

# Make:

## EXPLORE THE DEEP

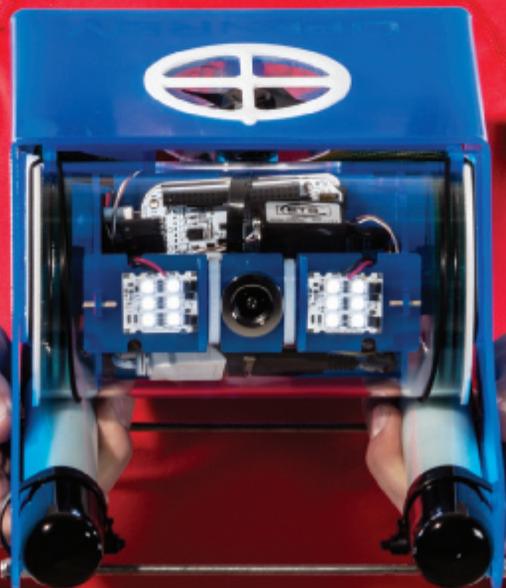
ERIC STACKPOLE: OPENROV Co-CREATOR

## UNDERWATER ROBOT (IN A KIT)



EASY  
ARDUINO  
COFFEE CAN BOT

**PLUS:**  
MINI BOOMBOX  
GEIGER COUNTER  
JAPANESE TOOLBOX  
DOORTOP STASH



**21**  
PROJECTS  
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A CELEBRATION OF AMAZING CREATIONS AND THE PARTS THAT MADE THEM POSSIBLE.

# MONKEY COUCH GUARDIAN

## Use an Arduino to build this stalwart defender of upholstery!

When MAKE's editor-in-chief Mark Frauenfelder wanted a gadget to chase his pesky pets off his favorite couch, he programmed an Arduino microcontroller to read a motion sensor and activate a motor in response — in this case, the motor of an old-fashioned cymbal-banging toy monkey. Take that, cat!

The Monkey Couch Guardian is a great project for getting started with microcontrollers, the tiny computers you can use to control everything from home heating systems to robots.

Since we first published this Weekend Project, it has entertained thousands on YouTube, Boing Boing, Virgin America, and at Maker Faire. Make yours this weekend!

### Here's how it works.

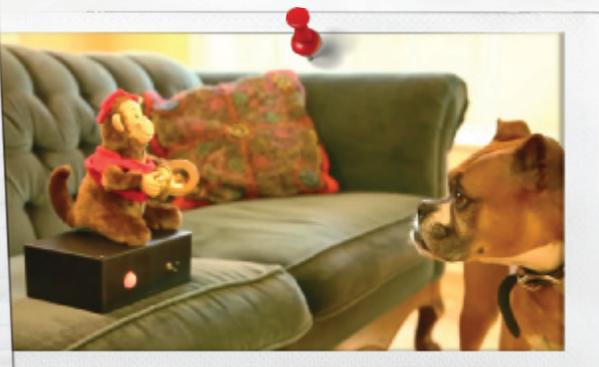
**1. Program the Arduino.** Download the free Monkey Couch Guardian code from the project page, then open it in the Arduino development software (also free) and upload it to the microcontroller. Simple. The code tells the microcontroller to listen to the motion sensor, and then switch on the monkey when something moves!

**2. Hack the monkey.** Tap into the monkey's battery power supply, and add wires to connect a relay that'll bypass the monkey's switch.

**3. Connect a relay.** On a breadboard, connect the relay's switch to the monkey's power and ground, and connect the relay's coil to the Arduino's ground and digital I/O pin 13, which you'll use as an output.

**4. Connect a motion sensor.** It's powered by the Arduino; just connect the PIR sensor to the Arduino's 5V power, ground, and for the sensor's signal, digital I/O pin 12, which you'll use as an input.

- PARTS**
- Arduino Uno microcontroller #276-128
  - Cymbal-banging monkey toy, 3V
  - PIR proximity sensor #276-135
  - Servo cable, 3-wire
  - Relay, SPDT, 5V DC #275-240
  - Solderless breadboard #276-003
  - Hookup wire, 22 AWG #278-1224
  - Project enclosure, 8"x6"x3" #270-1809
  - LED #276-330\*
  - Resistor, 220 $\Omega$  #271-1313\*
  - Toggle switch, SPST #275-634\*
  - 9V battery #23-866\*
  - 9V battery snap connector #270-325\*
  - DC power barrel connector #274-1569\*
  - Tape, adhesive, double-sided
  - Zip ties (2)
  - USB cable, standard A/B #55D10623
- \*optional



*Get along, doggie! This monkey detects intruders up to 20 feet away.*



*The Monkey Couch Guardian  
is ever vigilant.*

**5. Make an enclosure.** We like cigar boxes and RadioShack project boxes. Put the sensor on the front, the monkey on top, and the electronics inside. You can power the Arduino from a wall AC adapter or an optional 9V DC battery pack. Bonus: Connect an optional toggle switch and LED power indicator, so you know when your monkey is on watch.

**6. On guard!** When the Monkey Couch Guardian is switched on, any motion within about 20 feet will trigger the PIR sensor. The monkey will start shrieking and clanging his cymbals, scaring away any unwanted intruders, furry or otherwise.

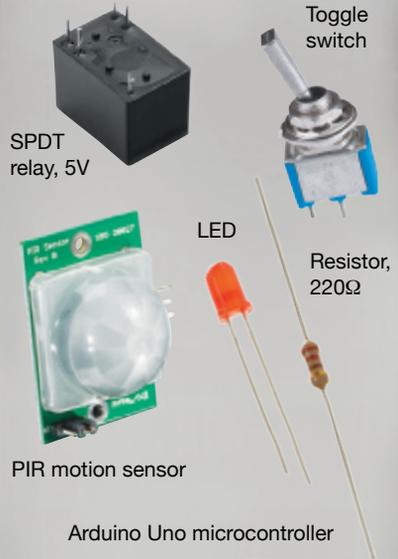
You can use the Monkey Couch Guardian to guard a whole room or just your stash of snacks.

And now that you know how to use an Arduino, you can easily adapt this circuit to switch on lights or appliances in your home, yard, or workshop, by substituting the appropriate relay.

—Keith Hammond, MAKE Projects Editor

To see full build instructions, schematics, breadboard layout, and project video, visit the project page for this build: [radioshackdiy.com/project-gallery/monkey-couch-guardian](http://radioshackdiy.com/project-gallery/monkey-couch-guardian)

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**SUBMERSIBROS:** David Lang, Eric Stackpole, and their OpenROV. Photograph by Gregory Hayes. Art direction by Jason Babler. Makeup and styling by Margaret Caragan.



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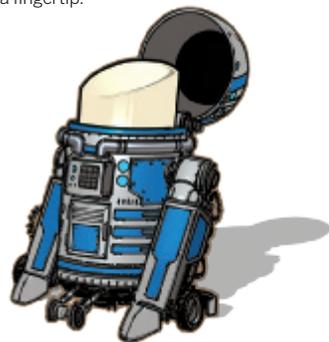
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# High Voltage Hot Rods makes classic hot rods go electric.



High Voltage Hot Rods CEO Andrew McClary holds an aluminum adapter plate he designed, and built with the ShopBot, to mount his high-energy electric motor to a 1966 Corvair's original Powerglide transmission.



**High Voltage Hot Rods** can take a classic Corvair, Mustang, Thunderbird and the like, basically any car that you may have a hankering for, and refurbish it as an all-electric hot rod — for a price tag around \$50,000 (for car and new motor). The company rebuilds original classic cars, replacing the gasoline engines with state-of-the-art electric motors, and also collaborates with car replica manufacturers.

They recently completed a project using a 1966 Corvair. The project is called the Electrovir III, because back in the 1960's, the original car manufacturer tinkered with developing two electric versions of the Corvair.

**WHY SHOPBOT?** Company CEO Andrew McClary explains, "I needed a manufacturing tool that would be precise, easy to reconfigure, and not take up too much room in the shop — every square foot is prime. We already were familiar with the power and precision of ShopBots, as we'd used a ShopBot in a wood furniture business. Our new ShopBot Buddy takes up very little space. We chose the optional casters so we can move it around easily as needed — nice wheels!"

**WHERE** Boca Raton, FL

**BUSINESS** HighVoltageHotRods.com

**SHOPBOT** 52" Buddy PRSalpha

**NEXT UP** Look for High Voltage Hot Rods upcoming TV show.

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**READ ME** Always check [makezine.com/34](http://makezine.com/34) before you get started on projects. There may be important updates or corrections.

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"A robot may not injure humanity, or, through inaction, allow humanity to come to harm."

—Isaac Asimov's so-called "Zeroth Law of Robotics"

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**Nate Van Dyke** (robot illustrations) currently drinks and draws in San Francisco. He's worked in video games as a concept artist but has been focusing on freelance illustration and gallery shows as of late. Some of his clients include *Wired* magazine, Burton, Island Def Jam, Sony, Scion, Sega, Activision, Levi Strauss, Gap, MSN, Upper Playground, Slayer, *Heavy Metal* magazine, and so on. In 2012 he made a dream come true by being a part of a Metallica-themed gallery show, which opened with the band in attendance. Van Dyke has also been doing a lot of live painting for major music festivals in recent years, even though he hates crowds of people staring at him.



**Syuzi Pakhchyan** (*Tracking Our Bodies*) is a fashion technologist and author with a passion for beautiful code and conductive cloth. Her playful tinkering at Art Center College of Design inspired her to write *Fashioning Technology*, the first DIY book on interactive fashion. She continues to chronicle the constantly evolving developments in wearable technology on her blog, [fashioningtech.com](http://fashioningtech.com), while running her research-based design practice focused on bringing crazy ideas for next-generation wearables to market. Currently she is tapping into her childlike curiosity while working on a fun line of wearable tech products for kids.



The first time **David Lang** (*The Accidental Maker*) water-tested his OpenROV with co-creator Eric Stackpole, it sank to the bottom of the pool. Lang admits, "I was heartbroken, while Eric was excited to learn what went wrong. I learned that part of the maker mentality is never seeing a project as complete. Every failure is a great learning opportunity." He lives on a sailboat in the Berkeley, Calif., marina. "It gives me a cool feeling that every little improvement we make has the potential to tell us a little bit more about the ocean. It keeps the stories of tool use close to the tool making."



**Paloma Fautley** (MAKE engineering intern) is a student at the Santa Rosa Junior College currently pursuing a degree in robotics engineering. Her interests range from origami crafts to costume makeup to building robots. Her passion lies in combining art and technology in new and interesting ways. When she's not working in the MAKE Labs providing comic relief and her unsolicited opinions, she's at home working on her own personal projects.



**Michael Overstreet** (*DARwin-OP*) is a computer programmer by day and an amateur roboticist by night. Overstreet and his humanoid robot Boomer have competed in the last six RoboGames and have won multiple bronze, silver, and gold medals. For the past three years he has been experimenting with 3D-printed robot designs at his local hackerspace (CCCKC), of which he's a founding member. He's active in the 3D printer community and is working on his own 3D printer design. He's also been a grassroots supporter of the Kansas City Maker Faire as well as attending all of the national Maker Faires. He blogs his robotic adventures on "I, Bioloid".



**Judy Aime' Castro** (*CoffeeBots*) is a San Francisco artist and designer working with textiles, metal, industrial materials, and electronics. She learned tinkering from her machinist father and sewing from her mother as a family trade. The concept for CoffeeBots came to her while reading a call for artists for a robot art show. "As a joke I said, 'How difficult can it be to make a robot? It's a couple of wheels and a bunch of wires.' I wanted my robot to have a personality ... and I wanted hundreds of them running around." Her concept was accepted, the programming "started at the show, by the audience," and she's now working on CoffeeBot 2.0 kits.

WELCOME

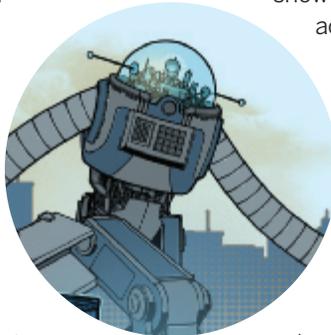
# Join the Robot Uprising!

By Gareth Branwyn

This is MAKE's third issue featuring robots, after Volume 06 in 2006 and Volume 27 in 2011. So, what's changed in robots in that span of time from a maker's perspective?

Those issues focused on the playful side of DIY robotics: robots as toys or pets, robots that entertain. But bot builders are also getting serious. Like many makers, they're evolving from hobbyist to professional. As hardware becomes ever more sophisticated and less expensive, as maker communities grow (both online and off) and offer better advice and collaboration, and as crowdfunding boosts good ideas from prototype to product, all forms of maker innovation are benefiting.

In the robotic realm, there's no better example than our cover story. In this first-person account by David Lang we meet Eric Stackpole, who, joined by David and hundreds of collaborators, created an open source underwater exploration vehicle, the OpenROV. Typically ROVs are incredibly expensive, but this humble project is a game changer. The creators had no prior experience building underwater robots, but were able to leverage online expertise, local makerspace tools, and off-the-shelf parts. After an impressive Kickstarter campaign, they now even offer a kit. Their inspiring story caught the attention



of Google and NASA. The venerable National Geographic Society has even approached them to talk about using similar rovers in their Explorers Program.

Humanoid robots are normally prohibitively expensive, too. Even the DARwIn-OP, an open source robot created as an affordable mini humanoid, costs upwards of \$12,000. By 3D-printing his own parts and sourcing cheaper components, robot builder Michael Overstreet built a DARwIn-OP clone for half that price. His 1.5-foot-tall robot is a state-of-the-art humanoid that's as capable as commercial robots costing three times more.

There's never been a better time to delve into robotics, whether you're a tinkerer or a more serious explorer. With the powerful tools and expertise now available, the next great leap in robot evolution is just as likely to come from your garage as a research lab. Beginners will love our Arduino-based CoffeeBot. We even

show you how to make a mini linear actuator out of a lip balm tube. So what are you waiting for? The robots aren't going to build themselves. Yet.

The ingenuity in this issue doesn't stop with robots. You'll find a clever door-top "safe" for stashing valuables, a surprisingly good-sounding cigar box speaker built with the lowly LM386 audio amp chip, and a hand-cranked Geiger counter. *Très* steam-punk! And do you think the output of your hobby-grade 3D printer is the best you can do? Think again. Matt Griffin, who helped us mastermind our popular *MAKE Ultimate Guide to 3D Printing*, shows you finishing techniques to take your 3D prints to a whole new level.

You'd be forgiven for wondering: Who the heck comes up with this stuff? Makers — clever, creative people exploring the limits of their imaginations and skill sets, and just having fun making and sharing things. I don't know about you, but in some small, weird way, that lip-balm actuator gives me hope for the future. ■

Gareth Branwyn is MAKE's editorial director.

Nate Van Dyke



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## TORMACH MAKER PROFILE - ROAMBOARD

Engineer and maker Rob Green uses the Tormach PCNC 770 to manufacture steering knuckles and steering mounts for the innovative RoamBoard, a four wheeled articulated skateboard that brings surfing and snowboarding to the streets.

"As an engineer, I love to create stuff. About ten years ago, two of my three boys were old enough to be into unicycles and skateboards and doing tricks on bicycles. So I asked them, 'Hey what do you guys think about building an electric skateboard?'"



With the help of his oldest son, Green began prototyping and then manufacturing the board about three years ago. When it came time to move some of the manufacturing in-house Green chose the Tormach PCNC 770, and now has plans to move all RoamBoard manufacturing in-house.



Read the full story at: [www.tormach.com/roamboard](http://www.tormach.com/roamboard)



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# 3D shootout, upcycling visions, pure Pyrex, and unholy smoking.



» Excellent job on your MAKE Ultimate Guide to 3D Printing ([makezine.com/3dprinting](http://makezine.com/3dprinting)). I'm thinking about buying or building a 3D printer with my grandson, so I read the issue looking for insight into what makes a good one.

One article advises to put the printer on a solid table; another talks about moving the extruder off the hot end to reduce mass. Both indicate that a lack of stiffness is a big problem in the design of a 3D printer. Combine this with drives that have substantial backlash and bearing systems that are relatively loose, and it's easy to see why only one printer reproduced the hole in the bird's beak.

This reminded me of a packaging machine I worked on years ago. It had a reciprocating carriage, and when we mounted a barcode printer on the machine, the printing smeared badly due to vibration. I set up a dial indicator with its probe touching the printer housing, and we found that one part of the mount deflected far more than the rest. We reinforced that part and the printer worked perfectly.

I suspect a little time with a dial indicator would be a real eye-opener for these 3D printer builders. MAKE could do technical reviews too, on the pros and cons of construction methods and how they affect the outcome.

—Gary H. Lucas, *Hightstown, N.J.*

» Your 3D printer “shootout” really helped set the standard and challenged us to do better for our users. We loved that you got together such a great team of testers, and that they were able to generate so much useful input in such a short time. We're working hard to do better at the “Christmas morning test.” The “torture test” prints have also challenged the community: expect to see many more printers achieving top results on that one!

