss RC-20XL Loop Station is surprisingly simple to use. Layer upon layer of guitar riffs, piano progressions, and vocal harmonies can be looped atop each other with the press of a pedal.

How does it work? The RC-20XL records your riff and plays it back to you in real time. Play a line, press the pedal, and your music immediately repeats. Press the pedal again and overdub an additional line over your first; repeat up to 11 times. When you're satisfied with your creation, the entire loop can be saved to the internal memory for later use.

The dual-pedal device has three inputs for mics and other instruments, so countless sounds and tones can be utilized. Start with a drumbeat, groove a funky bass line, shred a face-melting guitar solo, and then you may need to fire your bandmates. You now possess an entire orchestra of sound sitting under your sneakers. Whether it's for practice, live use, or just impressing your friends, this is a great buy for any musician. *—Justin Morris*

Transform Analog to Digital

KID REVIEW

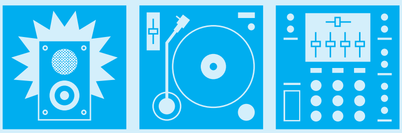
CD recorders

$35 used, $200+ new

There's an easy way to cheaply get songs off your old vinyl albums and onto CDs, which can easily be loaded into iTunes. All you need, besides your ordinary analog music setup (turntable, speakers, preamplifiers), is a CD recorder like my old TEAC RW-CD22 that will transfer music from your albums to a CD-R or CD-RW.

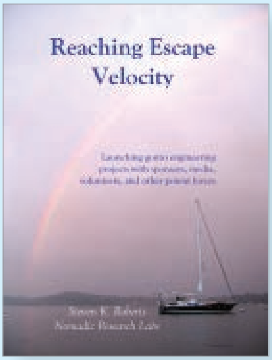
With stores selling used vinyl for less than a dollar, music fans can load up to 70 minutes of music onto a recordable CD. Just connect your turntable to the recorder with standard A/V cables — although since most recorders offer CD copying, you may have to switch from the digital-digital mode to the analog-digital mode. Now roll down the windows and blast some Barry Manilow, and show those punks how cool you are.

—Brian Kerfs



DIY on Demand

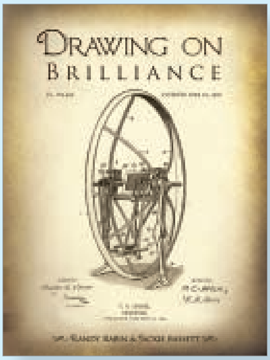
When I first got involved in hardware hacking, in the late 1980s, a lot of what I learned came from a series of hardware "cookbooks" self-published by a guy named Don Lancaster. He desktop-printed and bound the books himself. It seemed like on-demand publishing was finally here. It wasn't (for most of us), but it is now, with services like Lulu and CreateSpace. Recently I received four new self-published books in a single week, exploring different areas of making. Amazingly, they're some of the best books to have crossed my desk in a while. *—Gareth Branwyn*



« Gonzo Wisdom

Reaching Escape Velocity **by Steven K. Roberts**
$14 microship.com

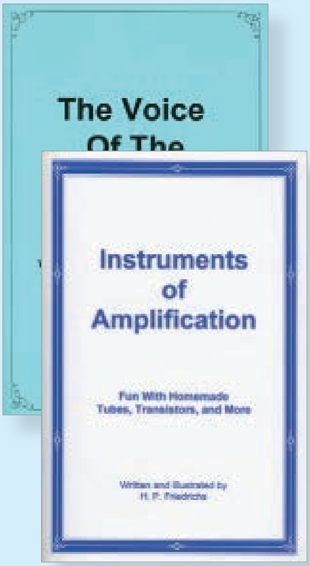
Steve Roberts was also an early hardware hacking pioneer, writing his first self-published book, *Computing Across America* (in the late 80s), literally from the seat of his tricked-out, gadget-laden, internet-connected bike. This new, deceptively slim volume contains 25 years of Roberts' trade secrets on how to capitalize, publicize, and find support for your own "gonzo engineering" projects. It's meta-hack project wisdom from the original high-tech nomad (*see MAKE, Volume 06, page 28, "Tech-Nomading from Shore to Ship"*).



« Patent Genius

Drawing on Brilliance **by Randy Rabin and Jackie Bassett**
$40 drawingonbrilliance.ning.com

After the U.S. Patent Office digitally scanned its 200-year-old collection of some 6 million patents, they decided to trash the originals. A horrified Randy Rabin spirited away as many of these patents as he could before they met the shredder. This book collects some of these gorgeous documents and offers some historical context for each, plus a takeaway thought for would-be inventors.



« Crystal Clear

The Voice of the Crystal **by H. Peter Friedrichs**
Instruments of Amplification **by H. Peter Friedrichs**
$15 and $20 hpfriedrichs.com

The Voice of the Crystal has a stellar reputation amongst radio geeks, and for good reason. This guide to building radios is filled with great ideas and utterly awesome projects. I love the author's assertion that every curbside can of garbage contains all the parts to build at least one radio. Peter Friedrichs builds headphones from soup cans, shoe polish tins, and disposable lighters, along with paper tube condensers (old-school capacitors), detectors (old-school diodes), radio coils, and more. If you have a maker bone in your body, you can't look through this without itching to grab your tools and dive into the nearest dumpster.

In his follow-up book *Instruments of Amplification*, Friedrichs shows you how to build vacuum tubes, transistors, transformers, and other homebrewed amplifying devices. The 297-page book is also crammed with lots of basic electronics background, history, theory, and build tips. I can't recommend these books highly enough.

Electric Spin Dryer

$135 laundry-alternative.com

I love drying my clothes on the line, both for environmental and aesthetic reasons (not much beats the smell of clothes dried in the sunshine), but my shady San Francisco courtyard is only practical at the height of summer — the rest of the year, I can hang a towel out from dawn to dusk and it just won't dry.

Enter Laundry Alternative's cool electric spin dryer. A small portable electric device, it spins up to 12lbs of wet clothes at 3,200rpm for about 4 minutes, leaving your clothes just a touch damp. I was amazed at how much water came dripping out of the little spigot (almost a quart), and when I hung the clothes out on the line, they dried in less than an hour, even in the late afternoon.

While that won't help me on foggy winter days, it will significantly extend my clothesline season, and cut down on the length of time I use the dryer on rainy days. Next up: testing out their hand-cranked washing machine!

—Arwen O'Reilly Griffith

Movie Madness

$1–$5 rifftrax.com

Have you ever seen a really bad movie that you really wish would be ripped to shreds? The people at RiffTrax have, and they continuously rip lame movies to pieces in the form of humorous commentary. Comedic genius Michael Nelson of *Mystery Science Theater 3000* fame and his cohorts from the same show, Bill Corbett and Kevin Murphy, take famous movies such as *Twilight*, *Casablanca*, *Transformers*, *Jurassic Park*, and *Ocean's Eleven* and add some of the funniest observations on the internet. Each riffing costs only a few bucks, and then you sync the commentary to the movie using audio cues, and you're set.