Community standards are fundamental — there is so much interest, and so many wonderful new printers, that developing a common language and set of metrics will really be important for users now and in the future. We have several thoughts on how to develop even more accurate and objective testing procedures. We really hope you will consider making this a regular issue. We believe your continued active role will be crucial to ensuring a collaborative and open 3D printing community in the future.

—Espen Sivertsen and the  
*Type A Machines team, San Francisco*



» I really enjoyed Chris Hackett's “DIY Welding Rod” project (Volume 33), but I noticed the NaOH (and HCl) chemistry was done in a Pyrex measuring cup. When World Kitchens bought the rights to make Pyrex cookware in the United States, they switched the recipe from borosilicate (true Pyrex) to tempered

soda-lime glass (like car window glass). Tempered glass is strong and heat resistant, but scratches will significantly weaken it, and when it breaks it shatters into little cubes. People have cooked with it for years and most have no problems, but I suggest splurging on real Pyrex labware to heat acids and bases at home.

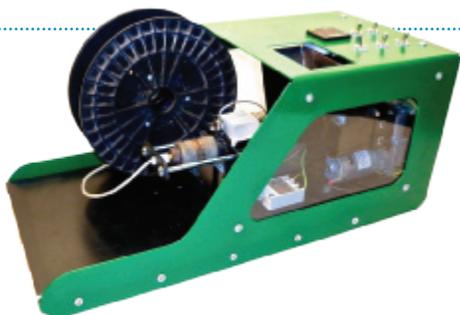
—Josh Feldman, Lawrence, Kan.

» I enjoyed your DIY meat smoker project (“Nellie Bly Smoker,” Volume 32). I realize it uses an electric element as a heat source, but if readers do experiment with adding charcoal as you suggest, regular charcoal briquettes should never be used, as they contain anthracite coal and will impart a less-than-desirable flavor. Natural lump charcoal made from hickory, mesquite, etc., will keep the smoke flavor pure and temperature consistent.

—Brent Benson, Corona, Calif.

#### PROJECTS EDITOR KEITH HAMMOND REPLIES:

Brent, you’re right, we should’ve cautioned against fossil-fuel-fortified briquettes; veteran BBQers consider them sacrilege. When testing the Nellie Bly Smoker, I experimented with natural mesquite lump charcoal to raise the temperature on a big batch of beef brisket. It worked. And tasted great.



» The 3D printing movement and Tyler McNaney’s Filabot ([makezine.com/go/filabot](http://makezine.com/go/filabot)) are so exciting. I imagine legions of young people becoming fabulous recyclers, walking down the street, picking up discarded plastic items, thinking: “This is exactly what I need to make \_\_\_\_\_!”

I imagine oceans without islands of plastic.

I imagine manufacturers and the packaging industry stamping a number on every piece of molded plastic, so it can be easily reworked.

I imagine companies like 3M creating labels that can be easily peeled from plastic packaging, without solvents, so that every square inch of the plastic can be recycled or reformed. Let’s all work on this together!

—Jacqueline Brook, Putney, Vt.

» Reading the “Little Big Lamp” project in Volume 32, I was surprised to see pulse-width modulation (PWM) used to reduce the voltage across a string of LEDs from 12V to 10V. This approach, with ULN2003 grounding a string of three LEDs, allows adjustment of the average current and voltage but leaves peak current and voltage uncontrolled. During the pulse the LEDs will be subjected to full power supply voltage (minus 1V collector-emitter saturation voltage of the Darlington array). LED forward voltage of 3.67V (11V/3) most likely exceeds the maximum ratings of available devices. Forward current will also be excessive as a result. As a result, both longevity and power dissipation will suffer.

I would suggest that the right way to build an adjustable-brightness LED lamp is to use an adjustable switch-mode current source.

—Dmitry Teytelman, San Jose, Calif.

**AUTHOR CHARLES PLATT REPLIES:** The LEDs I recommended were rated 3.3V “typical” but their acceptable maximum is 3.6V. While the 12V DC power supply is at the upper limit after passing through the Darlington array, I felt it was acceptable, especially as many AC adapters deliver less than their rated voltage under load. The LEDs are still available from eBay’s TopBright LED Store, although the typical forward voltage has been increased to 3.4V (same maximum as before).

I think an adjustable switched-mode current source would be more expensive, so I feel PWM is an acceptable way to run these LEDs, as the heat which is a major factor in stressing the LEDs will diminish in ratio with the duty cycle.

## MAKE AMENDS

In Volume 33’s project “Panjolele: The Cake Pan Ukelele,” we advised readers to draw a chord and its perpendicular three times to find the center of a circle. It’s only necessary to draw two such perpendiculars; their intersection will mark the center. Thanks to reader Michael Nachtigal of Wesley Chapel, Fla., for the fix!

# A Meeting of the Minds

By **Ryan P. C. Lawson, Esq.**

Small Business Advocate

As a maker, you have some great ideas. You probably have some solid skills, too. You might be a welder, an electronics whiz, or a woodworker. Odds are, though, you're not all of these things. If you want to turn your ideas into a successful business, at some point you'll probably need help. For example, you may need someone to make CAD drawings of your finished product for replication or to apply for a patent. No matter what the work is, if you have someone helping you, they're performing a service. Alongside that service should be some sort of service contract.

A service contract doesn't have to be in writing. You and Bob could shake hands and agree that you'll buy Bob dinner if he quickly welds two pieces of metal together for you. If it's anything more complex than that, though, you'll want to get things in writing.

Most lawyers will tell you that you want a written contract as insurance in case anything goes wrong. A contract serves as proof of what you agreed to, and can be used as evidence in court.

But a contract can be used for something much more important: setting expectations between two people about the services to be performed. When service contracts fail, it usually stems from a lack of alignment between the people involved. Writing a good contract eliminates ambiguities and makes sure you and the other person have the same expectations from the beginning.

Think of hiring a painter. A simple contract might say, "John agrees to paint my living

room for \$200." While that is a written contract, it doesn't address who is going to buy the paint. John might think you are, and you might think that a painter comes with the paint. To solve this, you can say, "John will paint my living room for \$200 with paint and brushes that I supply." Now you both agree on who will shoulder the cost of the supplies. When writing a contract for services, think about who is supplying materials and tools.

Another critical area to consider is time. Do you care when the service gets done? If you pay someone to mow your lawn weekly, what day they mow may not be important. But if you pay someone to mill parts for you, you might need them by the end of the month. In that case, your contract should specify a time.

Of course, if you set deadlines, you have to think about consequences if they're missed. I need someone to solder a circuit board by the end of the month. If it comes in a week late, maybe I only pay half price. Or maybe I get a 2% discount for each day it's late. If you have measurements of either time or quality that you agree to in a contract, you can also specify consequences if they're not met.

A service contract should specify how someone is being paid. The two usual ways are a fixed fee for a job (or a portion of a job, such as \$5 per part) or an hourly rate for work performed. If it's hourly, make sure you both understand what's included in billable hours. Are meetings to discuss the project billable? What about time spent to correct for errors in workmanship? Make sure you both agree.

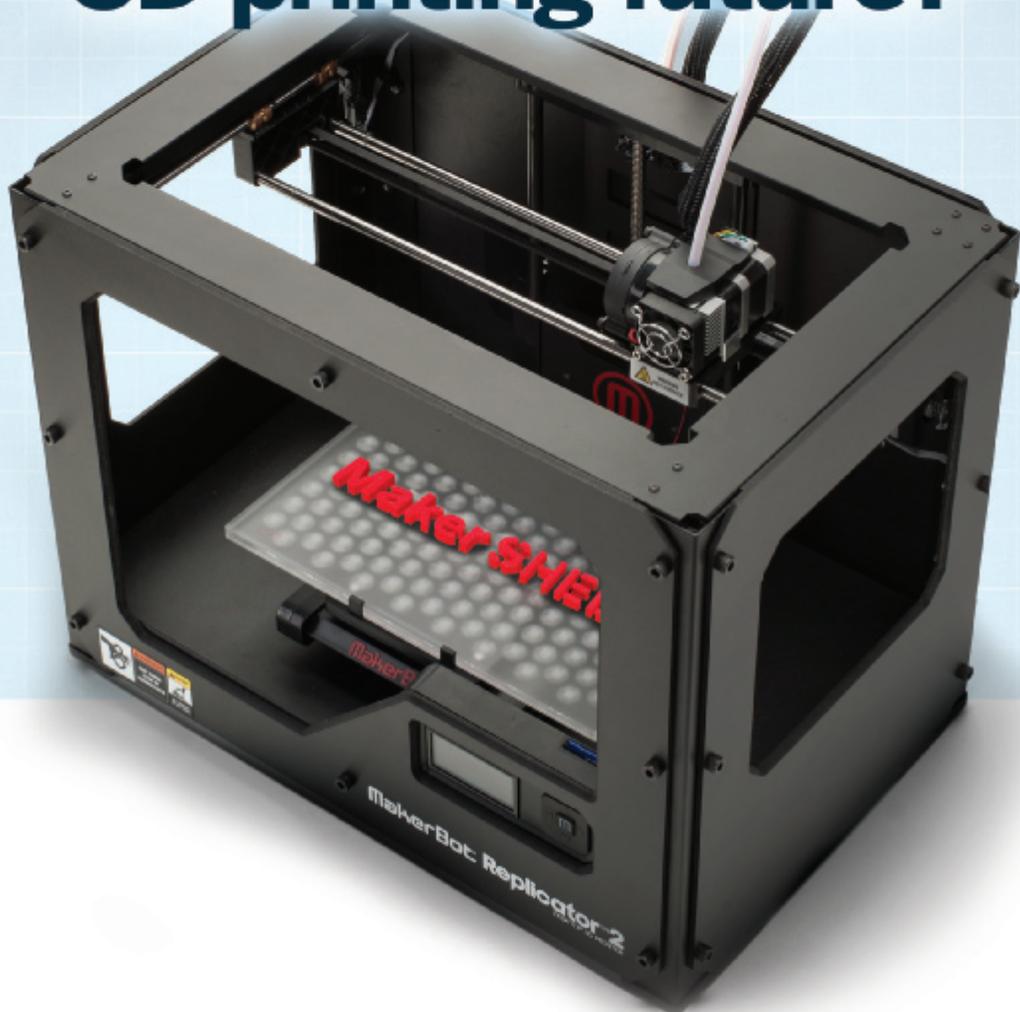
If you're being charged per job, it's critical to define what the job is. In my living room example, does it include painting the ceiling, or just the walls? Is it one coat or two? Is trim work extra? Define the work up front to make sure you're both happy with the outcome.

There are other terms you may want to include — look online for sample contracts. Crafting a well-written contract is a lot easier than you might think, and can help to avoid disagreements later. ■

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Ryan Lawson is a Michigan lawyer. His practice focuses on technology licensing and advising small businesses.

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MAKING  
TROUBLE

# Soft Robots

By Saul Griffith  
Omnivorous Inventor



Traditional robotics is doing brilliantly right now. To try and beat these guys at their game is a losing proposition, especially for people who don't have an extensive background in robotics. There are, however, wide-open fields in robotics.

The promise of the “soft” robotics work we've done to date is great. These robots are soft, compliant, and human-compatible. For wearable applications — prosthetics and exoskeletal (exodermis?) suits — and for human-safe “co-robotics” they have great applications. I'm just geeking out on the interesting design problems in this space.

I'm lucky enough to be working with a fabulous team. Peter Lynn brings just the right odd mix of background, including “soft” kite design, mechanical engineering, and thermodynamics, which helps us design in this strange new world of soft machines. The

world's first “chief seamster” is Della Shea, who builds our prototypes and wrangles ungodly bundles of PVC-coated nylon fabric into shape. We recently were lucky enough to convince Kevin Albert to come on board and teach us how to control these machines, an extremely important part of the process. He comes from experience helping the (in-) famous robot Big Dog learn to walk. Martin Wicke, Geoffrey Irving, Keith Pasko, and Ryan Alexander are helping us write the software tools to design and analyze these things.

We're still in the R&D stage of things; we've built a very slow, lumbering, air-powered robot, but the more sophisticated iterations are literally just arms strapped to a board. They're a glimpse of things to come. ▣

---

Saul Griffith is chief troublemaker at [otherlab.com](http://otherlab.com).

Arwen Griffith

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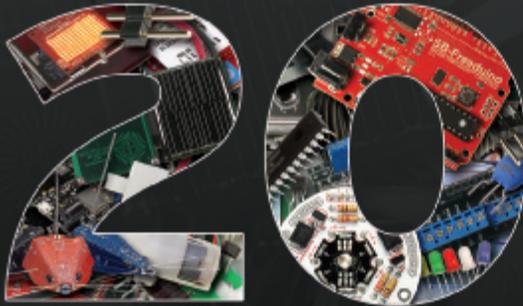
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# Tracking Our Bodies

By Syuzi Pakhchyan

Fashion Technologist

Last year, I attended my first Quantified Self meetup in Los Angeles. I was vaguely familiar with the movement — whose motto, “Self Knowledge Through Numbers,” naturally converged with my interests in big data, biosensing, and wearable technology. I had recently leaped onto the self-tracking bandwagon, logging everything from how many glasses of water I drank to how many steps I took a day.

Thanks to the recent explosion of devices such as the Nike FuelBand, Jawbone Up, and Fitbit, the ability to ubiquitously track everything from our heart rates and activity levels to sleeping patterns is becoming remarkably simple. For self-improvement, there are apps to help you track your water intake, productivity, mood swings, and fertility. There's even a digital fork, the HAPIfork, that will monitor how fast you eat. These apps and devices are the latest fitness and self-help craze that promise to help transform you to a thinner, more efficient, and sufficiently-hydrated you through daily monitoring, tracking, feedback, and social encouragement or competition.

As expected, the presentations at the QS meetup were chock-full of detailed spreadsheets and charts, revealing a resounding fetish for numbers. Curiously, as much painstaking attention was given to gathering and mapping the data, the data was also openly acknowledged as often being inaccurate or

“too noisy.” My FuelBand and Fitbit data never agree — although I never expected them to, as I wear one on my wrist and the other on my waist. If the accuracy of the data is really not that important, then what — or more importantly why — are we tracking, exactly?

Self-tracking, it turns out, much like yoga, is a “practice.” It's a practice of self-observation that leads to self-awareness and ideally some form of behavioral change or self-improvement. The apps and devices aspire to be more motivational than accurate and use social motivation as a carrot for reaching your goals.

My phone pings me when it's 3 p.m. and I've only had three glasses of water. It also winks at me and lets me know that my friend Paige is well on her way to having hydrated, supple skin. Just wearing the FuelBand is a visual reminder of the commitment I made to myself — and it does irk me when my stats are below the average in my demographic, even

when I know that the reason for my recent drop is that I kept forgetting to charge the device.

With the development of new, sophisticated biosensors, these new technologies will soon reach beyond motivating us to get off the couch and will offer us a true sense of empowerment and feeling of control over own health and body. Soon we will have instantaneous access to real-time measurements of various biomarkers including stress hormones or cardiovascular disease. Our garments will remind us to breathe when we get stressed and let us know that we're at high risk of muscle cramps because our potassium levels are dangerously low.

If this data can be translated into meaningful feedback and actions, we'll have new sets of tools for “listening” to our minds and bodies in our everyday lives in hopes of perhaps discovering something new about ourselves. What we see now is just the beginning. ▣

Syuzi Pakhchyan is a fashion technologist and author of the first DIY book on interactive fashion, *Fashioning Technology* ([fashioningtech.com](http://fashioningtech.com)).



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In December of 2005, we had published four volumes of MAKE, each chock-full of exciting projects and ideas from diverse makers. We imagined these makers would all get along famously. Then, one late night in the office, Dale Dougherty, founder of MAKE, got that familiar sparkle in his eyes, broke out in a huge smile, and said,

“Wouldn't it be cool if we could get all these makers together in one place to share what they make?”

There was no denying it was a great idea, and so Maker Faire was born.

Andrew Kelly (Diet Coke & Mentos); Branca Nitzsche (crowd); Gregory Hayes (face sculpture, MAKE booth, racing bike, soldering); Gunther Kirsch (Imperial Guard); Sabrina Merlo (mechanical hand)

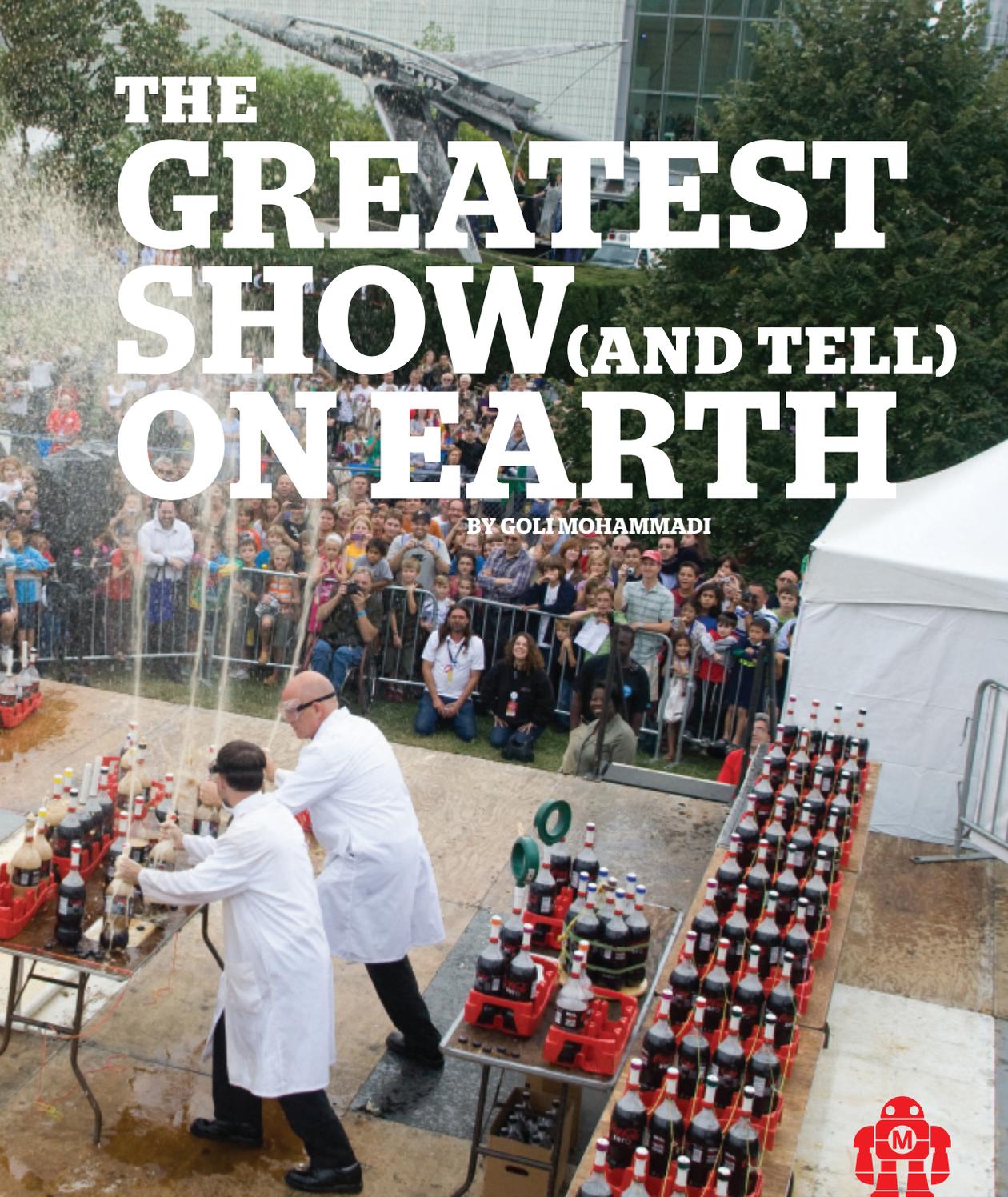
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# THE GREATEST SHOW (AND TELL) ON EARTH

BY GOLI MOHAMMADI



▼ FIRE ARTS ▼ GADGETS ▼ BALLISTICS ▼ TEXTILES ▼ BICYCLES ▼ WOODWORKING ▼ YOUNG MAKERS ▼ PHOTOGRAPHY ▼



Our first Faire took place in April of 2006 at the San Mateo Fairgrounds south of San Francisco (where we still host our annual Bay Area Faire). We had a heck of a time explaining to folks what a Maker Faire is, since no one had heard of it before. Our team bootstrapped the whole event, DIY style. That first year 100 makers proudly displayed their projects, and 20,000 folks came out to share the joy of making.

We're in our eighth year now, and Maker Faire has truly grown to become a cultural phenomenon and "The Greatest Show (and Tell) on Earth," with 61 Faires held last year. Our 2012 Bay Area Faire drew 110,000 attendees and featured 900 amazing projects and thousands of makers. And while our flag-

ship Faires are in the Bay and New York City (in September), there have been community-based, independently produced Maker Faires in Japan, Africa, Spain, Australia, China, Ireland, Chile, Israel, the U.K., and soon Italy, not to mention in countless cities across the U.S. Why?

**BECAUSE MAKING IS UNIVERSAL, AND WE ARE ALL MAKERS.**

At Maker Faire it's cool to be smart. There have been businesses founded at Maker Faire (like TechShop), hackerspaces started, startups launched, and collaborations initiated. A generation of kids is growing up at the Faire, gaining a whole new appreciation of science and engineering, making connections



with mentors, and realizing their full creative potential. These makers are our future.

What will the Faire be like 10 years from now? We can't wait to find out. We hope you'll join us at a Maker Faire this year and find out for yourself what the buzz is all about. We guarantee you'll leave inspired.

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Sam Murphy (fire arts), Mark Madeo (giraffe); Scott Beale (mousetrap); Gregory Hayes (BrollyFlock)

WE HOPE YOU'LL JOIN US  
AT A MAKER FAIRE  
THIS YEAR AND  
FIND OUT FOR YOURSELF  
WHAT THE BUZZ  
IS ALL ABOUT.

WE GUARANTEE  
YOU'LL LEAVE  
INSPIRED.

# MAKER FAIRE CALENDAR MAY-JULY

## MAKER FAIRE BAY AREA

May 18–19 San Mateo, Calif.

Our flagship Faire launches into its eighth year, promising to be the biggest and best yet, as we transform the entire San Mateo Fairgrounds into The Greatest Show (and Tell) on Earth.

[makerfaire.com](http://makerfaire.com)

## MAKER FAIRE KANSAS CITY

June 29–30 Kansas City, Mo.

Held in Union Station, Kansas City's 1914 beaux-arts train station, this growing Faire is now in its fourth year. Last year's Faire drew 10,000 attendees and featured 230 makers.

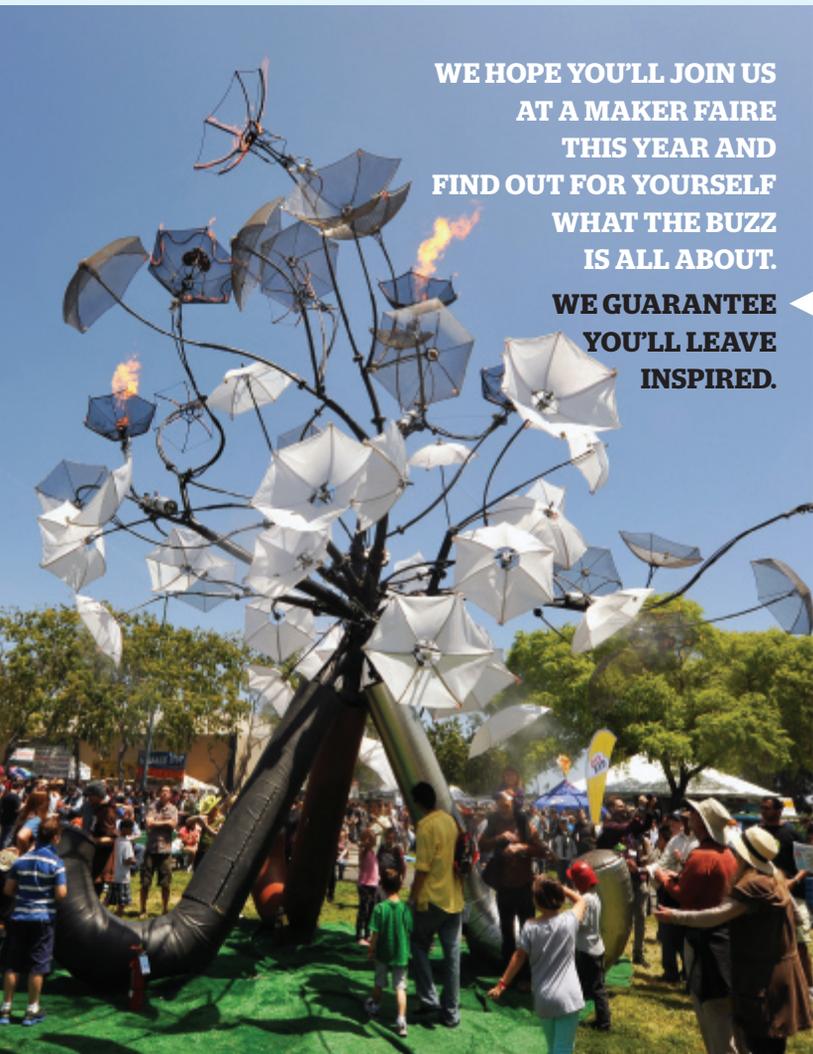
[makerfairekc.com](http://makerfairekc.com)

## MAKER FAIRE DETROIT

July 27–28 Detroit, Mich.

Also in its fourth year, Motor City's Maker Faire, hosted by the Henry Ford Museum, truly shines light on the home of American ingenuity. Midwestern makers of all stripes come together to share knowledge and inspiration.

[makerfairedetroit.com](http://makerfairedetroit.com)



▼ **MAY 5**  
Austin Mini Maker Faire  
(Texas)

▼ **MAY 11**  
San Luis Obispo Mini  
Maker Faire (Calif.)

▼ **MAY 18**  
Chicago Northside  
Mini Maker Faire (Ill.)

▼ **MAY 18-19**  
Maker Faire Taipei  
(Taiwan)

▼ **MAY 25-26**  
Boise Mini Maker Faire  
(Idaho)

▼ **JUNE 1**  
Columbia Mini Maker Faire  
(S.C.)

▼ **JUNE 1-2**  
Vancouver  
Mini Maker Faire (Canada)

▼ **JUNE 8**  
Ann Arbor Mini Maker  
Faire (Mich.)

▼ **JUNE 8-9**  
Danbury Mini Maker Faire  
(Conn.)

▼ **JUNE 8-9**  
Seattle Mini Maker Faire  
(Wash.)

▼ **JUNE 15**  
Eugene Mini Maker Faire  
(Ore.)

▼ **JUNE 15**  
Maker Faire North  
Carolina (Raleigh, N.C.)

▼ **JUNE 15**  
Waterloo Mini Maker Faire  
(Canada)

▼ **JUNE 22**  
McAllen Mini Maker Faire  
(Texas)

▼ **JULY 6**  
Elephant & Castle Mini  
Maker Faire (London, U.K.)

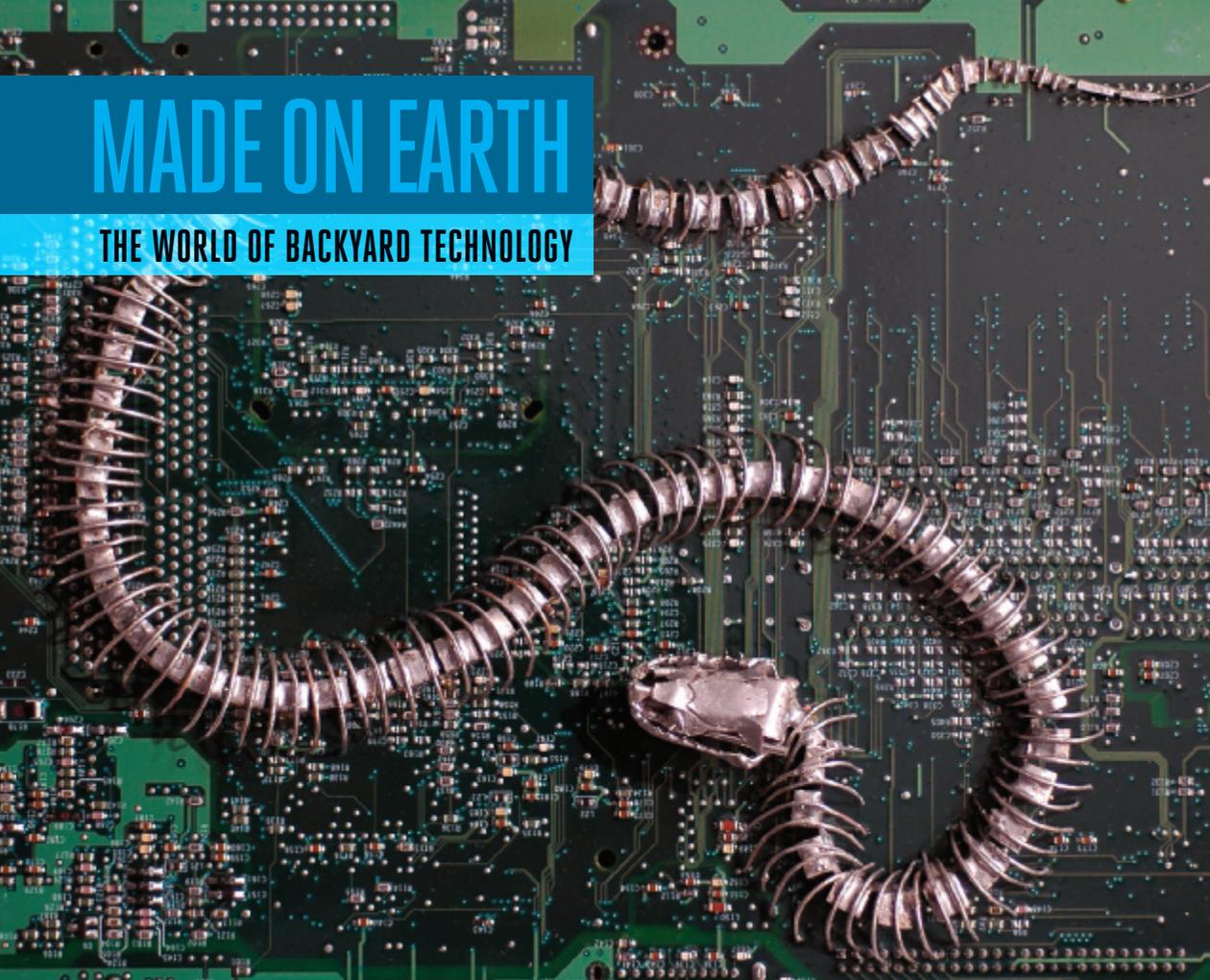
▼ **JULY 14**  
Kingsport Mini Maker  
Faire (Tenn.)

▼ **JULY 20**  
Hong Kong Mini Maker  
Faire (China)

▼ **JULY 20-21**  
Bilbao Mini Maker Faire  
(Spain)

▼ **JULY 27**  
Dublin Mini Maker Faire  
(Ireland)

▼ **JULY 27-28**  
Singapore Mini Maker  
Faire (Singapore)