If you think you're funny enough, you can even upload your own commentary for profit. I've tried, and it's given me a renewed respect for what these guys do. RiffTrax is the best and funniest website you aren't visiting.

—Eric Ponvelle

Whiteboard Your World

$99 and up ideapaint.com

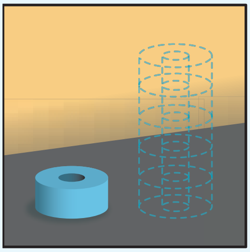
When you have an idea, you write it down. But just as chalkboards made their way out of our lives, it's time for whiteboards to do the same. Get IdeaPaint instead, which turns almost any flat surface into a whiteboard. Simply figure out what color you want — IdeaPaint comes in ten colors — and where you want to apply it.

Our interns Kris Magri and Tyler Moskowite tested it out here in the MAKE Labs. While it's a bit of a long process (the paint is supposed to cure for 7 days), it's a lot of fun once you start. If you can't find Daniel Carter, our creative director, at his desk, he's probably in the Labs, drawing away. You can watch the whole process at vimeo.com/7671005.

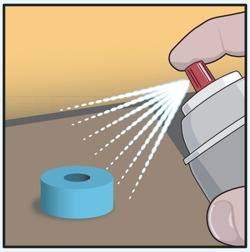
—Ed Troxell

Tricks of the Trade By Tim Lillis

Hack a hot glue mold.

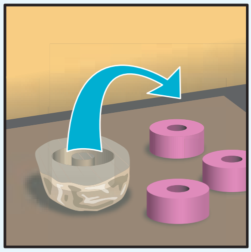


Need multiples of a part? Don't have any casting materials? Need it now? Use this trick from Marc de Vinck, MAKE's CNC Maker.



Apply a release agent to the master. If you don't have actual mold release handy, sometimes even water will work. Otherwise a light coating of oil will do.

Place the master on a flat surface (glass or parchment paper works well) and use a *very* heated-up hot glue gun to coat the piece. It may take a few tries to get the right speed down.



Use the hot glue mold to cast a new piece in plaster, auto body filler, epoxy, etc. (use release agent again). You can also use this technique with caulk or sealant, or even Jell-O!

Have a trick of the trade? Send it to tricks@makezine.com.

Silicone Rescue Tape

$25 for 2 rolls rescuetape.com

In case the advent of plastic bakeware wasn't enough to convince you of the wonder of silicone polymers, I relate the following tale. Shortly after moving into my current home, an air conditioner drain line in the attic sprung a leak, and water started dribbling through the ceiling. The proper fix would have been to cut out the leaking section of pipe and replace it, a task I was not looking forward to in the Texas summer heat. After complaining to a fellow chemist, he suggested I try silicone tape as a temporary fix.

Four years later, that "temporary" repair, which took all of 45 seconds to complete, is still going strong. Apart from a bit of dust, there's no sign of degradation in the tape, and I'll be surprised if it doesn't make it another four years at least.

Rescue Tape comes in relatively short rolls, which is necessary because it's about 1mm thick and requires backing on both sides to keep it from sticking to itself, which it does almost instantly. If you wait a minute or so and then try to pull the bond apart, the tape itself will fail before the joint does. It's soft and flexible and highly resistant to heat, cold, water, and oil, and it can be used on any kind of material, clean or dirty. —*Sean Ragan*

Arwen O'Reilly Griffith is the mother of a 9-month-old engineer-in-training.

Brian Kerfs is a 13-year-old 80s music enthusiast living in California.

Tim Lillis shows you how to use stuff better than you knew you could.

Sam Mason is a solar PV installer who lives, works, and plays in Boulder, Colo.

Justin Morris is an avid guitarist and aspiring technophile.

John Edgar Park is the host of the Maker workshop on *Make:* television.

Eric Ponvelle is a graduate of Nicholls State University in English with a concentration in technical writing.

Sean Ragan's ancestors have been using tools for 5,000 generations.

Visit **Donald Simanek**'s pages of science, pseudoscience, and humor: www.lhup.edu/~dsimanek.

Bruce Stewart is a freelance technology editor and writer, as well as an infrequent contributor to *Wired*'s geekdad.com.

Ed Troxell is MAKE's photo intern.

Adam Zeloof lives in Central New Jersey and enjoys sailing, camping, birding, geocaching, and of course, making.

Have you used something worth keeping in your toolbox? Let us know at toolbox@makezine.com.

By Donald Simanek

The Chinese South-Pointing Chariot

Many ingenious mechanisms are devised with no "practical" purpose in mind. They are examples of invention for the sheer fun of it. This phenomenon occurred early in many cultures.

» The classic mechanisms of the ancient Greeks were often just toys, made to amaze and entertain. Hero (or Heron) of Alexandria (c. A.D. 10–70) built a coin-operated vending machine (dispensed holy water); a clever hydraulic mechanism for mysteriously opening temple doors when a burnt offering heated water beneath the altar; and the aeolipile, a cute little engine that whirled around under the force of steam, like a rotary lawn sprinkler.

But these were rather simple contrivances compared to the legendary "south-pointing chariot" from China. It was a two-wheeled chariot, pulled by a horse, with a statue of a person riding on it.

The statue's arm was extended, pointing south no matter how the chariot moved. The chariot could travel in curves, loops, or any convoluted path, even backward, but the statue stubbornly continued pointing south — but only if the ground was flat and level and the wheels didn't slip.

An Ancient Wonder

Though legend has this chariot invented as early as 2,634 B.C. by the Yellow Emperor Huang-di, the first historically confirmed version was created by Ma Jun (c. A.D. 200–265).

Its secret was a geared mechanism inside the enclosed body of the chariot. The differential motion of the wheels drove the gears, which in turn caused the statue to rotate the same angle as the carriage turned, but in the opposite direction.

Simple to say, but not so simple to invent. In fact, history tells us this closely guarded secret was lost several times and reinvented, and in each case the inventors received much acclaim.

When the chariot was shown in public ceremonies, the mechanism was hidden in an enclosed chamber underneath the statue. Some people supposed that the chamber concealed a person with a magnetic

FOR FUN OR FUNCTION? A Chinese south-pointing chariot, model by George H. Lanchester on display at the Science Museum of London.