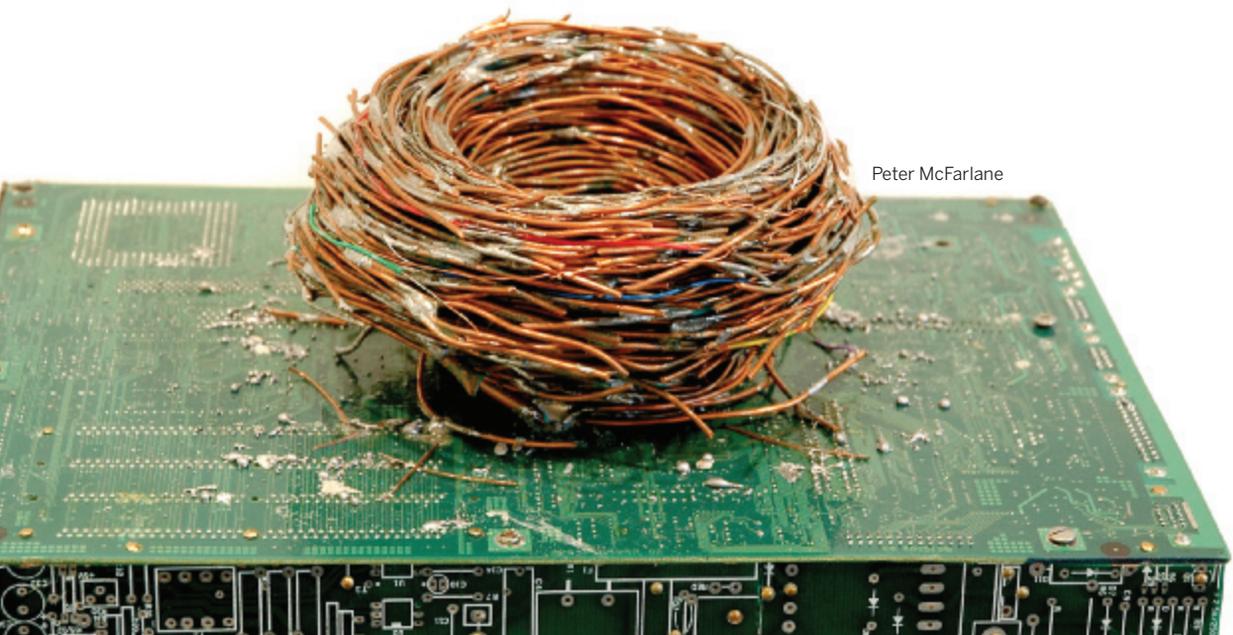
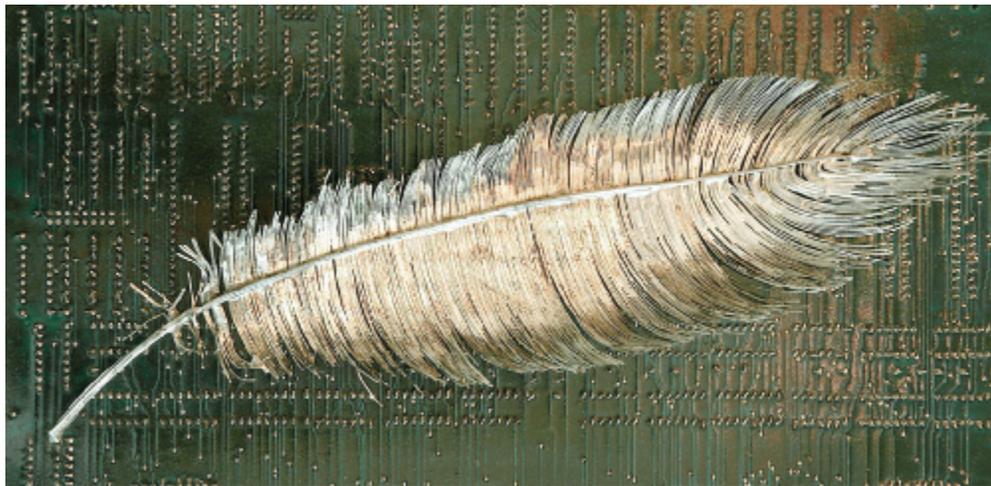
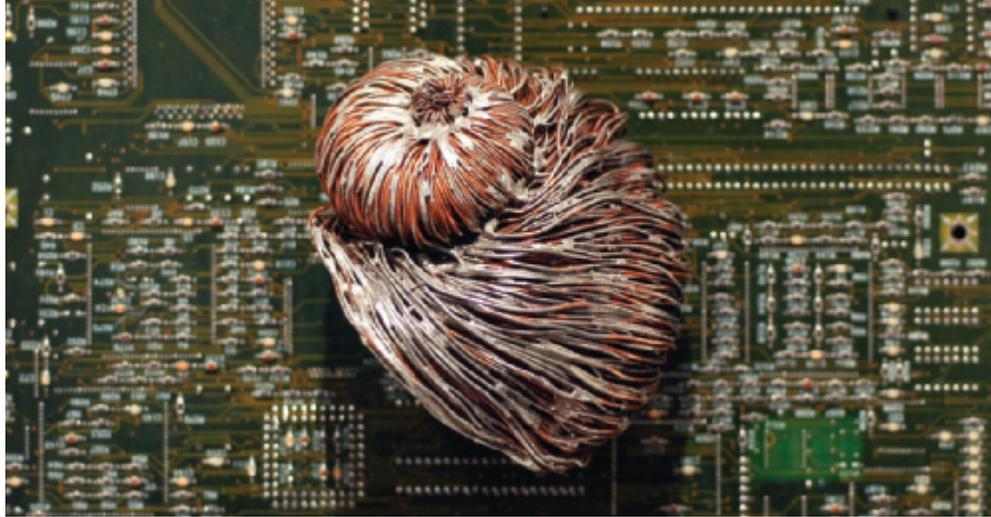
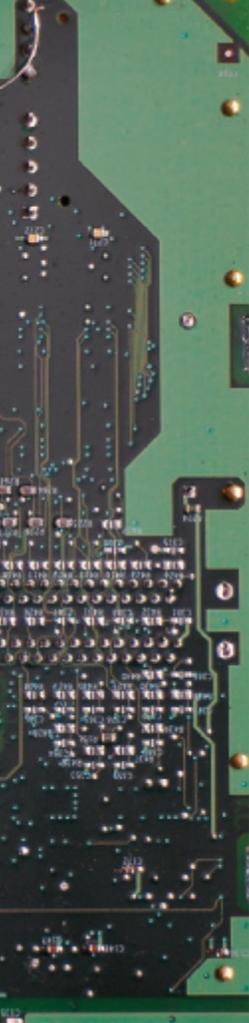
# MADE ON EARTH

## THE WORLD OF BACKYARD TECHNOLOGY

# Circuit Court of Appeals

By Goli Mohammadi [petermcfarlane.com](http://petermcfarlane.com)

While working as a computer sales consultant nearly 20 years ago, Canadian artist **Peter McFarlane** was profoundly struck by the rapid evolution of electronics and the subsequent volume of electronic waste. He was determined to give new life and meaning to these discarded parts. McFarlane re-contextualizes circuit boards into canvases masterfully overlaid with old wires and obsolete components to mimic images of nature and his surrounding environment, turning “landscrap” into landscape. He aptly states, “To me, waste is just lack of imagination.”



Peter McFarlane

# Silica Speakers

By [Laura Kiniry shawnayerst.com](http://LauraKiniryshawnayerst.com)

With his impressive *Ohm Sound* installation, glass artist **Shawn Ayerst** has both audio *and* visual stimulation down pat. The Alberta-born artist first got into glass-blowing nearly a decade ago, but it was a multiday intensive yoga workshop a few years back that gave him the idea to combine tactile art with sound.

"We were in the middle of a chant on our fifth day, and I could specifically hear the voice of one of my teachers coming from a few rows diagonally behind me," says Ayerst. "It made me think about where sound originates and how it provides energy."

Ayerst created *Ohm Sound* in 2010 while a student at Alberta College of Art & Design, using molten silica to color, blow out, and shape six cone-shaped glass speakers, which he then cooled in an annealing oven for approximately 20 hours. He next added the electrical components — including amplifiers and receivers, attached each speaker to a wood-based metal stand, and displayed them in an empty room in two widely spaced rows of three.

To fully experience Ayerst's multisensory piece, which is no longer on display, the viewers walked into the room's center, where an ultrasonic sensor triggered three different chant recordings, each with left and right individual audio designed to play at various times. "It's all about perception," says Ayerst. "When the sound starts from behind, you feel yourself pulled, and then it comes from a few feet ahead of you and your awareness is brought somewhere else. [Familiar sounds] can lift you out of your thoughts into someplace bigger."



# Playing with **FIREWALL**

By **Matt Richardson** [michaelpallison.com/firewall.html](http://michaelpallison.com/firewall.html)

**Michael Allison** and **Aaron Sherwood** are both musicians and performance artists who partnered to create *Firewall*, an interactive performance object that's made of a piece of spandex stretched across a large frame. A Kinect senses the depth and position of how the spandex is manipulated by the user, and responds with projection and music. A Processing sketch handles the fiery visuals, while a Max/MSP patch manipulates a MIDI track that plays music in concert with the user's movements.

For a final project in their physical computing class at NYU's Interactive Telecommunications Program, Sherwood wanted to work on a piece that could be used at the Tribeca Performing Arts Center, where he has a residency. "I wanted to create some sort of interactive membrane or wall that the dancers

could press into but be trapped behind," he says. "I saw an early video experiment Mike posted online of people pressing into latex and projecting on it using a Kinect. I had already been thinking I'd like to work with Mike at some point, so I suggested we team up."

Sherwood focused on the music while Allison worked on the visuals. *Firewall* "really came together when we combined both of these," says Sherwood. "All of a sudden the piece seemed like it might be something really special." They debuted *Firewall* to the public at ITP's Winter Show last December. "Watching faces light up with wonder was something I'll never forget," Allison reflects. "I live by a philosophy of positivity and optimism, and sharing that kind of joy and wonder couldn't have made me happier."



# Perhaps the Ending Has Not Yet Been Written

By **Craig Couden** [riumphus.com/mystbook](http://riumphus.com/mystbook)

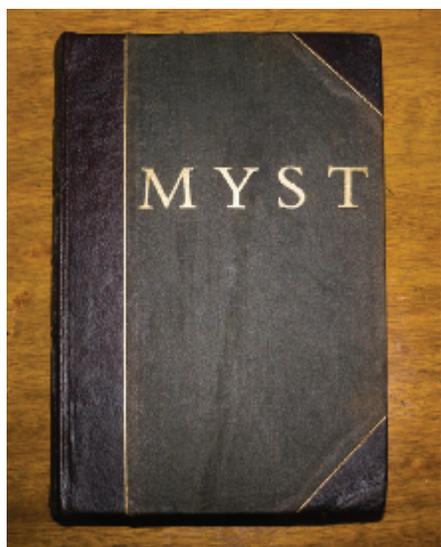
Like many PC owners in the 90s, I loved the point-and-click adventure game *Myst*. The rich mythology behind the sparse but intriguing narrative kept me hooked, even as I glared at the screen for hours to solve the often-inscrutable puzzles. So imagine my excitement when I saw **Mike Ando's** gorgeous recreation of a *Myst* linking book, which, in the game, teleported characters to other worlds.

"The *Myst* series means a lot to me," Ando says. "I've created a couple other pieces of *Myst* fan art over the years, and I wanted to make something truly epic."

Ando, of Coorparoo, Australia, recreated the window-like aesthetic of the books in the game using a 5-inch LED-backlit touchscreen connected to a fully working PC that's smaller than most laptops and fits inside the book. Every *Myst* game is playable, along with some familiar videos from the series.

Matching the look and feel of the book was also a key factor. After seeing the original copy of *Harper's New Monthly Magazine* that was used by the game's creators as a texture reference during a fan convention, Ando settled on a 135-year-old copy of the same book as the closest usable match. While it might sound like a waste to gut an old book, he notes that interior designers buy them in bulk for the aesthetics of the spines, not the content. His book "is basically a cross between a *Reader's Digest* and a gossip magazine, and many of the articles are incomplete."

While the specs are impressive, it's Ando's dedication to detail that makes the project so striking. "A couple people had created replica *Myst* books by inserting a picture frame inside an old book, and these look great, but I thought I could do a better job. What can I say? I have high standards."



# TIMBER TOPPER

By [Jason Babler](#)



I met **Carl Stoner** at Maker Faire New York, where he was a volunteer. Actually, I met his wooden hat first, as I was enamored with the idea of a wooden hat that actually looked comfortable to wear.

To create one of these stiff-brimmed beauties, Sharon Springs, N.Y.-based Stoner uses a freshly cut 18"-diameter log, and when he starts turning, he doesn't stop until it's finished — usually within a few hours. The wet wood is shaped to about  $\frac{3}{32}$ ", and on the lathe the water is spun out from the thin areas. He has to ensure that the wood is completely even, or it will crack. After sanding, he puts it in a press to give it its oblong shape, using large rubber bands to get the curve in the brim. Sanding is followed by a polyurethane finish, and just like that, another handsome hat is hewn.

Carl Stoner



**FOUNDERS:** (Left to right) Alan Rorie, Nemo Gould, Christopher T. Palmer, and Jeremy Mayer.

# The SMART GALLERY

Written by Goli Mohammadi ● Photography by Gregory Hayes

## HOW THE ARTISTS OF OAKLAND'S LOST AND FOUNDRY ARE PAVING THEIR OWN PATH AWAY FROM CONVENTION.

At the end of the 300 block of Center Street in Oakland, Calif., otherwise sparsely lined with drab residential houses, sits the shell of the old Lehnus iron foundry. Once alive with production, times changed and the building sat uninhabited for years. Today, behind the industrial roll-up steel doors and wrought iron fencing lays the unexpected: the beginnings of a powerful paradigm shift in the art world.

Upon entering the Lost and Foundry, you're greeted by a large, clean, open gallery space, high ceilings accented by massive wood beams. The room is tastefully arranged with a variety of intriguing sculptures made by the seasoned, professional artists who cofounded the collective. One of Jeremy Mayer's life-sized busts peers forward curiously, made entirely of dry-fit typewriter parts (page 35). To its left, Nemo Gould's eight-and-a-half-foot tall kinetic sci-fi creature pulses with a Jacob's ladder in its head. Nearby, Alan Rorie's mini-submarine-like steel and glass *Neuron Chamber* (page 39) traces a replica of our neural pathways in electricity. Mounted on one wall, a newly finished interactive piece by Christopher T. Palmer (CTP) illuminates a reel of vintage film (page 32). But unlike most galleries, behind these walls are the studios of the artists whose work is on display.

There's magic to seeing an artist's workshop, pieces of a next project beginning to take form,

but typically making the art and exhibiting and selling it aren't done in the same place, or even by the same people. Traditionally, in the professional art world, an artist is represented by a gallery, who offers "four white walls, crackers, boxed wine, and a mailing list of people you never get to interact with," says Gould. In return, the gallery takes 50% of an artist's sales. While this standard may have been the best (or only) way for decades, in this age of the internet, the model is shifting. The artists at the Lost and Foundry are out to re-create the gallery model on their own terms, by doing it themselves.

Mayer argues that today, with the pressures to be well represented online, most galleries can't handle the full social networking needs of the artists they represent. In addition, the face of the new art collector is changing; many of the Lost and Foundry artists' clients aren't comfortable in a traditional highbrow gallery setting. The alternative is for artists to create their own collective gallery and represent themselves, combining their networks to grow their clientele.

Seems simple enough, but the resistance to this notion is decades strong. Even the most logical paradigm shift is inherently up against convention and history. Paradoxically, the biggest opponents to artists self-representing are often other artists (some naturally entrenched in galleries) and even traditional art schools that teach that artists make art, while showing and conducting the business

of art should be left to the galleries. Gould adds, "Making art is the point. Selling art is the unfortunate secondary aspect, but if you want to afford to do another piece you have to think of a way to make money."

Until now, artists haven't coalesced to a point where they can effectively press back against convention and affect change to the system as a whole. But the Lost and Foundry artists propose that if enough artists self-represent, the standard 50% cut that galleries take begins to fade as the norm. Galleries thrive on owning the discourse and the clientele, but are they the best equipped to do it anymore?

And with so much of art representation and sales happening exclusively online, why even have a physical space? Why not buck the gallery as a whole and conduct all business online? That's certainly an option, especially considering the Lost and Foundry artists get a great deal of exposure online, and many of their sales and commissions originate on the internet. But to the members of the collective, as an artist, if you produce and sell exclusively online, you're up against "a comfortable irrelevance."

They hold that a work of art is not actually complete until others physically interact with it, and until then it's missing the vital element of art culture. Gould adds, "Art has to get talked about, and become part of the story of the art and the artist." And there's no substitute for real-time, physical interaction. Even with the most visually well-documented piece, when viewed exclusively online, details are missed; the web makes things artificially perfect. And perhaps most important to the physical gallery experience is watching someone else react to a work and recognizing yourself in the reaction or not. •



## START OF A COLLECTIVE



**MAYER, GOULD, RORIE, AND PALMER** share a lifelong maker mindset and an appreciation for collaboration. Back in 2007, Gould, Palmer, Rorie, and Reuben Margolin exhibited at the second annual Maker Faire Bay Area, under the moniker Applied Kinetic Arts (AKA), a tongue-in-cheek name that originated when they were filling out the entry form. They've exhibited at every Bay Area Maker Faire since, joined by Mayer a few years ago, and the way they transform a corner of the Faire into a miniature gallery is always impressive.

Equally notable is the collective's signature abundance of camaraderie and lack of pretension. Gould said in a 2010 interview, "AKA started out as a way to share the burden of exhibiting at large venues, but it has really evolved into something much more meaningful ... By focusing on the things we have in common it becomes clear that we are all part of something bigger than our individual studios. We have a contemporary art movement on our hands, and by banding together we strengthen our case with the public and the art world at large."

Then, as fate would have it, roughly two years



**IN THE EYE OF THE BEHOLDER:**

(Clockwise from this page) Nemo Gould's kinetic *Minotaur*, pictured with the artist wearing one of his custom masks; Jeremy Mayer's *Deer III* typewriter assemblage; Alan Rorie's *Triaparator* kinetic brass apertures.

space to the left of the main room (the gallery). His massive worktable was soon covered in the organized chaos of infinite salvaged typewriter components, surrounded with floor-to-ceiling shelves bearing neatly stacked typewriter carcasses and typewriter cases full of catalogued parts. A big screen often displays an anatomy app, focused on the part of the body he's working to re-create.

A year later, Gould was looking to move his workshop and decided to join Mayer in the foundry. Because he's a found-object artist, much of Gould's time is spent salvaging materials and building his vast stockpile. Moving into the spacious Lost and Foundry allowed him to weed and organize in a logical manner. His studio

inhabits a large room to the right of the gallery, full of labeled bins, drawers, and wall-sized shelving bearing all manner of reclaimed materials, large and small. He believes he has more artistic freedom in this type of space: "I want the right to make something that's truly inconvenient to everyone, works a gallery won't show."

When MAKE photo editor Greg Hayes and I first began researching the Lost and Foundry at the end of 2012, only Mayer and Gould had fully established their studios, and the main gallery was a work in

**"I WANT THE RIGHT TO MAKE SOMETHING THAT'S TRULY INCONVENIENT TO EVERYONE, WORKS A GALLERY WON'T SHOW."**

Nemo Gould (*Minotaur*); Alan Rorie (*Triaparator*)

ago, Mayer met Brad Peik, owner of the old Lehnus foundry building. Having an affinity for old buildings and shops, Peik had purchased the foundry roughly five years prior. Dismayed at how buildings with rich history are so often abandoned or torn down in lieu of box stores, he was interested in honoring the years the structure had housed a workspace where people made things with their hands. Peik was ready to accommodate the right group of artists.

Mayer moved his workshop into a mid-sized

progress. By our second visit, Rorie and Palmer had also joined the collective and moved their studios in. Rorie previously had a workshop at St. Louise Studios, an industrial arts space in Oakland. While that space was functional for creating art, it lacked access to a clean, clear space to display and photograph finished pieces, as well as meet with clients and teach private classes. Now Rorie's studio is set up in the room directly behind the gallery, his full-sized CNC mill front and center, and pieces of his latest custom Voronoi bookshelf waiting to be assembled. Palmer shares Rorie's workshop as well as the adjacent large shipping container. The enclosed space is perfect for Palmer because much of what he does, in both art and teaching, involves electronics, and his studio has become somewhat of an electronics "clean room" insulated from the sawdust.

Just as Peik sought artisans who make by hand, the artists were equally drawn to the building's history, undeniable character, and raw, malleable quality. To work in a building that can be customized to house workspaces, a permanent gallery of finished works, and a professional meeting area is something all the members were seeking. As of this writing, they've managed to make it a reality, and are looking to grow it even more. The collective was recently joined by Jeff Hantman, who works primarily in wood and paper, Matt Feeney, creator of Pass & Stow handmade bike racks, and Benjamin Carpenter, interactive artist, fabricator, and teacher. And while all of the artists have a common thread in their works, the selective inclusion of these artists forms a creative harmony, where they all inspire one another and help grow the clientele without turf issues in style.

Of course, swimming against the stream is never without its challenges. Being represented by a gallery would certainly be easier in a lot of ways, but

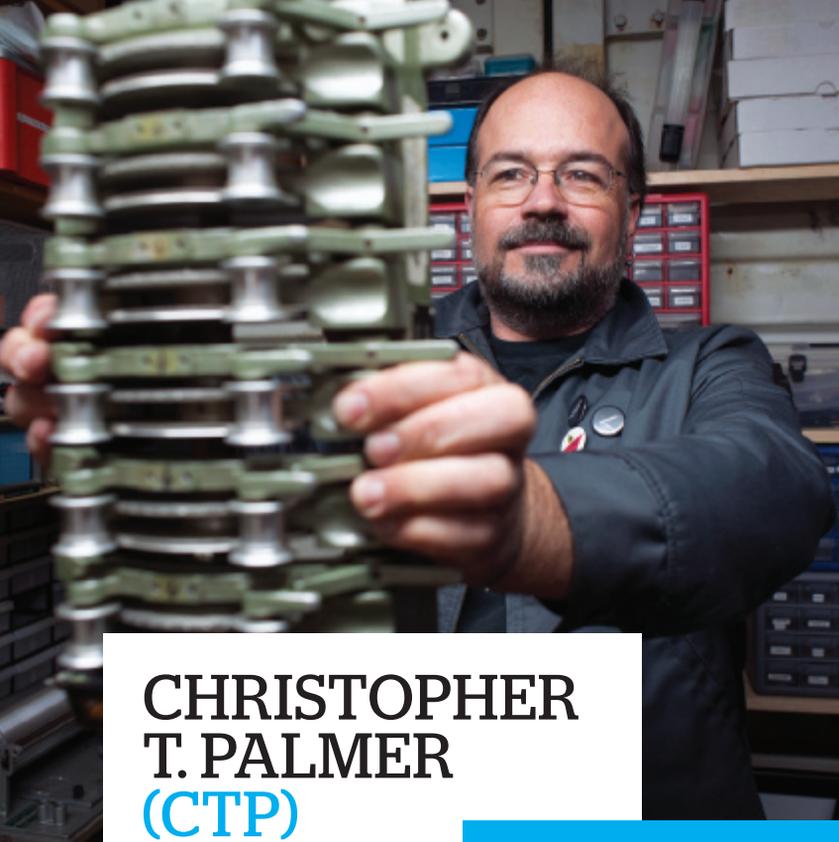


**"WE HAVE A CONTEMPORARY ART MOVEMENT ON OUR HANDS, AND BY BANDING TOGETHER WE STRENGTHEN OUR CASE WITH THE PUBLIC AND THE ART WORLD AT LARGE."**



CTP's *Your Lucky Numbers* sculpture;  
Gould's Honda CX500 *Cachet Racer*;  
Mayer's *Mayuko's Damselfly*.

it would require ignoring the benefits of self-representation. We've yet to see if the example they set will ripple out through the art world effecting large-scale change, but if the palpable buzz of the crowd at their first large gallery opening is an indicator, they're certainly making waves. •



## CHRISTOPHER T. PALMER (CTP)

### ARTIST AND EDUCATOR CHRISTOPHER T. PALMER

is rarely called by his full name. Everyone knows him as CTP, and he's the crowned "Fairy Tech Father" of the collective for the electronics knowledge he brings. As an artist, he most enjoys collaborative work; he's an active member of Five Ton Crane and has worked with the Flux Foundation and the Flaming Lotus Girls.

Raised in a house full of art and books, CTP was taught early on to value creativity and encouraged to create. His father, now retired, was a machinist and instrument technician, so he was also introduced to machine tools at a young age. With this upbringing, it's no wonder CTP proficiently straddles art and tech.

Upon finishing his undergrad in photography and visual communication, he launched his own business, CTP Design and Creation, which he's now had for 23 years. His specialty is "arts engineering,"



"I LIKE TO OPEN SOURCE  
MY BRAIN."

private classes at the Lost and Foundry, teaching intros to soldering, electronics, LEDs, and Arduino, in addition to a class he calls "Beginning Electricity for the Intermediate," aimed at helping established makers gain a better understanding of electricity.

In his infinite spare time, he's the Chief Snark Officer at his Snarky McF Button Company, he's director of technology for a non-profit community service organization, and he's working on a new book for MAKE titled *Make: Machines and Mechanisms*. • [ctpdesign.com](http://ctpdesign.com)

CTP holds the newly salvaged 16mm film synchronizer that he transformed into his *Your Lucky Numbers* sculpture. Below, his *Breatalyzer Genie* on display at Roboexotica in Vienna.

a term he coined to describe the consulting and fabrication he's done for other artists. "Since I have my foot in both sides, I can help them realize their vision, without trying to add myself into it, or change it significantly." While he took commissioned work for years, he generally doesn't anymore, preferring to teach clients to make it themselves. "If they just want it made and handed over to them, then I'm probably not the guy to come to."

CTP spent 11 years teaching at Oakland's industrial arts school, The Crucible, heading the Kinetics and Electronics department for a spell. Among the classes he taught were Electronics for Artists, Demystifying the LED, Microcontrollers for Artists, and Kinetic Sculpture. For the past seven years, he's been on the faculty of the San Francisco Art Institute, teaching three courses: Intro and Intermediate Activating Objects and Active Wearable Objects. He now offers pri-

# JEREMY MAYER

**SCULPTOR JEREMY MAYER** still remembers the first typewriter he typed on, at the young age of 10 in rural Minnesota. He would spend hours peering into his family's 1920s Underwood #5, imagining himself inside the tiny mechanical city, reminiscent of Fritz Lang's *Metropolis*. He also dreamed of disassembling it, but that was not an option.

Mayer began selling his drawings at the age of 14, but it wasn't until 1994, when he was 22, that he got into making his signature typewriter assemblages. He was living in Fairfield, Iowa, working under a few different artists, doing everything from package design to stained glass to casting anatomical models and Hindu deities, picking up new skills along the way. With no formal art education, Mayer learned strictly by doing.

Then one fated day, he was handed an Olivetti Lettera 32 typewriter and asked to deliver it to the thrift store. Naturally, instead he "scratched a decade-long itch" and took it completely apart, much the same way he does today, sitting cross-legged on the floor with an array of screwdrivers and pliers at the ready. Mayer was struck by how the pieces seemed a perfect blend between his old Erector set parts and the "techno-Baroque" drawings he was doing at the time. His first assemblage was a little dog, which was politely dismissed by the artists he worked with.

Knowing he could do better, Mayer started collecting and disassembling castoff typewriters in earnest. Today, 19 years later, he is



"I DESTROY TYPEWRITERS.  
I VERY GENTLY KILL THEM UNTIL  
ALL THAT REMAINS IS A PILE ON THE  
FLOOR AND A CAST-IRON CARCASS  
IN MY HANDS. I EVISCERATE THEM."



Jeremy Mayer works on a commissioned portrait in his studio. (Below) *Bust V (Grandfather)*, a self portrait; (opposite) *Nude* is life sized.

a master of his trade, seamlessly assembling typewriter components into amazingly expressive full-sized, anatomically correct human figures, insects, and animals. A diehard purist, he prides himself on a process of entirely cold assembly: no solder, no glue, no welds, no wire, no parts foreign to a typewriter, rules he set for himself early on. An astounding amount of work goes into each piece: *Nude IV (Delilah)*, for instance, took 1,200 hours, contains parts from 40 typewriters, and is 6'4" standing up.

Mayer claims the inherent relationship between typewriters and the human form is what facilitates his art. The width and size of the typewriter were designed to be directly proportional to our anatomy. Further, the look and process of the keys mirrors the process of the fingers that push them. In fact, an intact typewriter looks like a face all by itself, he says: "a menacing creature with a toothy grin." •

[jeremymayer.com](http://jeremymayer.com)



Jeremy Mayer (*Grandfather*); Kate Watts (*Nude*)



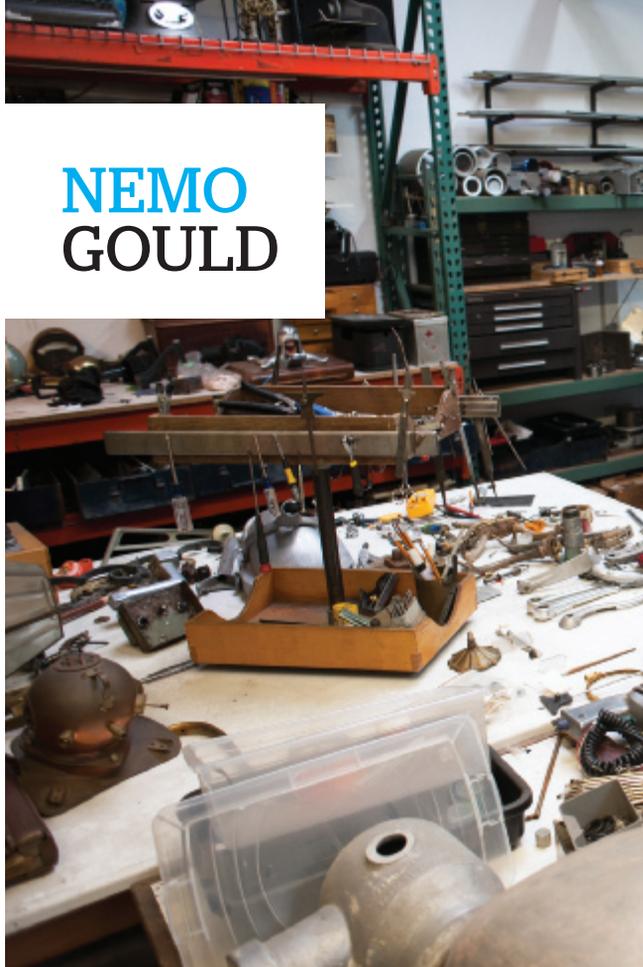
**FOUND-OBJECT FINE ARTIST NEMO GOULD**

professes, “I take silly very seriously.” So seriously, in fact, that a look at his portfolio will deeply challenge any preconceived notion of what art made from salvaged materials can look like. He is a master of creating kinetic sculptures that bear clean, polished lines, exhibit fluid motion, and evoke a genuine, child-like sense of wonder and surprise.

Raised by artist parents, Gould’s creative talents were fostered from a young age. He’s also had a lifelong obsession with collecting and dismantling anything with moving parts and remembers his mother bringing him along on a trip to the dump when he was no older than 7; he told her he wanted to work there when he grew up.

Gould took the unwavering path through a full art education, earning his BFA, then proceeding directly on to an MFA from the University of California Berkeley. In 2000, he was “finally released into the realm of free will” and has been fine-tuning his signature style since, making a living as an independent and internationally recognized artist for the past 13 years. Gould values his MFA program for having taught him discipline through total immersion: 10-hour days in the studio, surrounded by an ecosystem that valued art.

His love of science fiction and comic books first led him to pursue becoming an animator, but when he learned how tedious the work can be, Gould conclud-



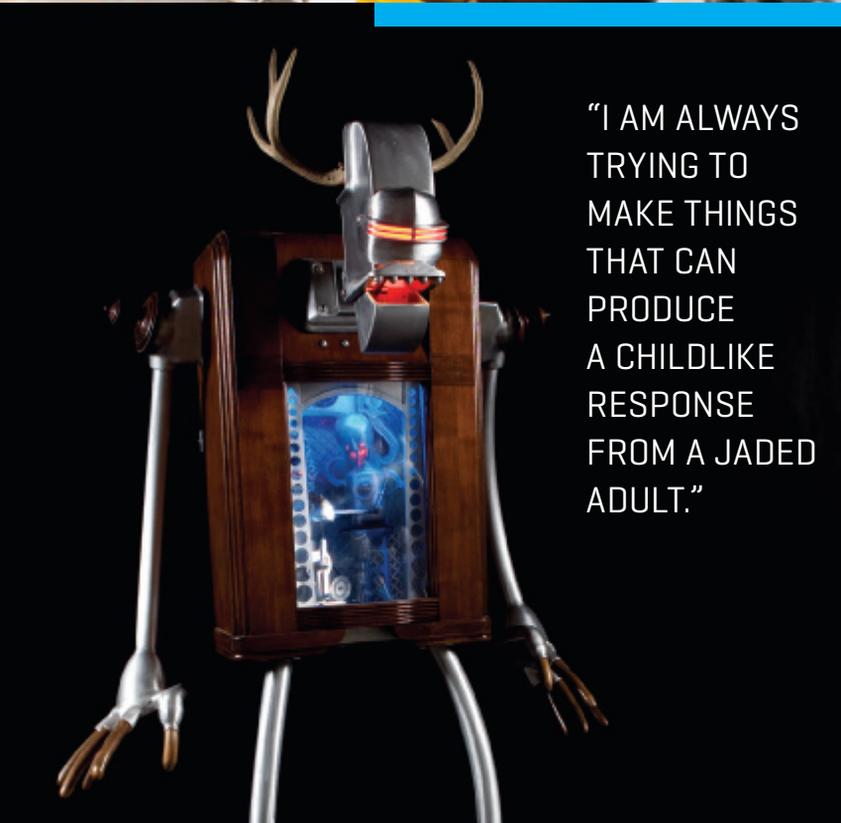
**NEMO GOULD**

ed that the challenges of making things move on their own were easier for him to overcome than the patience required to make things seem to move on film, so he began making kinetic sculptures.

Gould spends a lot of time salvaging for materials, with Leatherman, multi-head screwdriver, and Allen wrenches on hand, letting the objects he finds inspire the sculptures he creates. He says, “A ‘found object’ is just a familiar thing seen as though for the first time.” He is the re-animator, seamlessly transforming mundane castoffs into fantastical creatures from a parallel universe. An ordinary old garlic press becomes the animated cosmonaut of a perfectly polished miniature spaceship. “What makes a thing fascinating is to not completely know it,” he says. “It is this gap in our understanding that the imagination uses as its canvas.” •

[nemogould.com](http://nemogould.com)

Nemo Gould (all but workshop)



“I AM ALWAYS TRYING TO MAKE THINGS THAT CAN PRODUCE A CHILDLIKE RESPONSE FROM A JADED ADULT.”

Nemo Gould in his workshop, making magic. The clean lines of Gould's kinetic works (clockwise from top) *In the Forest*, *Catmonkey*, *Colonel Ostomy*, *Little Big Man*, and *Congonaut* defy expectations of what found-object art can look like.



# ALAN RORIE

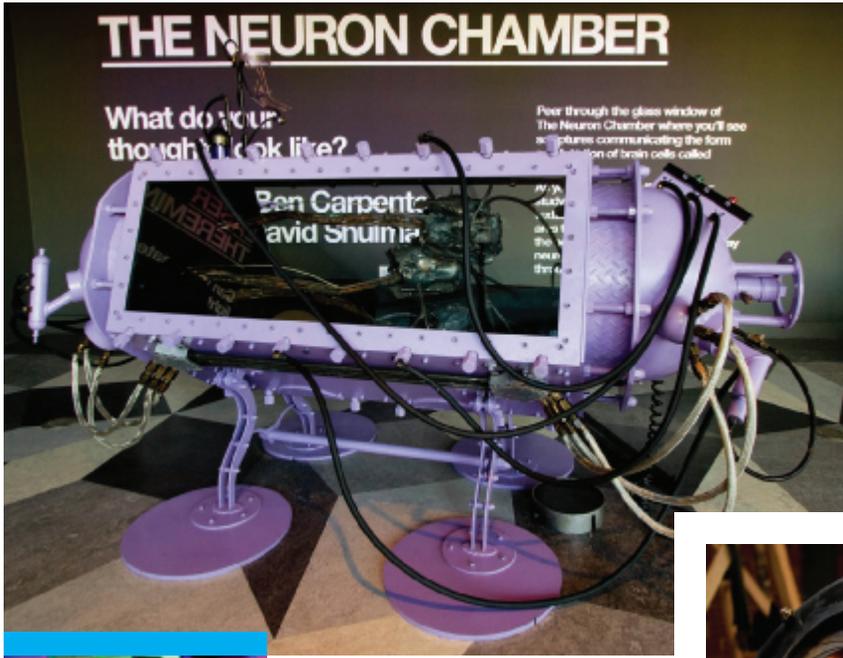
## MULTIMEDIA ARTIST AND FABRICATOR

**ALAN RORIE** is not only skilled in a multitude of tools, he also holds a Ph.D. in neuroscience from Stanford. Though he was genuinely passionate about his doctoral research, his dissatisfaction with how abstract and removed from the physical world it was inspired him to delve into making things. Through the Burning Man community, he met Bay Area artists doing amazing metalwork, so with his research grant for tools, he opted to buy welding equipment and slowly taught himself how to weld.