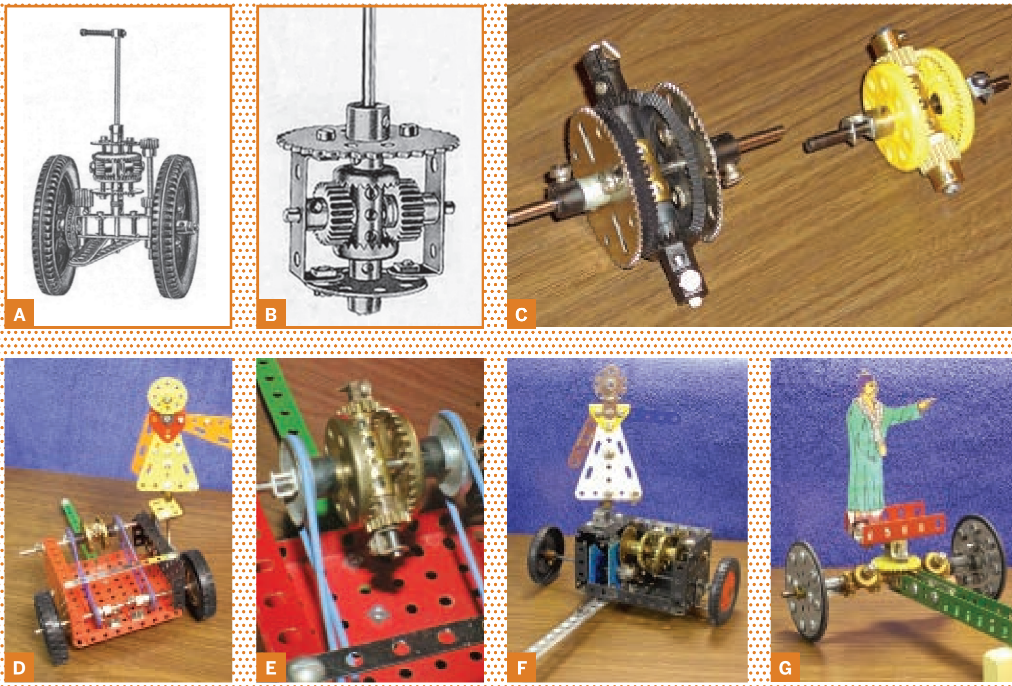
compass, continually rotating the statue to keep it pointing south. Some even thought a magnet could be strong enough to turn the statue by itself.

But of what use was it? Probably only ceremonial use, to impress, puzzle, and entertain an audience. Some historians fell into the error of assuming it had military uses (as the legends claimed), such as guiding armies traveling in a desert at night, or in smoke or fog. That's hardly likely, as the carriage only works well on solid and level ground (such as a parade ground). Potholes and even small hills compromise its accuracy quickly. Also, the wheels must not slip or slide.

Legend even tells of a similar "south-pointing ship," but this goes beyond credibility, for the mechanism requires a flat, level, and unmoving surface to work properly. If such a ship existed, it more likely used a magnetic compass, which was known in China during the Qin Dynasty (221–206 B.C.) and was certainly a more practical and reliable tool for navigation. The south-pointing chariot was not.

The chariot mechanism had 4 wooden gears, arranged in much the same way as the differential gear of an automobile. But it was being used backward. Additional, conventional gearing was required to connect the differential to the wheels. The wheels drove the gears, which in turn rotated the statue. The

Photograph courtesy of Science Museum London/SSPL



CLASSIC CHARIOT REDUX Fig. A: Meccano model, Lanchester design, from *Meccano Magazine*, Jan. 1957. Fig. B: Differential, from instruction book of *Meccano Standard Mechanisms*, 1934, U.K. edition. Fig. C: Differentials, using Eitech parts with bevel gears (left) and Meccano parts with crown and pinion gears (right). The gear's grub screws will be removed, since all these gears must rotate freely on their shafts. Fig. D: My open version of the south-pointing chariot. Mechanism and housing mostly of Erector parts. Fig. E. The differential. Fig. F: Erector model, modified Lanchester design. Fig. G: Meccano model, Nuttal design.

Photography courtesy of Meccano (A–B); and by Donald Simanek (C–G)

gearing *could* have been used to drive the wheels, if only the Chinese had had an engine of some sort to power it. Sometimes a clever idea isn't implemented fully because some other technology isn't available yet to support it.

Making Your Own Version

Hearing the chariot described, even seeing detailed plans, may not convince you that it works as claimed. You have to build one and experiment with it.

Hobbyist mechanics build many variations, from small desktop models to full-sized carriages pulled by ponies or horses. Steel construction toy sets used to include plans for one, back when such toys were intended to educate youngsters about mechanisms and physics. These days the internet has many sites with pictures of models, and often complete plans for building the chariots, even parts lists (see Resources, following page).

The differential gearing is the heart of this project and requires either 2 crown gears and 2 pinion gears, or 4 bevel gears. You'll need a shaft coupler with 3 setscrews (grub screws), or some other way to fasten perpendicular shafts together.

The shafts can be rigidly fastened, for the gears of the differential unit turn freely on them. Figure C shows the use of Meccano or Exacto parts (generally the best quality readily available), or Eitech parts (metric standard). I keep a supply of size 6 washers, both metal and nylon, to use as spacers for this sort of mechanism.

I've made several versions of this toy, but for this article I made a larger one with the mechanism exposed so it could be photographed with all important components fully visible (Figures D and E). It's not elegant, but it works. Most hobbyists use Meccano parts for such models, but I chose to use Erector parts since I had a lot of them.

The differential is the Lanchester design, but rotated 90°. I could have used spur and pinion gears to link it to the wheels, but I took the simpler route and used rubber O-rings (blue) and 4 pulleys. One belt must be crossed to reverse the direction in which it drives the differential (Figure E). (With gears, an extra idler gear is required to accomplish the same reversal.) The pulleys link to the crown gears of the differential with short sections of rubber tubing, since these must turn independently of the axle that passes through them.

In the time-honored tradition of tinkerers I didn't do any calculations, I just let the design evolve as I built it. I tested it and then experimented with different wheel diameters and adjusted the spacing between the wheels until it worked properly.

Once the gearbox is built, these are the only two remaining adjustable parameters. I wouldn't be at all surprised if this was the way the original inventor did it. However, the math isn't that bad. The separation of the wheels is 14cm, and the wheel diameters are 7cm, for a rotation angle ratio of ½. The pulleys are all the same diameter, so the belts have a rotation ratio of 1.

If you hold one wheel stationary and rotate the other, you notice that the small gear in the differential rotates on the stationary crown gear while the other crown gear drives the small gear, for an additional rotation ratio of 2. The gears of the differential have a gear ratio R, but the gears under the statue are in the reverse order, with a gear ratio $1/R$, for a combined ratio of 1. Multiplying all these ratios gives 1, and the twist in one belt reverses the statue's rotation to be opposite to the rotation of the chariot. An additional small fudge factor is required to compensate for the tire width.

It's best to use rubber tires on the wheels, so they don't slip. Rubber O-rings of the right size work well. Also, weight is an asset. Heavy wheels are less likely to slip on smooth surfaces, or you can add "load" in the bottom of the box.

Oh, by the way, why does the man point south instead of north or some other direction? Actually he simply continues pointing in the direction he was initially set to point. In Chinese culture, south, being the direction where the sun reaches its highest elevation, is more important than north, and is considered the reference direction on maps.

Alternative Designs

The first model I built was the Lanchester design, out of Erector parts (Figure F, previous page). The perpendicular axles are solidly fixed to each other. All of the wheels and gears must turn freely on their axles. Short pieces of plastic tubing connect the large gears to the crown gears of the differential.

In Chinese culture, south, being the direction where the sun reaches its highest elevation, is more important than north, and is considered the reference direction on maps.

The necessary reversal of direction of the drive from one wheel was accomplished with an idler gear, mounted on the two fiber plates at the left.

My second model used parts from Meccano sets (Figure G). I followed an elegant construction called the Nuttal design, which I found on the web. It required gears of specific sizes, so I ended up ordering quite a few brass gears. Fortunately there are still sources where you can buy individual parts, even rare ones.

This model has everything visible, and though the principle is the same, the gearing is quite different from the museum models. The model is completely symmetric around the statue, and no reversal gimmick is necessary. The wheels must move independently, so they are not fixed to their axles. The Nuttal model has just one long axle for both wheels. Note the heavy, rubber-rimmed wheels.

You can see stereo 3D pictures of my models at makezine.com/go/spc. I'd be happy to see your creative versions. Email me at dsimanek@lhup.edu.

Resources

» **South Pointing Chariots** Harry Siebert's great website with many different models, and plans and instructions for some of them, including Lego models. odts.de/southptr

» **Wikipedia** History, legends, and a brief explanation of the SPC. makezine.com/go/chariot

» **Girders and Gears** A fabulous place to get parts for hobbyist projects. girdersandgears.com

» **Exacto parts** Erector and Meccano compatible, with ½" hole spacing. Every English-standard construction set part ever made, and more. exactosystem.com

Donald Simanek is an emeritus professor of physics at Lock Haven University of Pennsylvania. He writes about science, pseudoscience, and humor at www.lhup.edu/~dsimanek.

Jan	Feb	Mar
Apr	May	Jun
July	Aug	Sept
Oct	Nov	Dec

MAKER'S CALENDAR

Compiled by William Gurstelle

Our favorite events from around the world.

Bent Festival

April 22–24, New York City

An annual art and music festival celebrating DIY electronics, hardware hacking, and circuit bending. Each year artists come to perform music with their homemade or circuit-bent instruments, teach workshops, and showcase the state of the art in DIY electronics and circuit bending culture. bentfestival.org

›› FEBRUARY

Family Science Days

Feb. 18–22, San Diego, Calif.

Browse interactive exhibits, learn about cool science jobs, and have your questions answered by experts at the annual convention of the American Association for the Advancement of Science. aaas.org/meetings/2010/program/fsd

›› MARCH

National Science and Engineering Week

March 12–21, United Kingdom

This year's theme is "Earth." Expect nearly a million people to participate in the ten-day program of science, engineering, and technology events and activities all around the U.K. britishscienceassociation.org

2010 Green Energy Summit

March 24–27, Milwaukee, Wis.

The Green Summit's schedule of events includes renewable energy demonstrations, workshops, and training seminars. Keynote speakers include a NASA scientist and several Congress members. renewableenergysummit.org

Scifest Africa

March 24–30, Grahamstown, South Africa

Last year, 68,000 people attended Scifest, making this event the biggest of its type on the African continent. During its weeklong run, visitors explore more than 500 exhibitions, lectures, workshops, excursions, and whiz-bang science shows. scifest.org.za

›› APRIL

Breakpoint

April 2–4, Bingen am Rhein, Germany

What happens at Breakpoint? The concept is simple: organizers set up a stage, invite programmers, artists, and musicians from around the world to enter competitions, and then audiences watch in amazement at the audiovisual "demo" presentations that come out. breakpoint.untergrund.net

SparkFun Autonomous Vehicle Competition

April 17, Boulder, Colo.

Electronics wizards, roboticists, and just plain geeks compete to create a vehicle that can autonomously navigate a course around the SparkFun building. A cash prize is awarded to the winner. sparkfun.com

Trenton Computer Festival

April 24–25, Trenton, N.J.

In 1975, the world's first personal computer, the Altair 8080, came out. The very next year saw the first personal computer expo. The show celebrates its 35th anniversary with a host of events including conferences, contests, speakers, exhibits, and a flea market. tcf-nj.org

IMPORTANT: All times, dates, locations, and events are subject to change. Verify all information before making plans to attend.

Know an event that should be included? Send it to events@makezine.com. Sorry, it's not possible to list all submitted events in the magazine, but they will be listed online.

If you attend one of these events, please tell us about it at forums.makezine.com.

By Tim Anderson

Instant Paddle

Here's a better, quicker, inexpensive way to make a paddle.

» A paddle can be laborious to make. It can cost a lot to buy. Here's a better, quicker, inexpensive way.

The old-time Hawaiians sometimes made paddles this way, and I've seen paddles made the same way in Nicaragua. I myself have done a lot of paddling with paddles like this. They work great.

And there's not much to it. Drill 2 pairs of holes in a board. Tie loops of string through the holes. Jam a stick in the loops and go paddling.

Pictured is a Naish carbon stand-up paddle that retails for $399, next to my "copy" which didn't cost anything to make and took an hour or so of work (Figure A). Here's how you can make one, too.

1. Trace a blade you like.

In the surf industry this process is called R&D, which stands for "rip off and duplicate." The shapers all do it and joke about it with pride. I traced the blade onto a piece of scrap paper. It happened to be a map of Burning Man 2008. I folded the paper over to make sure my blade would be symmetrical, and cut it out with scissors. I added a bulge at the top of the blade so the lashing wouldn't slide off.

My scanner is smaller than the paddle blade, so I folded the paper into quarters and scanned it. The blade is 9½" wide and 18" long. The lashing holes in my blade are 0.372" and are drilled in the wide part of the blade. Download the template at makezine.com/21/heirloom, print it out at the proper scale, and trace it to make your blade.

2. Cut out a blade and drill the holes.

I used a laser cutter to cut blades from 5⁄16" thick Baltic birch plywood that came from a packing crate for a Contex large-format scanner (Figure B). Use whatever plywood you have handy.

I lend away a lot of paddles, so I made a dozen while I was at it. Use whatever tools you have; usually I use a handsaw and a hand drill. That's almost as fast as a laser cutter. A lot faster if you count CAD time.

3. Rip the sticks.

A hockey stick is a perfect shaft for a canoe paddle. Graft 2 of them together with a scarf joint for a stand-up paddle. I didn't have enough hockey sticks for all these paddles, so I ripped some nice scrap wood on my table saw (Figure C). Ripping means cutting along the grain of the wood. It's one of those jobs that's a whole lot easier with power tools. I've done it with a handsaw and it's a day-eater.

A diameter of 1¼" is about right for a round softwood stand-up paddle shaft; 1½" is too thick, and 1" wouldn't be too thin for your hand but it's too flexible for a shaft this long. Measure some paddles that look and feel good to you to see how thick you want yours to be. The handle of the Naish is 1.15" diameter and is 86" long overall. A rectangular shaft can be thinner than a round one and have the same strength. If you want a T-handle on top of your paddle, feel free to add one, although the old-time Hawaiians never did.

4. Round the shaft corners.

I usually use an octagon scribe to mark the corners and shave the shaft with a drawknife, plane, and spokeshave. That's fun, and you can hold a conversation while doing it. When I'm in a hurry I use a router with a quarter-round bit (Figure D). I clamp the router securely in a work stand.