Rorie was instantly drawn to the inherent challenges of kinetic art for its seamless blending of engineering and design. He began collaborating and co-founded Oakland-based art collective Five Ton Crane. His first kinetic piece was a set of three fully functional brass apertures, called *The Triaparator* (page 30), for the mammoth 40-foot *Steampunk Tree House* installation. Rorie says that what he learned most from

“LESS THINK, MORE BUILD.”





the Ph.D. program is how to discover, observe, and troubleshoot.

Simultaneously, in 2007, he launched his own art and science hybrid business, aptly named Almost Scientific. The

name arose from comments he received on how his method of working was “very scientific,” to which he replied, “I know how science works. This isn’t scientific, it’s almost scientific.” A year later, upon earning his Ph.D., he became a post-doctoral fellow at the Exploratorium, where he developed hands-on methods for teaching science. Over the years, he’s produced a number of kinetic, interactive pieces, like *The Neuron Chamber*, a massive, submarine-like steel and glass structure that demonstrates the firing of neurons in the human brain.

His newest venture, launched in 2012, is Hero Design, where he brings clients’ visions to life through custom design and fabrication. Rorie has made projects as unique as the StampMobile, commissioned by Ben Cohen (co-founder of Ben and Jerry’s ice cream), an enormous, mobile, Rube-Goldberg-like sculpture that stamps actual dollar bills with political messages. Though Rorie’s tool of choice is his full-sized CNC mill, in the

course of eight years he’s become well versed in everything from CAD design to metalworking to programming, and offers a complete array of private maker classes in his studio, teaching “tools your grandfather used and your grandchildren will use.” • [almostscientific.com](http://almostscientific.com) • [hero-design.com](http://hero-design.com)

Two views of Rorie’s *The Neuron Chamber* and his *Aperture Lamp*. (Opposite) Rorie working on the *StampMobile* and *The Uira Engine*, which creates lightning, on display at the Sonoma County Museum.



# Modern STRING DUET

Written and  
photographed by  
Gregory Hayes

***Make: Believe*** talks puppetry and 3D printing with Images in Motion.

**Kamela Portugues** and **Lee Armstrong** have been making puppets and performing together for over 25 years. Armstrong, who'd gotten her big puppetry break on Jim Henson's *Fraggle Rock*, met talented sculptor Portugues at a puppet festival; the two soon combined their talents to create their Sonoma, Calif., studio, Images in Motion. Since then, they've been steadily producing TV shows, commercials, and live performances, as well as lending their expertise to major studios and toy companies. Perhaps most memorably, you may have seen their marionettes in the movie *Being John Malkovich*; director Spike Jonze sought Portugues specifically after seeing the line of celebrity toys she'd sculpted.

Watch Portugues and Armstrong's puppets in motion in the upcoming episode of our *Make: Believe* video series, and learn how they keep the ancient art of puppetry current with an infusion of 3D printing technology. Then, stay tuned for a behind-the-scenes look at stop-motion animation, and visit the *Make: Believe* page for effects tutorials and even more ways to blur the line between dreams and reality. [makezine.com/go/believe](http://makezine.com/go/believe)

Besides wrangling MAKE photography, Gregory Hayes helps produce *Make: Believe*.



1. Portugues' analog sculpting station.
2. Portugues at her digital sculpting station, working in Maya.
3. Portugues takes the John Cusack marionette from *Being John Malkovich* out for a spin.
4. Armstrong and Portugues pose with a small selection of their creations.
5. Portugues and Armstrong demonstrate a smoke-breathing dragon puppet.
6. A 3D-printed skull replica commissioned by Paleomill, made from an on-site scan from the Black Hills Institute.





# By **Tim Heffernan** Ironwood

**One of the world's great engineering materials grows on trees.**

A simple shed up a gravel drive off a country road in rural Virginia is not where you'd expect to find the world's largest stockpile of one of the great engineering materials. But find it there you will. The material is a tropical hardwood called lignum vitae (*LIG-num VYE-tee*). And the stockpile is the property and passion of a man named Bob Shortridge.

Shortridge is an expert timber framer — he's the founder of Dreaming Creek timber frame homes — and for years, he used an old lignum vitae mallet to carve mortises and tenons in heavy oak beams. "You don't want to be tap-tap-tapping on your chisel all day," he said, and the lignum mallet had a heft that lighter plastic mallets couldn't match. But the mallet was stolen, and he was unable to find a ready-made replacement, or even the raw material to make one himself. He got curious. What made lignum vitae work so well? And why couldn't he get any?

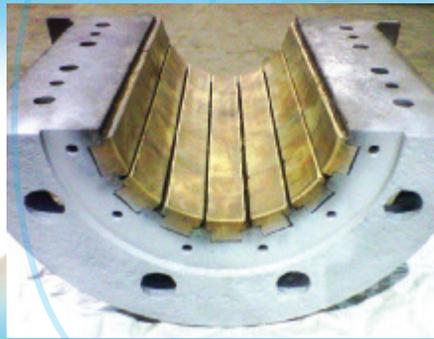
Lignum vitae is the wood of two closely related species, *Guaiaicum officinale* and *Guaiaicum sanctum*, native to the Caribbean islands and the arc of coast from the Yucatan through northern Brazil. They grow slowly and crookedly and don't reach much more than

40 feet in height and 2 feet in diameter.

The name is Latin for "wood of life," and comes from its adoption by late Renaissance Europeans as a kind of panacea. Filled with fragrant resins and oils, the heavenly scent was thought to be good for the earthly spirit and fleshly ailments. A 1540 pamphlet was entitled *Of the Vwood Called Guaiaicum, That Healeth the Frenche Pockes, and Also Helpeth the Goute in the Feete, the Stone, Palsey, Lepre, Dropsy, Fallynge Euyll, and Other Diseses*.

But it was lignum vitae's physical properties that brought it into widespread use. It's one of the so-called ironwoods, 20 or so species (mostly tropical) renowned for the strength, durability, and density of their timber. Most ironwoods have specific gravities greater than 1: put them in water and they sink.

Lignum vitae is considered the toughest, strongest, and heaviest of them all. And its copious resins and oils render it virtually pest-proof, almost immortal in both fresh and salt water, and naturally self-lubricating. And so it quickly became the high-strength stainless steel of the Age of Sail, used to make blocks and deadeyes for tensioning masts and sails, fids (oversized marlinspikes) for splicing ropes,



Lignum vitae stern tube bearings were used by the U.S. Navy.

and the pinions and bearings of the rudders. For two centuries, if it was vital to the working of a sailing ship and had to last, it was made of lignum vitae.

But amazingly, the wood continued to be vital long after sailing became obsolete. It turned out to be an ideal material for the thrust blocks and bearings needed to support propeller shafts: it can handle enormous axial loads, needs no oiling, and uses the water itself as coolant. Right through World War II, navy ships and even submarines relied on lignum bearings. The engineers of two of the largest icebreakers ever built, the U.S. Coast Guard's 13,500-ton *Polar Star* and *Polar Sea*, mounted the ships' triple screws on lignum. And the massive turbines of many older hydroelectric plants rest on it, as well.

In the second half of the 20th century, artificial bearings largely replaced lignum vitae. Shortridge built his stockpile because he wants to bring it back. He's a lifelong, pragmatic conservationist. One reason he got into timber framing was to create a more valuable, sustainable market for mature white oak, which was being clear-cut just to make cheap, one-time-use pallets. And lignum is

non-polluting, unlike metal bearings, which leak oil; natural and non-toxic, unlike the exotic materials used to make synthetic bearings; and renewable.

For years, Shortridge had to track down and buy up old stocks of lignum lumber, because *Guaiaacum* had been virtually wiped out across its original range. But recently, he discovered an area in Central America where a healthy, self-sustaining population still grows. (He declines to specify where, worried that doing so would endanger them.) He has secured harvesting rights and implemented a forestry plan that takes only a fraction of the mature trees, and renders all harvested areas off-limits to further cutting for decades. His new venture, Lignum Vitae Bearings, is supplying brand new parts to shipbuilders, hydro plants, and other industries. Just like the originals, they'll last 50, 60, even 70 years before needing replacement. It's not a business that'll ever rely on high-volume sales — but it's one that's built to last. ■

Tim Heffernan writes about heavy industry and the natural world. He lives in New York.

# Solar OBSERVATORY

A



How I fashioned a low-tech setup to record the sun's movement.

By **Craig Van Horn**

Originally, I just wanted to make a fancy sundial. My idea was that instead of projecting a shadow on the dial face, I would set up a lens and project a bright circular image of the sun instead. Also, I wanted the dial face to be big, so the lens had to have a long focal length. I wanted to follow the sun during the winter months when its path tracks lowest and closest to the horizon, and to have enough accuracy to see the daily change in its altitude as the days got shorter, then longer again starting around December 22.

My house has a south-facing deck, and the roof there is supported by a post, which made for a convenient place to mount the lens. I calculated that a 4-meter focal length would focus the image against the south wall of my house, and its size would be 37 millimeters. Perfect! All I needed was an objective lens with a focal length of 4 meters. Here was problem number one. I invite you to price a 4-meter lens at Newport or Melles Griot; they can cost hundreds of dollars, if you can even find one. The focal length is the problem.

To the rescue came my optometrist, who offered to order me a couple of ophthalmic lens blanks. These are a terrific resource for affordable optics! They are pre-formed to the right focal length, and the optometrist then grinds each one to fit your eyeglass frames. Polycarbonate single-vision lenses are readily available in 70-millimeter diameter and a wide range of focal lengths, and are cheap as dirt.

Ophthalmic lenses are measured in diopters instead of focal length. The rule is:

**$F$  (in meters) =  $1/D$  (in diopters)**

So a 4-meter lens would be 0.25 diopter.

In the catalog, the smallest positive lens was 1 diopter and the smallest negative was  $-0.75$  diopter. Lenses can be combined, and the simple rule is to add the diopters:

**$D = D_1 + D_2$**

**$F = 1/D = 4$  meters**

So using these two lenses produced a combined lens with a focal length matching what I needed.

For a lens mount, an ABS plastic electrical conduit fitting turned out to be just right (**Figure A**). I glued the first lens in place and made a thin spacer to hold the two lenses apart. If you want a different focal length, you could fine-tune this by spacing the lenses a little further. See the Combining Lenses sidebar for that equation.

With the lenses in their mount, I had a rugged unit I could mount on the beam above my deck (**Figure B**). This only works when the sun is within about  $15^\circ$  of where the lens is pointing. I aimed the lens at the point in the sky where the sun was at high noon, on November 10. This gave me about an hour on each side of noon where the sun's image would be visible against the wall.

Each day I would go out at noon and record with a pencil mark where the sun was. On some days I recorded its position every 15 minutes as long as it was visible. The pencil marks made a permanent record on the side of my house (sacrifices must be made in the interest of science). This way I could follow its



passage as it dipped lower toward the southern horizon and finally, around December 22, began its slow climb back.

There was also an interesting movement of the spot from left to right as the moment of high noon (by the clock) shifted. Solar noon is not always at clock noon, and you can watch this movement as the season progresses. Astronomers have calculated the yearly variation and refer to it as the equation of time.

Not only did my experiments lead to some interesting astronomy, the equation of time, and a better understanding of the Earth's movement in the solar system, but it was also reassuring to see definite signs that the sun was a little higher each day. When friends came over one sunny day in December, I showed them the pencil marks, and could assure them we won't have an infinite winter — spring will definitely return. (At this point my friends started referring to "Craig-Henge.")

Recently we had a chance to observe a rare solar eclipse. It was time to take down the assembly anyway, so it served wonderfully as a solar eclipse viewer. We simply projected the image against my friend's garage door.

Several people told me that the focused rays would set the house on fire. Not so. The lens has a diameter of 70 millimeters and focal length of 4,000 millimeters. Thus its so-called f-number is  $4,000/70 = 57$ . Photographers will recognize that the f-number determines how bright an image is cast at the focal plane. High numbers mean the image brightness is quite a bit reduced. I found I could comfortably hold my hand at the focal point and feel only mild warmth.

But "dim" is a relative thing. It's still too bright to look at the image without very dark glasses. And looking through the lens at the sun will definitely burn your eyes! Bad idea: it's a telescope, for Pete's sake! ❑

## Image Size

The sun as viewed from planet Earth measures approximately 32 minutes of arc, or 32/60 of a degree. It's effectively at infinity as far as our lenses are concerned, so rays coming from the sun are focused right at the focal length of the lens,  $F$ . The size of the image is given by the equation:

$$H = F \times \tan \theta$$

$$\text{For } \theta = 32/60^\circ, F = 4,000\text{mm}, H = 37\text{mm.}$$

## Combining Lenses

Combining 2 lenses with diopters  $D_1$  and  $D_2$ , and spaced a distance ( $d$ ) apart gives a combined effect of a lens of  $D$  diopters where:

$$D = D_1 + D_2 - D_1 D_2 d$$

Or if you prefer focal lengths:

$$F = \frac{F_1 F_2}{F_1 + F_2 - d}$$

## Optical Quality

The lens we have constructed here is good enough to image a bright spot, but it's not of optical quality. You can't see sunspots. Each lens introduces its own distortion, and they're additive.

If you want a really good image, for a telescope you'd use an achromatic objective lens made with two elements of different types of glass. In a good objective lens the curvatures of the four surfaces are chosen:

1. To minimize distortion
2. To minimize spherical and coma aberrations
3. To make all wavelengths focus at the same place (reduce chromatic aberrations)

A top-quality 70mm achromatic lens like this would be difficult to make and cost well into hundreds of dollars. A 160mm lens for astronomy would be in the thousands! That's one reason most amateur telescope makers choose to build reflectors instead of refractor telescopes.

Craig Van Horn was a mechanical engineer doing propulsion R&D right when people started using the phrase "it's not rocket science" — and for him, it was rocket science.



# WATER to WINE COOLER

**Our miraculous illusion converts water into flowing red wine.**

By **Pierre Michael and Robert Kaye**

✦ **TIME: A WEEKEND** ✦ **COST: \$\$\$**



Brian J. Matis

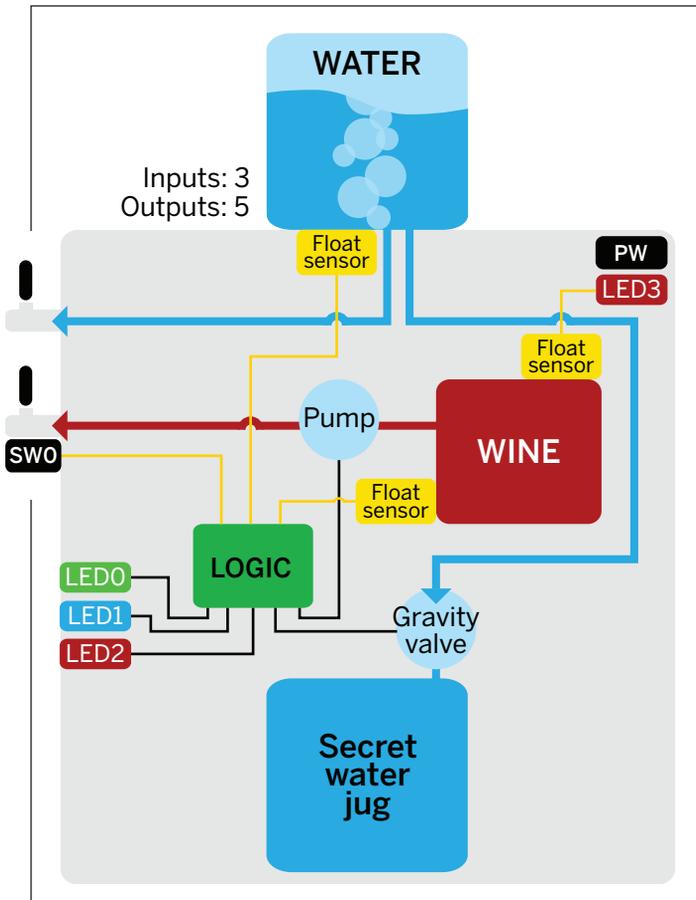
Our longhaired friend Greg was planning a Jesus-themed birthday party, and people joked about a cool possible prop: a machine that would seemingly convert water to wine. “Hey!” we thought. “We can do that!”

We obtained a ceramic-crock water dispenser, sprinkler valves, aquarium pumps, and assorted PVC fittings, and proceeded to make a glorious mess nearly every time we tried to create the illusion, because we would inadvertently start a siphon that we couldn’t stop.