Choose the radius of the quarter-round bit to suit yourself. If its radius is half the thickness of your work, you'll get a round shaft. When I'm in a hurry is when I get injured, but today things went smoothly. That's not my blood on the work stand. I think it's paint.

5. Prepare the stick and blade.

So now you've got a stick and a blade. Cut the end of the stick so it tapers down to the end on one side like a wedge. The handle for this particular paddle is a broken hockey stick from the rink at Kihei, Maui. I know from growing up in Minnesota that a hockey

Photography by Tim Anderson

stick is the most suitable shape for grasping. I don't know why I've never seen canoe paddles with rectangular shafts. It works and feels great.

This blade is 8½"×18", which is big like a snow shovel (Figure E). Later I cut it down into a smaller, more graceful shape, which I unfortunately lost. Be sure to take a Sharpie marker (or a laser) and write a return address on all your gear.

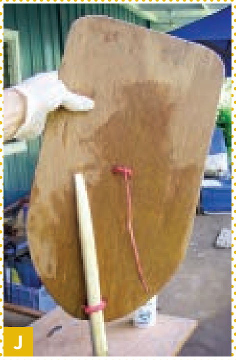
6. Make cord grommets.

Method #1: Braided Grommets: This style of lashing is popular in Bali. It's surprisingly quick to do. Put 2 turns of cord around the stick. The third turn gets zigzagged through the first 2 turns to form a 3-strand braid. For this example (Figure F), I kept following the pattern through the braid until I had 6 turns and the braid was doubled. Then I tightened it until it was the right size and pulled the tails through the inside of the braid.

Method #2: Half-Hitch Whipping: This method is simpler to learn and remember. (If you're in a hurry, use bigger cord and skip the whipping; if you soak it with paint, varnish, super glue, epoxy, or something similar, it won't unravel regardless of how crudely your lashing is finished.)

Use the tip of your paddle shaft as a spacer to set the size of the cord loops. Make sure the lashing mostly fills the holes in your blade. This mason's twine is thin, so it took 7 turns of cord to seem right. Then I tied a half hitch around the turns of string (Figure G). Pull the half hitch tight. The tip of the stick is there for a gauge. Don't make the loop too small. You'll want to jam the stick in there a few inches.

Now whip your loop by tying a series of half hitches around the turns of cord. Somewhere I've seen these called "French knots." To finish, use a spike to part the turns of cord (Figure H). Poke the tail through them, and pull it tight (Figure I). Your cord loop is done.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NICARAGUAN STYLE

Here's a Nicaraguan dugout with a pair of instant oars on Isla Ometepe in the middle of Lake Nicaragua. The blades are nailed to the shafts and the nails clinched (bent over). I saw others with lashed blades. Notice the simple rope-and-saddle oarlocks. Sudden winds of 30mph spring up on the lake. The fishermen need oars to make any headway against it.

Tie another, bigger one at the handle end of the blade. Calculate the size to match the taper of the shaft, so both loops will get tight when you jam the shaft in there.

7. Oil the components.

I painted linseed oil onto the mating surfaces of the blade and shaft, and also oiled the grommets.

8. Attach the shaft to the paddle.

If you drill the upper 2 holes at an angle, it's easier to put the shaft through the loop (Figure J). Then twist the blade into alignment, poke the shaft into the next loop, and pound it in, to make it secure (Figure K). You don't want the blade to come off while paddling.

Bent tip alternative: I glued this shaft to the blade with epoxy for extra stiffness (Figure L). I painted the mating surfaces with epoxy thickened with wood dust before jamming the shaft into the cord loops. Then I bent the tip while the glue dried so it would have a very slight curve later.

9. Trim the tails.

Cut the visible ends of string off. Nothing will unravel. For added protection, I painted the rest of the raw wood with linseed oil. Wipe off the excess when you're ready to go paddling, and just go. That's another good thing about linseed oil. No waiting.

10. Size your paddle.

This Hawaiian petroglyph shows how to size a canoe paddle to fit you (Figure M). The photo is from the book *The Hawaiian Canoe* by Tommy Holmes. Hold your paddle over your head with your arms in this position. Make your elbows into a 90° angle as seen here. If your paddle is too short for you to do that, your paddle is too short.

To size a paddle for stand-up paddleboarding I use a different method: I stand the paddle vertically and reach as high as I can. That's how tall the paddle should be. For me it's about 8' long. Got a favorite method of paddle sizing? Please share!

Tim Anderson (mit.edu/robot) is the founder of Z Corp. See a hundred more of his projects at instructables.com.

MAKE MONEY

Wind Chimes

By Tom Parker

Sometimes it costs more to buy it than to make it from the money itself.

Photograph by Tom Parker

$34.99

Wind chime bought online.

$4.20

Wind chime made from quarters and dimes.

I've always liked wind chimes. Maybe it's because my parents had one hanging on the front porch when I was a kid. They're usually made with pieces of glass, or shells, or hardened metal tubes. And anyone who's jingled a pocketful of quarters knows that regular coins lack the sweet musical ring of a wind chime. But hammer them thin enough and those same coins play a different tune.

I tried pounding on a few coins with a hammer and anvil, blacksmith style. It worked OK, but it was time-consuming and hard to make the coins sound just right. Luckily, there are train tracks near my house. So I lined up a dozen quarters on the hardened steel rails and left them waiting for the next train to rumble by.

Sure enough, by the next morning my 12 quarters had been rolled thin, like nicely matched metal potato chips. To make a frame for my wind chime, I carefully notched 4 more quarters and 2 dimes with a hacksaw blade, pressed them together in a vise, and added a dab of solder. Then I tied them all together with some monofilament fishing line using traditional clinch knots.

All you need to make this project is 16 quarters, 2 dimes, and a 100-car coal train to flatten your coins. I don't think the coal company minds. I think of it as their carbon credit. And you can't beat the sound of this money as it dances in the wind!

By William Gurstelle

Benjamin Franklin's Electrical Experiments

» There are two stories every American elementary school students knows: George Washington chopping down the cherry tree and Ben Franklin flying his kite in a thunderstorm to prove the electrical nature of lightning bolts. Both are good stories, but there's a difference: Ben actually did fly his kite in the thunderstorm.

Few people have made as large an impact on daily life as Benjamin Franklin. Aside from his political and literary contributions, he was colonial America's greatest scientist. It seems that nearly half the words we commonly use to describe our daily interactions with electricity — positive, negative, charge, discharge, battery, conductor, condenser — were coined by Franklin.

The kite story was first related by the famous English chemist Joseph Priestley in his 1767 book *The History and Present State of Electricity*. Priestley may have embellished the event, but even if some of the details are hazy, the overall import is unquestionable: in his legendary experiment with the key, the kite, and the thunderstorm, Franklin proved what many educated people suspected: lightning is indeed electrical in nature.