At the last minute before the party, we made it work, but it wasn’t pretty. The wine container sat on a shelf behind the dispenser while the pumping system sat on the floor — all of it draped with sheets, making it obvious that some shenanigans were taking place. Partygoers were still impressed, and the effect was certainly delivered. But we couldn’t resist the urge to remake the Water-to-Wine Cooler as the awesome contraption it deserves to be.

We brainstormed with block diagrams

# Block diagram of W2W electronics and plumbing systems



**A.** First we gutted the cooler, removing the water reservoir, heater, LED board, and this refrigerant compressor. (Dispose of properly.)

**B.** This mini lever switch, modified with a 4" extension, engages the trick system when the cooler's cold water button is pressed.

**C.** The hidden wine reservoir is a polypropylene box fitted with a right-angle "empty" float sensor and bulkhead outlet, plus a straight "full" float sensor in the lid.

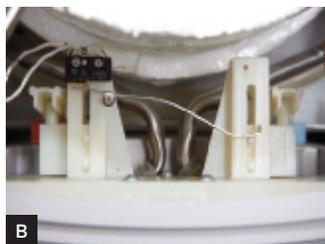
**D.** The wine pump sits in a plastic container of its own, surrounded with bubble wrap to quiet it down.

**E.** Inputs and outputs are wired to the microcontroller board using Molex snap connectors for easy disassembly. The code implements a simple state machine: Idle, Dispense, Out of Water, Out of Wine, and Out of Water and Wine.

**F.** The wine reservoir's refill tube runs to a bulkhead fitting on the back panel, for party in-flight refueling.



A



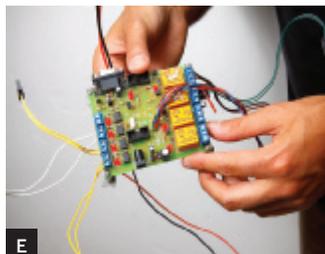
B



C



D



E



F

until we found a simple design we liked. Then we shopped for a water cooler. We knew we needed to electrically capture the mechanical action of the dispense button, covertly. We eventually found a GE water cooler that was perfect. It had hot and cold taps, so we could dispense wine out of the cold side, and for those in the know, room-temperature water from the hot side.

For the gurgling effect, we tried pumping air into the water bottle without letting water out. But we quickly saw that the excess pressure would have no place to go, unless we put a vent in the top of the bottle — and if we did, water would back-flow through the air pump and start a siphon. Again.

Our solution was to hide an identical water bottle below, for the top one to drain into. This lets the water level decrease over the course of the party, which is more realistic. When the water gets low, you just swap bottles and you're back in business. We added a fill port for the wine and LED indicators to notify us if something needs attention.

The finished Water-to-Wine Cooler (W2W) is indistinguishable from a normal water cooler, and we can stand at a distance and chuckle as our unsuspecting friends go from shock, to bewilderment, to amusement.

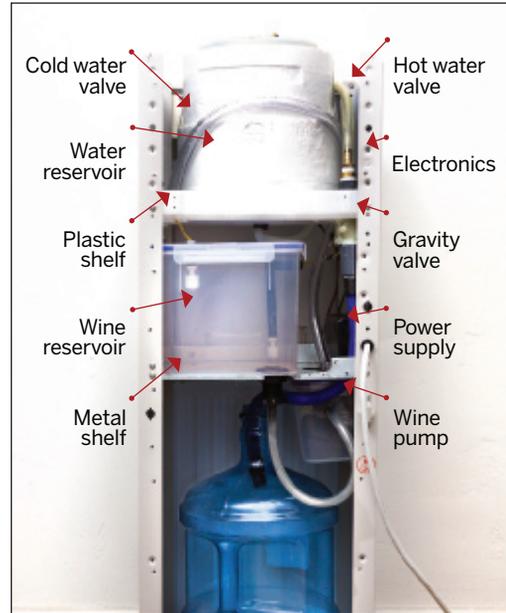
## W2W Design

In the unmodified GE cooler, the inverted jug on top empties into a reservoir with two pipes coming out, one to the refrigeration unit and the other to the heating element. We rerouted one pipe directly to the hot water tap, and the other to a gravity valve that controls flow to the second jug hidden in the bottom of the cooler.

We added a plastic reservoir to hold the wine, and installed electronics and plumbing so that a press of the cold water button simultaneously drains water into the lower jug and pumps wine out the cold water tap.

Control comes from an Olimex ATmega AVR microcontroller development board with 4 relay outputs. The inputs to the board are a mini lever switch triggered by the cold water tap, a “water is empty” float switch, and a “wine is empty” float switch. On the output

## Layout of secret W2W components inside the cooler (rear view)

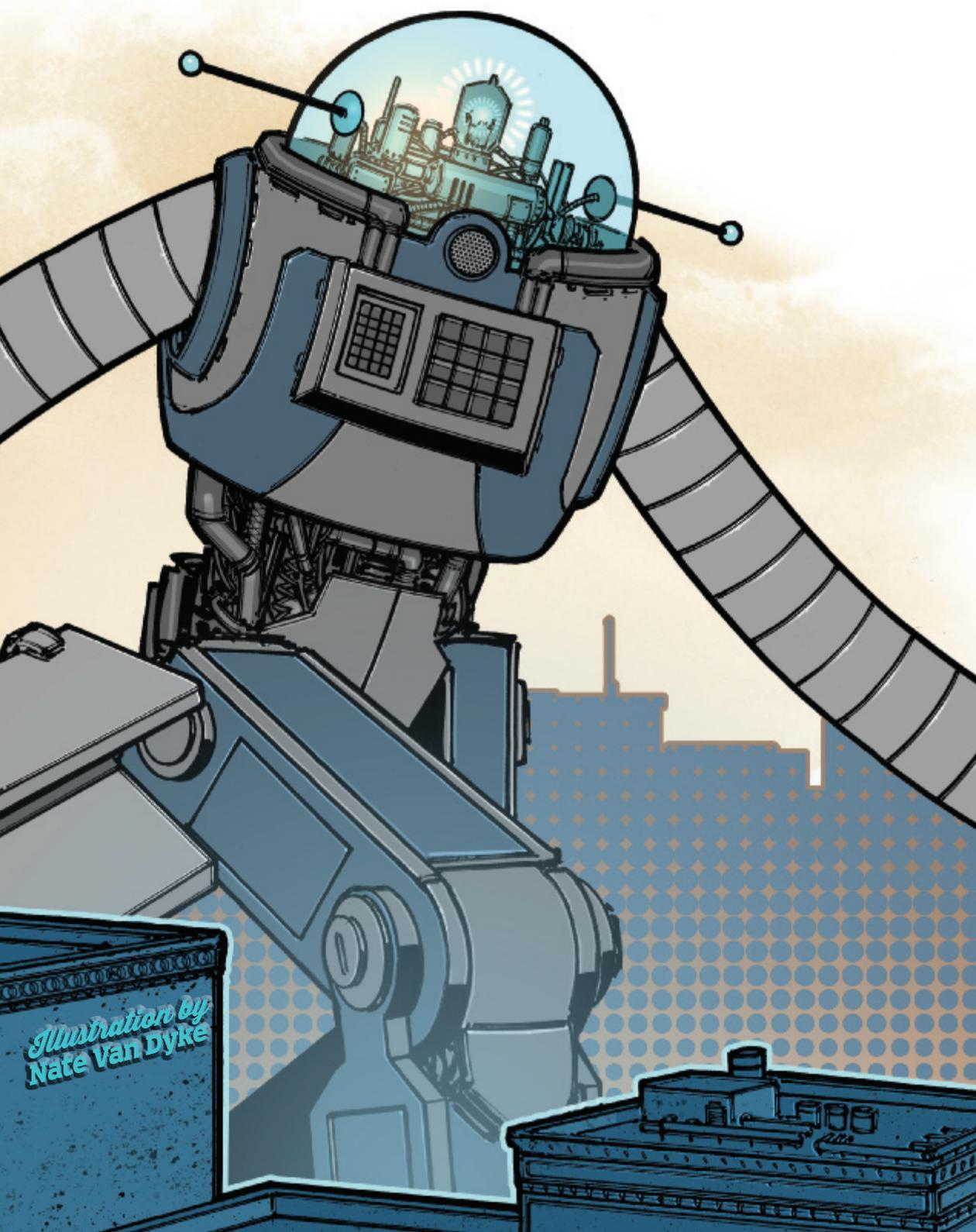


side, 2 relays control the water drain valve solenoid and the pump that dispenses the wine. The board also controls 3 LEDs that flash to show that the software is working and to indicate empty water and wine reservoirs.

Finally, a wine-full float sensor connects directly to an LED that shines through a small hole in back, bypassing the microcontroller, to let you know when to stop pouring refill wine. W2W has a lot going on inside, but after you remove the compressor and heater from inside the cooler body, and if you use 3-gallon jugs instead of 5-gallon, it all fits.

The result is a miraculous illusion where water glugs down from the bottle to emerge mysteriously from the tap as wine. We debuted our new W2W machine at BarBot, a cocktail robotics event in San Francisco, to many laughs. To throw your own water-to-wine party, follow our build instructions and download the W2W code at [makezine.com/34](http://makezine.com/34). ■

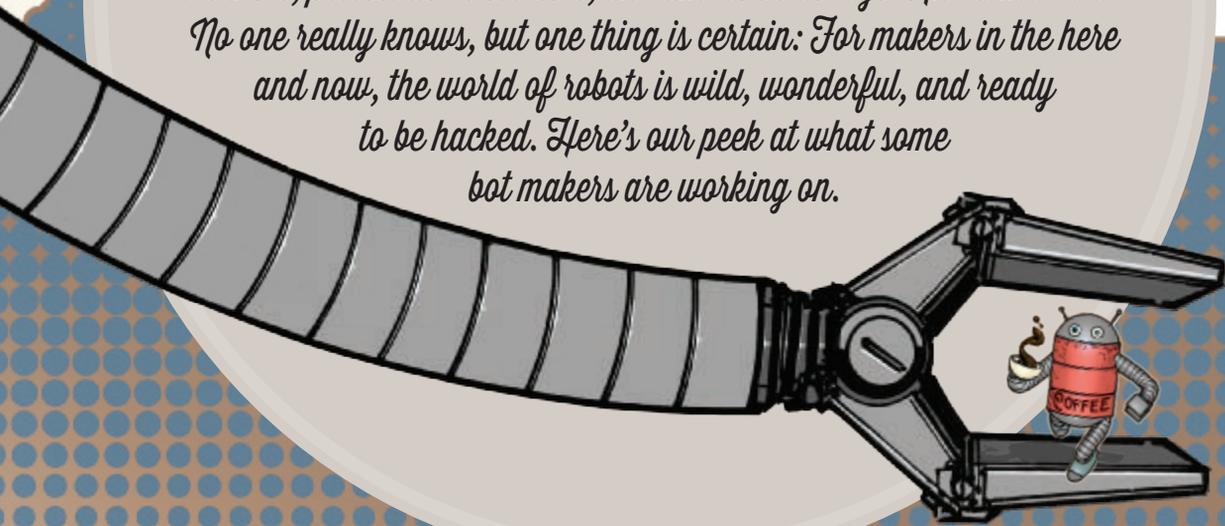
Pierre Michael is an electrical engineer at iRobot, where he works on robots that save lives. Robert Kaye is a founder of the MetaBrainz Foundation, which uses acoustic fingerprinting to identify and tag large collections of music. Both work and live in San Luis Obispo, Calif.



*Illustration by*  
**Nate Van Dyke**

# JOIN THE ROBOT *Uprising*

*While the word robot was only invented in 1920, the idea of humans creating something that moves and acts on its own, as if alive, is ancient. Today, robots serve us as workers, protect us as soldiers, and amuse us as toys. And tomorrow? No one really knows, but one thing is certain: For makers in the here and now, the world of robots is wild, wonderful, and ready to be hacked. Here's our peek at what some bot makers are working on.*



**SPECIAL**

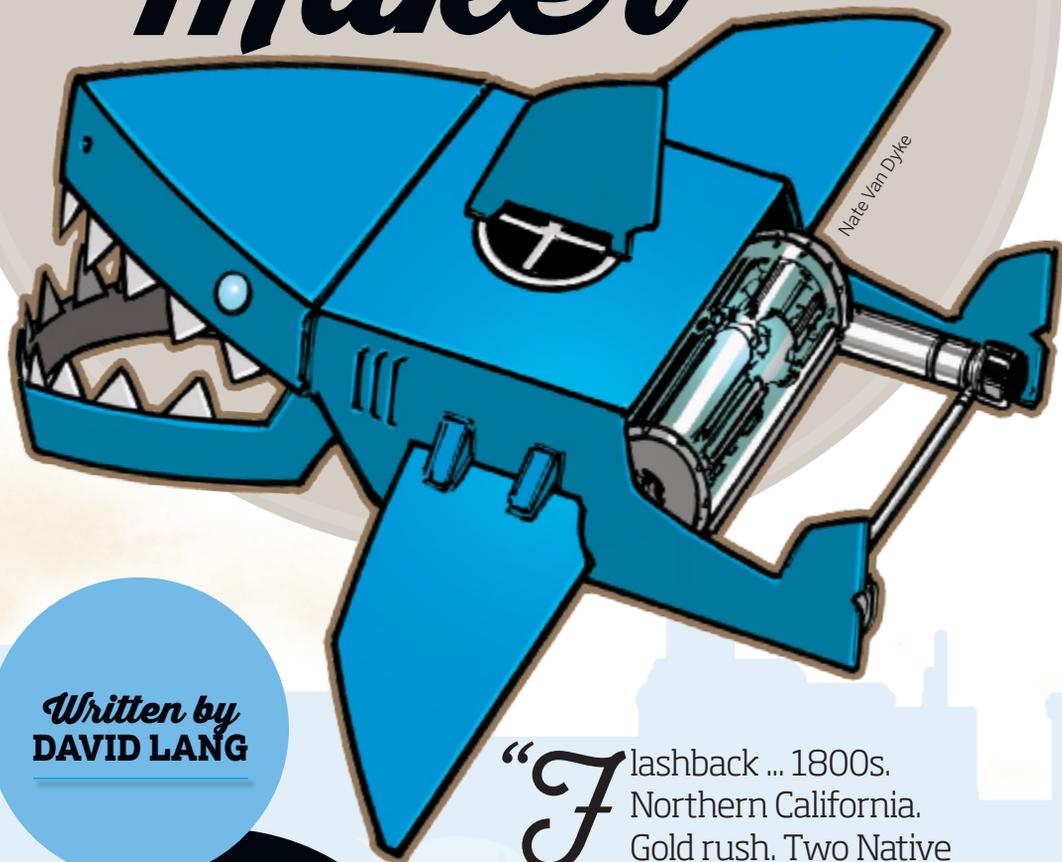
**JOIN THE ROBOT UPRISING**



Gregory Hayes

David Lang and Eric Stackpole, co-founders of the OpenROV underwater robot project.

# THE ACCIDENTAL *Maker*



*Written by*  
**DAVID LANG**

*A pursuit  
of bandit gold  
leads to a  
different kind  
of treasure.*

“Flashback ... 1800s.  
Northern California.  
Gold rush. Two Native  
American men rob a gold mining  
operation and make away with  
an estimated 100 pounds of gold.  
A sheriff's posse is assembled to  
track them down.

After days of chase, they eventu-  
ally catch the two men, but they  
no longer have the gold. The  
sheriff's posse makes an offer:

‘Tell us where you hid the gold and we’ll spare your lives.’ The men explain that they hid the gold in the Hall City Cave. Despite the sheriff’s promise, both men are hung on the spot.

The posse returns to the area the men described and, sure enough, there’s a cave. They don’t find the gold, but toward the back of the cave they find a hole six feet in diameter and filled with water. The underwater cavern extends down farther than they can see, and they lack the tools or technology to explore further, so the sheriff’s posse gives up.”

Eric Stackpole, standing in the lobby of the Fisherman’s Wharf Hostel in San Francisco, took a deep breath and continued his story. He went on to recount numerous cave divers and treasure hunters who, having heard the Legend of the Hall City Cave, had tried and failed to reach the bottom, many of whom had stories of near-death experiences.

By this time, my jaw was on the floor. This was the first time I had met Eric in person. The cave story was, quite literally, the beginning of the conversation. After Eric showed me an early prototype of the robot he was building to explore the cave, I knew I wanted to be involved — I had to be involved.

There was just one problem: I was completely useless. I had no making, design, or engineering skills to bring to the table. I had never even soldered before. But despite my lack of manual literacy, I convinced Eric to let me tag along. Having read about MakerBot and DIY Drones, I encouraged

## Underwater Exploration



At Maker Faire Bay Area 2011, Eric Stackpole inspires visitors with the story of the Hall City Cave.

OpenROV (Remotely Operated Vehicle) is a robotic submarine designed to be built, deployed, and modified by anybody. Its onboard camera sends live video to the surface by way of a tether. An operator can pilot the ROV using a handheld controller or computer keyboard, just like a video game.