One day in June 1752, the skies darkened as clouds rolled into Philadelphia. Franklin and his son William headed north to an open field with a small shed. They carried a kite framed from cedar sticks, covered with silk cloth, and topped with a sharp-pointed wire to attract the "electrical fire."

The wind blew and soon the kite strained against the kite string. Franklin and son waited inside the shed, no doubt impatiently, until the storm began. Then Franklin noticed the kite string's thin strands of hemp moving. Seemingly of their own volition, they stood as erect as soldiers at attention.

Attached to the kite string was a metal key. Franklin moved his knuckle toward the key. Suddenly, he felt a small shock as the electricity jumped from the storm-electrified key to the grounded Franklin.

FOUNDING MAKER: Franklin (1706–1790) not only sparked the American Revolution, he was a prodigious inventor and the leading scientist of his day in electricity.

Portrait from Getty Images

The storm continued, wetting the kite string, and conducting increasing amounts of electricity down into the small shed where Franklin collected the charge in a new but primitive type of capacitor called a Leyden jar.

Franklin had already turned his observations of electrical storms to great practical use by inventing the lightning rod, which was most effective for preventing the fires that frequently destroyed churches and other tall buildings.

But old ways die hard, as did the 121 bell ringers killed by lightning in Europe in the decades immediately after Franklin invented the lightning rod. Churchmen who believed lightning was caused by demons eschewed lightning rods in favor of the traditional method of defending churches against lightning bolts: ringing church bells during thunderstorms.

The Leyden jar that Franklin used to trap lightning is a simple capacitor consisting of two conductors separated by a thin insulating sheet. It was discovered accidentally in Leyden, Holland, just a few years before Franklin's experiment.

Physics professor Pieter van Musschenbroek was attempting to electrify a glass jar filled with water by touching the water with a brass wire conductor. When he accidentally touched the wire and the outside of the jar simultaneously, the Dutchman found himself stunned, literally and figuratively.

News of this incredible "jar of Leyden" spread like

LIGHTNING IN A BOTTLE: You can re-create Ben Franklin's electrical experiments by building this simple static electricity generator and a Leyden jar, similar to the one Franklin used to capture electricity from thunderclouds in his famous kite-flying experiment.

Photograph by Sam Murphy

wildfire throughout the scientific community. At last, here was a way to hold and store electricity.

Improvements were made as experimenters tried different techniques and finally developed the device now commonly used in experiments and presented in the how-to section that follows.

For a while it seemed everyone had a Leyden jar and people all over 18th-century Europe enjoyed shocking themselves and one another for fun and profit. Itinerant lecturers called "electricians" traveled from town to town, demonstrating the wonders of the recently discovered ways to control and utilize the phenomenon called electricity.

Perhaps the greatest electrician was the Abbé Jean-Antoine Nollet, a French priest and member of King Louis XV's court. In 1746 Nollet arranged for 180 royal guards to link hands in a great room in the palace. He cranked up his electrostatic generator (not unlike the one described in this article) and asked the man at the head of the line to touch a brass ball. Upon contact, all 180 men were mightily surprised by the shock from a big Leyden jar. Nollet later repeated the trick on a chain of 200 monks, who simultaneously jumped in the air. The king was delighted.

You can simply re-create the experiments of Franklin without flying kites in a thunderstorm. The static electricity generator described here is a type of modified Ramsden machine that uses rubbing friction between two electrically dissimilar materials to generate oppositely charged particles. A "comb" harvests the charges and directs them to a Leyden jar for storage.

And once you've got bottled lightning, the opportunities for science and entertainment, as the Abbé Nollet proved, are endless.

MATERIALS

For the Ramsden-style static electricity generator:
- 2×10 board, 2' long
- 2" PVC pipe, 16" lengths (2) for the uprights
- 2" PVC tee fittings (2) for upright supports
- 2" lag screws with washers (4)
- ½" PVC pipe: 20" length, and 5" lengths (2) for the roller support and 2 crank pieces
- ½" PVC elbow fittings (2) for crank
- ½" PVC cap fitting for crank
- 3" PVC pipe, 10" length for the roller
- 3" PVC cap fittings (2) for roller caps
- ¾" OD copper pipe
- ¾" copper pipe cap fitting
- Round brass knob with mounting screw
- #6×1½" brass screws (8) You could also cut aluminum flashing into a comb with 8 or more points.
- Fur such as rabbit

For the Leyden jar:
- HPDE plastic tub or jar with lid Recycling number 2. You can also use cardboard for a lid.
- Aluminum tape
- A few inches of copper pipe, with cap fitting
- Brass knob with mounting screw
- Beaded lamp chain

Ramsden-Style Static Electricity Generator

You can make the generator just about any size you want. Refer to the corresponding photographs to see the relationship of the parts.

1. Cut down the 2" tee fittings and attach them to the frame with lag screws and washers.

2. Drill 13⁄16" holes in the center of each 3" PVC cap.


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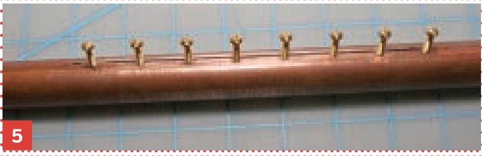
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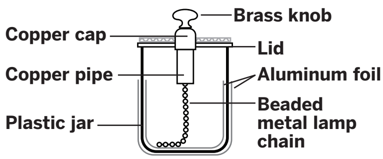

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WARNING: Leyden jars can pack an electrical wallop! Don't leave charged jars lying around, and limit the size of your jar; a quart is more than enough.

3. Drill two ⅞" holes through each of the 2" PVC uprights for the roller support and the copper pipe.

4. Attach the caps to the 3" pipe, and insert the roller support through the holes in the caps.

5. Drill eight ⅛" holes through the copper pipe at equal intervals, then fully insert 8 brass screws. Attach the brass knob to the copper cap with a screw.

6. Insert the copper pipe and roller support pieces into the holes in the uprights. Attach the copper cap with the brass knob to the copper pipe.

7. Place the uprights into their supports and glue them into place. Add the crank pieces to make the crank, and glue them, too.

8. Rotate the copper pipe so that the screw points just brush against the 3" PVC pipe when it's rotated.

Leyden Jar

9. Build your Leyden jar using the diagram at left. Line the jar inside and out with aluminum tape or foil, except the top 1" or so. Drill a hole through the copper pipe and thread the beaded chain through it.

10. Place the Leyden jar knob against the knob on the copper pipe. Press the fur firmly against the 3" PVC pipe and turn the crank rapidly. As you rotate the PVC pipe, the copper pipe becomes electrified and its charge is collected in the jar.

Touching the knob of a charged Leyden jar with your finger will induce a spark. Large sparks are painful, so you may want to discharge it by using a piece of curved wire to touch the knob and outside foil simultaneously. Use insulating material to hold the wire, such as a piece of PVC pipe (see page 169).

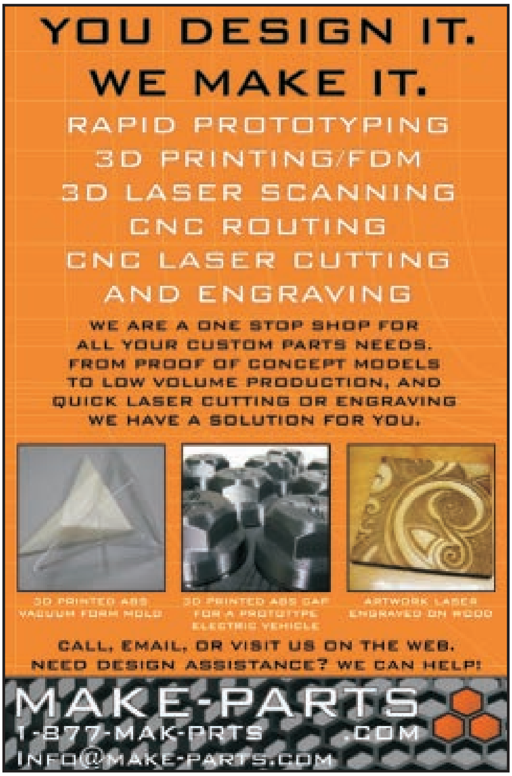
For a how-to video of this project, see makezine.com/go/electrostatic.

Thanks to Steven Walvig of the Bakken Museum in Minneapolis for his consultation.

William Gurstelle is a contributing editor of MAKE magazine.

Photography by Ed Troxell; illustration by Gerry Arrington


Master of Science in Technology Leadership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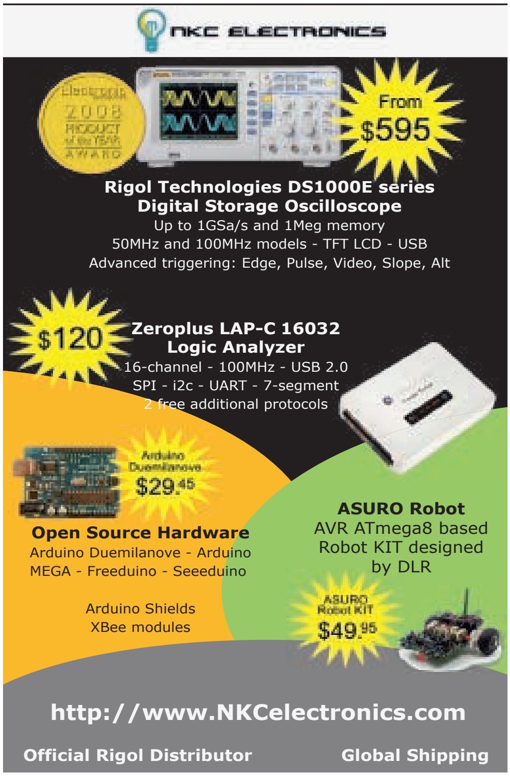
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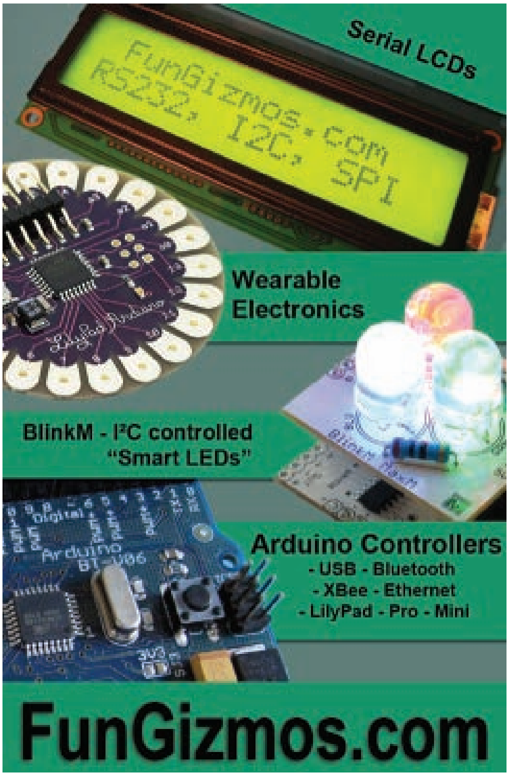
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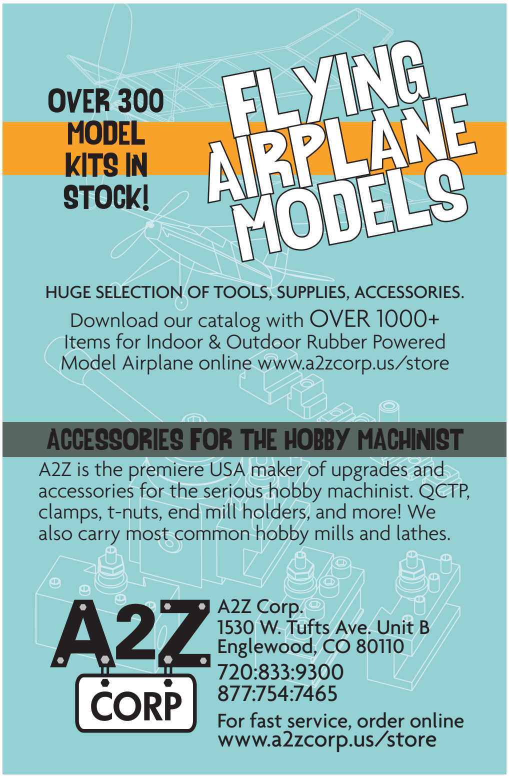
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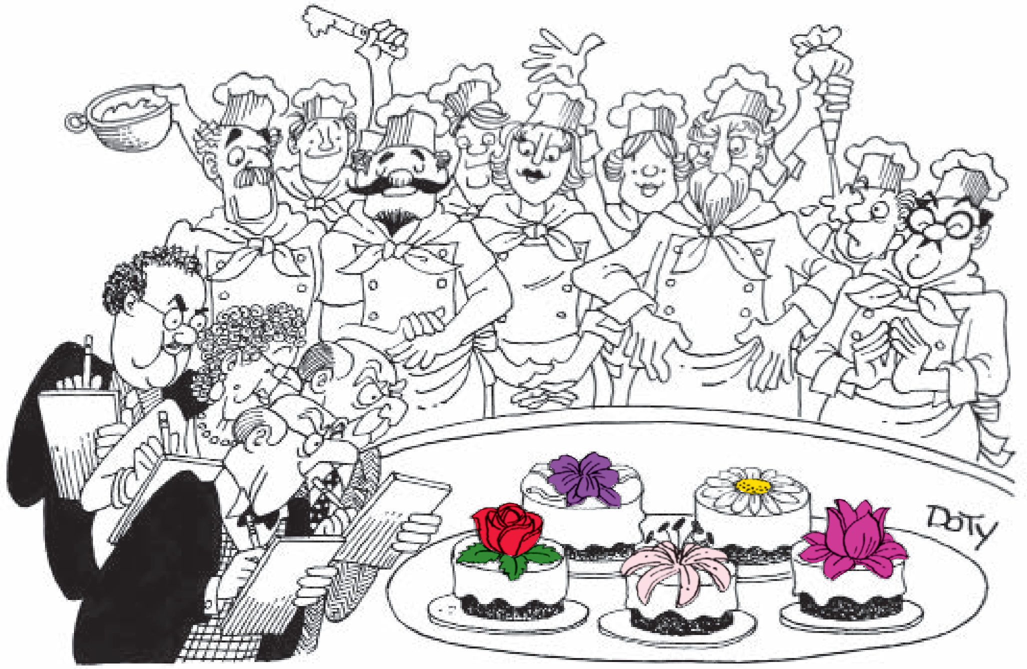
AHA! Puzzle This By Michael H. Pryor

MAKE's favorite puzzles. (When you're ready to check your answers, visit makezine.com/21/aha.)



Cake Competition

The top chefs of the world, along with their assistants, met for a competition to see who could create the most beautiful and innovative cake flower decorations. They used their fabbers to print 5 different types of flowers for the top of the cake: rose, violet, lily, daisy, and tulip.

The chefs (Wylie, Rocco, Wolfgang, Jamie, and Ming) had their assistants (Jacque, Jasper, Cathal, Julian, and Laurent) fill the fabbers with cheese, cookie dough, chocolate, peanut butter, and caramel. Each group took a different amount of time to perfect their creation (30 minutes, 35, 45, 50, and 55), and only 2 of the chefs received the coveted 3-star rating from the panel of judges. Two of the other chefs got 2 stars, and 1 chef only managed to get 1 star.

Name the chefs, their assistants, how long it took them, the ingredients they used, and the type of flower they created, along with their final star rating!

1. Ming did not create the cookie dough tulip.
2. Laurent finished in 35 minutes but got only 2 stars.
3. The 2 flowers that received 3 stars were the daisy and the one made of peanut butter.
4. The rose (not made of cheese) was created by Jamie (who was not Cathal's chef).
5. Jasper did not make the tulip, but his flower was made of chocolate.
6. The 1-star flower took 50 minutes to make, and was not made by Wylie.
7. The violet was made of caramel.
8. Wolfgang (who didn't work with Julian) took 55 minutes and got 2 stars.
9. Rocco and Jacque worked together and it took them longer than 30 minutes.
10. Julian made the lily but he did not get 2 stars.
11. When all 5 flowers were placed on the judges' table, the following groups stood behind their creations: Ming at one, the team that took 45 minutes at another, Cathal at another, the chefs who used chocolate at another, and the creators of the lily behind another.

Illustration by Roy Doty

Michael Pryor is the co-founder and president of Fog Creek Software. He runs a technical interview site at techinterview.org.

My *Big* Fortune Teller

By Roger Hess

Tom Hanks may have received top billing for the 1988 film *Big*, but one of the most pivotal characters received no screen credit at all. This character was not an actor, but a 9-foot mechanical arcade machine that grants your wish for a quarter.

While Zoltar Speaks may appear to be one of the finest examples of a vintage fortune-teller machine ever designed, it was unfortunately only a movie prop. And when you're a collector who really wants a fantasy collectible that never existed, you make one yourself. I was able to build the replica shown here entirely in my basement shop. Nothing was outsourced.

I began the year-long project by dimensionally scaling screen captures from the movie DVD, using the actor's height for reference. Zoltar's head and torso were sculpted in clay over foam cores, and prototypes for decorative trim parts were machined from wood.

Patterns for the ornate coin ramp and raised-lettering castings were created using UV-cured polymer resin exposed through artwork created in Adobe Illustrator. Silicone molds fabricated from the original patterns were filled with urethane resin to cast the final parts.

Mechanisms and trim pieces were all custom-designed, with the exception of the purchased hand wheels that aim the coin toward Zoltar's mouth.

Cloth-insulated wire was hand-laced into wiring harnesses, and old electrical items, hardware, and costume jewelry were found online and in surplus stores.

The only modern concession was the inclusion of a BASIC Stamp 2 microcontroller to control, among other things, a modified MP3 player for theme music and sound effects. User functions can be configured using the front coin-release push button while watching Zoltar's eyes flash with coded sequences. The microcontroller and USB-to-serial connectors are hidden in a separate module that can be removed without affecting the basic electro-mechanical operation of the machine.

And what does this 600-pound monstrosity do? Insert a quarter, and it springs to life. Music plays, the eyes light, and the head rocks. The backlit panels light in timed sequence, guiding you to use the cranks to aim the coin ramp toward Zoltar's mouth, make your wish, and press the button to release the coin.

If you're lucky, the coin enters Zoltar's mouth and your award card is released below. Your Wish Is Granted, the card says. For the moment, my wish is relatively modest: I need more room.

Roger Hess is an eccentric engineer, tinkerer, collector, and dog lover living in suburban Minneapolis.

Photography by Roger Hess and Becky Hart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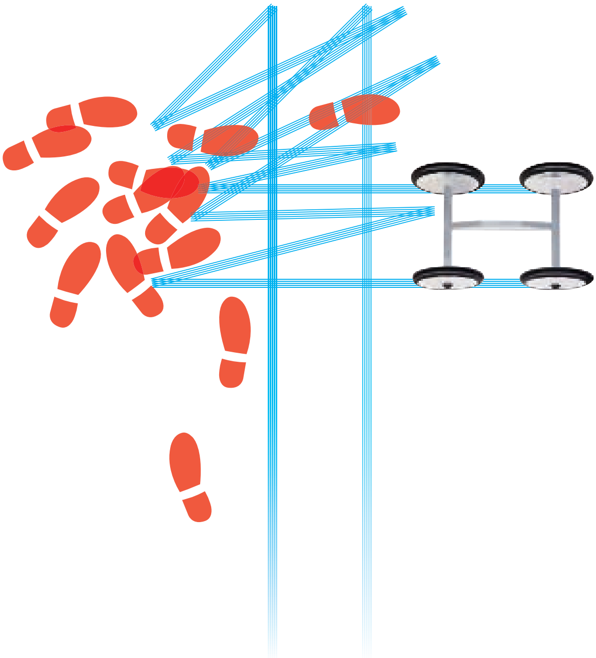
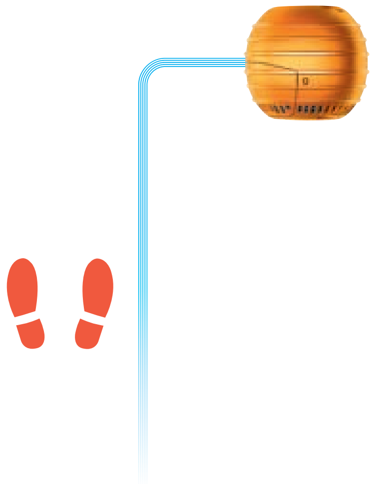
Come to think of it, eBay





A vacuum with wheels makes you go back and forth.

A ball just turns.

Vacuums still have wheels that make it hard work to move around objects and unnecessarily difficult to vacuum in corners.

dyson ball

No more awkward turns.

www.dyson.com