Almost everything used to construct the OpenROV can be bought off the shelf: consumer-grade HD USB webcam, common brushless R/C airplane motors waterproofed with liquid electrical tape from the hardware store, off-the-shelf rechargeable batteries. It’s got a small onboard computer running Linux and an Arduino-compatible microcontroller that operates onboard hardware such as motors and lights, and listens to the vehicle’s sensors. Its body is built from flat acrylic stock that can be cut with a laser cutter from plans available on our website. Putting it together takes less than a week.

The OpenROV can travel to a depth of 50m at a forward speed of 1m/s. It’s 300mm long and weighs 2.5kg. Battery life is about an hour.

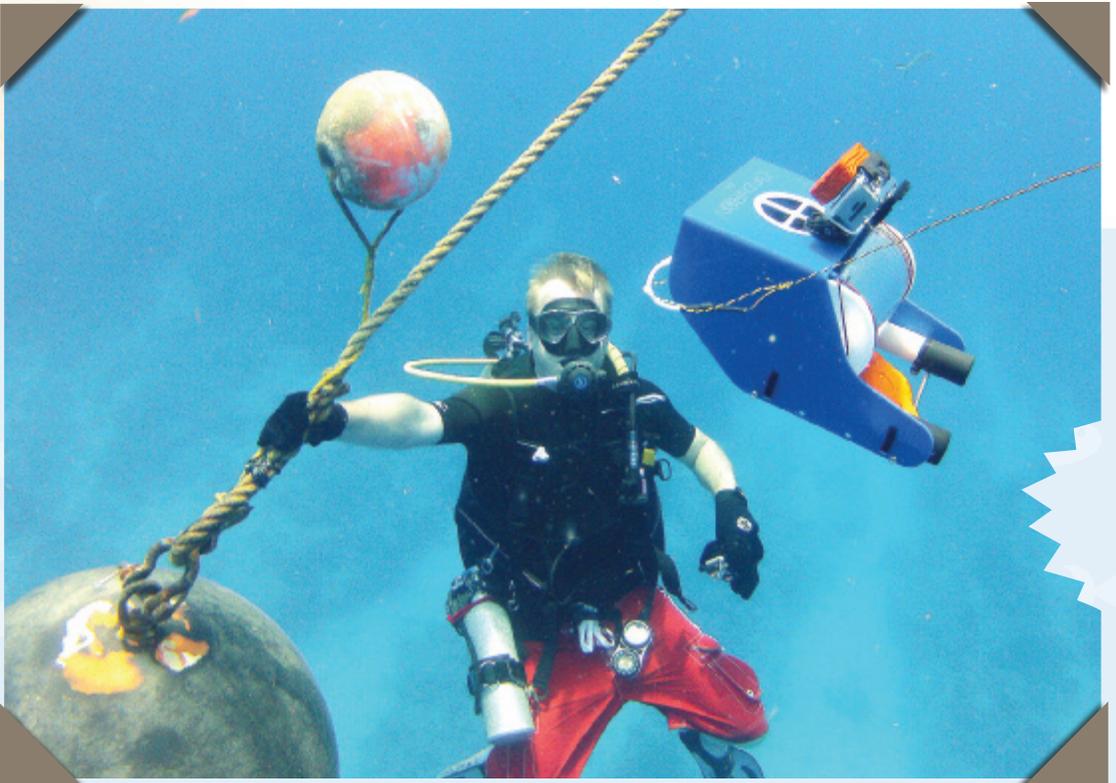
The big idea behind OpenROV is that it’s open source, so all the great ideas that come from people building and using these vehicles can be freely shared and the overall design improved. We hope that OpenROV is the beginning of a new era in underwater exploration, where new data is as common as YouTube videos, and anyone can partake of the profound discoveries enabled by this technology.

—Eric Stackpole



Testing OpenROV on NASA's NEEMO-16 mission to the Aquarius Reef Base undersea laboratory in the Florida Keys.

Chris Gerty (undersea laboratory)





Shown at TechShop with his laser cutting class and with his welding instructor, Lang used the skills gained during his Zero To Maker experience to help develop these early prototypes of OpenROV.

him to make the project open source, and told him I'd help document and share information. I knew how badly this type of adventure and excitement was missing from my office-bound life, and I was certain that others would feel the same.

I never could have predicted where my desire to get involved would lead.

## Zero to Maker

A few months after that inspiring meeting, Eric and I had created a website and forum for other DIY ocean explorers at [OpenROV.com](http://OpenROV.com). I enjoyed it — I was learning a little bit here and there — but I was still a long way from considering myself a maker.

My moment, my push over the edge of the getting-involved cliff, came when I lost my day job working for a startup in Los Angeles. Although I knew the company was in a tough spot, I wasn't prepared. The moment was sharp — a sudden realization that all I was qualified to do was sit in front

of a computer screen. After meeting Eric and getting a taste for the adventure and possibility inherent to engineering and making, I knew I couldn't just scramble back into the rat race.

I wanted the skills of an industrial designer but I didn't have the time or money to go back to school. Instead, I decided to create my own DIY Industrial Design curriculum. I showed up at TechShop in San Francisco, told them my plan, and spent the next two months taking as many classes as I could — woodshop to welding, laser cutting to 3D scanning.

During the same time, OpenROV began to gain momentum. The forums grew from a back-and-forth discussion between Eric and me (mostly Eric explaining physics and underwater robotics to me) to a community of hundreds of people — amateur and professional ocean engineers alike. The idea of a low-cost,

open-source underwater robot had clearly struck a nerve. With the help of this community, the robot design evolved, and we planned our trip to the Hall City Cave.

*"I knew I wanted to be involved — I had to be involved."*



My skills steadily increased as I continued my “Zero to Maker” journey, which I documented for MAKE ([blog.makezine.com/tag/zerotomaker](http://blog.makezine.com/tag/zerotomaker)). I was starting to move through the world differently: seeing problems as solvable and exciting, situations as malleable, curious about the origins and workings of everything.

The transformation didn’t take long — the span of just a few months — but it wasn’t always smooth. I found that the process was less about learning new tools than it was about adopting a “maker mentality.” There were subtle tricks I picked up through spending time with maker superheroes like Tim Anderson, writer of the “Heirloom Technology” column for MAKE, like learning “enough to be dangerous,” immediately trying to teach whatever I learned, and celebrating failure. Other lessons were big, obvious moments where I was clearly not one of the group. One of the most vivid lessons came the first time we water-tested our OpenROV.

### *Sunken Epiphany*

Eric and I had finally come to a point in the process where the next logical step was to test the robot in the water. We set up our experiment in the backyard of my aunt’s house around the swimming pool, with my aunt curiously looking on. We decided Eric would be the videographer, leaving me to control the ROV. As Eric positioned the underwater camera, I tested the motors — they all ran perfectly, but were about to be put to the true test below the surface.

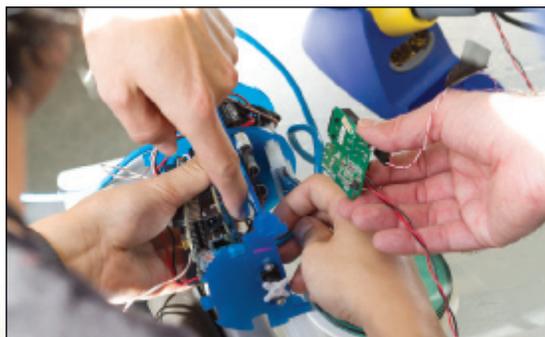
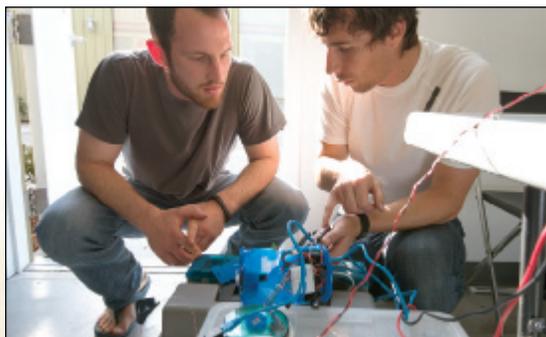
I lowered the robot into the water and walked back to the controls. Eric watched intently. I got back to the laptop and fired the forward thrusters — the two rear propellers which, when running in tandem, would push the robot forward. They worked! Well, they worked for a few minutes anyway, before one of the propellers stopped responding to the signals. We retrieved the robot and tried again, and it worked again briefly. Pretty soon, though, no matter what tricks or alterations we tried, we knew the ROV was underpowered. It sank to the bottom.



The OpenROV team inside the Hall City Cave, preparing to explore the underwater portion of the cave with an early OpenROV prototype.

At this moment — realizing all our previous work didn’t accomplish the goal — I saw the difference between Eric and myself. Again, I was useless. Nothing I could suggest would be of any help. While I was dwelling on the fact that it wasn’t working, Eric was already going through possible solutions. He was running calculations, trying different configurations,

Brian Lam, Zack Johnson (top)



suggesting alternatives.

My perspective on the moment was different than Eric's, in a way that couldn't be attributed to our level of interest or initiative. I was, just like Eric, completely fascinated and intrigued by everything we were working on. I had, just like Eric, the willpower to try something new. Something else was different — something deeper than initiative and less formal than a master's degree in engineering.

The difference was Eric's incorrigible willingness to try things another way.

I've come to define that distinctly maker trait as the Persistent Tinkering Mentality (PTM), and I didn't have it. Not naturally, anyway. But the robot-sinking epiphany became a catalyst for change, and I've since developed a much stronger PTM muscle.

*“The difference was Eric's irrepressible willingness to try things another way.”*

## Community Is Golden

As my maker skills continued to develop, so did the OpenROV design, not because of my contributions, but because Eric and I had vastly improved the most important maker skill of all: sharing. The robot's entire software stack was developed by the OpenROV community, which by the time we made the trip to the cave, had grown to nearly a thousand people. Nearly a dozen friends joined us for the adventure.

We didn't find treasure in the cave, but it didn't matter. We had built the robot we'd dreamed about and, more importantly, had a lot of fun doing it. We've discovered hun-

dreds of new friends and collaborators interested in what we're doing. Our open source team is now global, with the main software developers in Europe, and a distributed network of contributors and experimenters all over the world. Our development calls on Google+ frequently have participants from three continents.

The future of OpenROV is as much about the community as it is the robot. We want to continue to innovate and develop low-cost underwater robots — “cheaper and deeper” — but we also want to explore what's possible with a distributed network of DIY ocean explorers. What might we find? How will we share data? What can we learn together?

For me personally, the real treasure was never gold, but something far more precious. This maiden voyage of our little robot was a tremendous experience, but my journey started long before that day in the cave. My challenges were more fundamental than any technical design. I had gone from nonexistent engineering or design experience to making contributions to an award-winning underwater robot. A project that seemed intimidating and impossible to me only a year earlier had shaped me into a completely new person. I had flipped the switch from being a passive consumer of life to an engaged, creative participant in it. I had gone from Zero to Maker.

## Maker Misconceptions

Before I dove into making, I barely knew which way to hold a hammer. I wasn't sure I could





ever fit in or learn the ropes. I had preconceived ideas about makers: who they were, how they worked, and how they learned. I imagined a long, lonely, and tedious study of engineering, tools, and science — skills that I had bypassed on the fast track to be more “marketable.”

My assumptions were completely off. These preconceptions turned out to be the toughest obstacle I would need to overcome. Once I recognized how unfounded they were, my own inner maker was able to come crawling out of his shell.

### 1. *It's not about DIY.*

I quickly learned how makers really work: together. I was surprised that making was such a team sport. My first trip to Maker Faire left me with the impression makers were lone geniuses, toiling away in garages or workshops, putting countless hours into a project, repair, or invention and coming together once a year to show off their creations. This couldn't be further from the truth.

Makers are, above all, a connected and collaborative bunch. They meet online and share ideas on forums, blogs, and discussion



Ahoy, future! David Lang, left, and Eric Stackpole point the way.



Gregory Hayes

groups. They give away their designs and collaborate on projects with people all over the world — the exact opposite of the competitive secrecy I had come to embrace in the corporate world.

They've pooled resources to create fab labs and makerspaces — physical spaces that serve as hubs for sharing costs and maintenance of larger tools and equipment. It didn't take me long to understand that little of anything is being done "yourself." Making is not really about DIY, it's about DIT, or Do It Together.

## 2. These aren't my grandfather's tools.

Before my immersion, I had a sentimental notion that DIY was about bringing back a bygone era — before hammers and nails were replaced with video games and iPads. I imagined DIYers to be torchbearers, keeping alive the methods and craftsmanship that were marginalized by the onslaught of screens and advertisements. I wanted making to help me connect with something I felt had been lost over the past few generations — a part of being a self-sufficient human that was

missing from my life.

In a way, makers are the guardians of this industrious self-reliance I had hoped for, but together they're so much more. They understand and respect their place in history, in a long line of tool makers and tool users. While they do keep traditional knowledge alive, they're also busy inventing and bringing

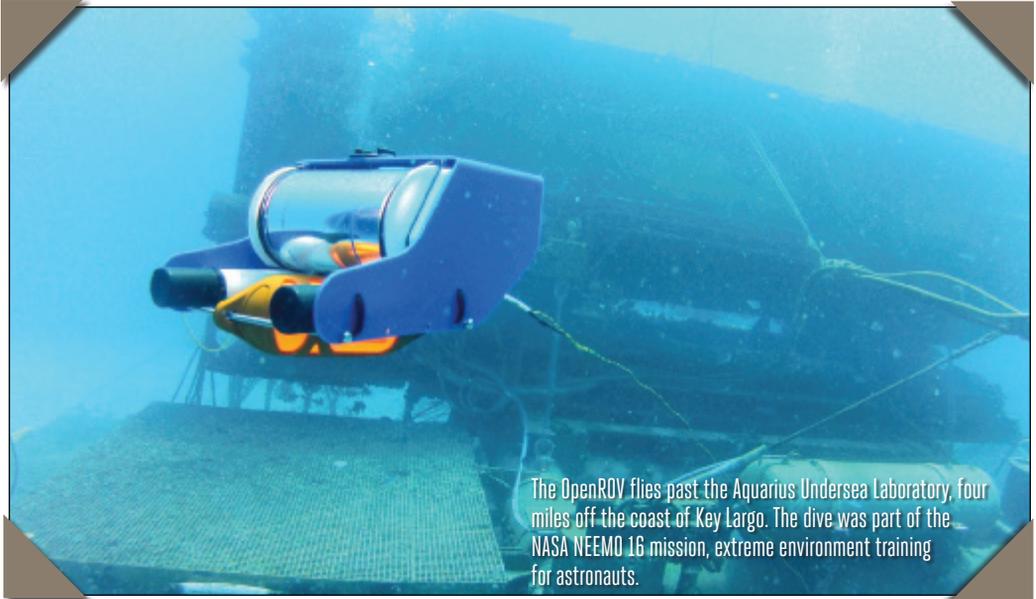
new technologies into the world.

The new maker tools are byproducts of increasingly affordable computers, components, and sensors. Fueled by the rapid exchange of ideas on the internet, they're empowering individuals and small groups with a slew of new personal fabrication tools. 3D printers, laser cutters, and other CNC machines

(automated machine tools) are now affordable for a home workshop and capable of creating customizable, consumer-ready products.

A product that would've cost hundreds of thousands of dollars to prototype and produce 15 years ago can now be created with a downloadable file and access to one of the makerspaces that are popping up in cities all over the world.

*"Makers are, above all, a connected and collaborative bunch."*



The OpenROV flies past the Aquarius Undersea Laboratory, four miles off the coast of Key Largo. The dive was part of the NASA NEEMO 16 mission, extreme environment training for astronauts.

Chris Gerty

### ***3. Only learn “enough to be dangerous.”***

Learning to use these tools was shockingly easy. When I started, I predicted I would need a degree in industrial design or mechanical engineering before I could make anything useful or valuable. I never imagined I could come so far in such a short time. In only a few months, I was 3D printing, teaching others how to use the laser cutter, and designing basic parts in CAD (computer-aided design) programs. I started welding, working with sheet metal, and creating plastic molds. I was clearly not a master welder or microcontroller programmer, but I knew enough to get started.

Anything I didn't know — how to use a machine, what material to use, how to assemble something — I could pick up on the fly. I learned skills as I needed them, depending on the specific problem facing me. And I was never alone. All the makers I met seemed to specialize in one area or another, and everyone was happy to teach what they knew. In fact, I discovered that everyone still had a lot to learn, but we were all able to leverage one another's skills and knowledge.

Once I let go of my misconceptions, I was welcomed into a community of possibility.



At the OpenROV HQ, members gather for one of the monthly build days.

Gregory Hayes

I realized I was part of something much larger: a maker movement. In exploring this new world, I saw another side of myself, a part that revels in the process of creating and sharing with others.

As it turned out, we never found any treasure in the bottom of the Hall City Cave. Instead, we discovered a community of global collaborators, which has been far more valuable and definitely more fun. ▣

## **BIO**

**David Lang** is a co-founder of OpenROV, an open source community of DIY ocean explorers. He is a contributing editor at MAKE and the author of *Zero To Maker*, a how-to guide for getting involved (and up-to-speed) with the maker movement. He is also a TED Fellow. Prior to underwater robots, David managed a sailing school in Berkeley. He currently lives on a sailboat in the San Francisco Bay.

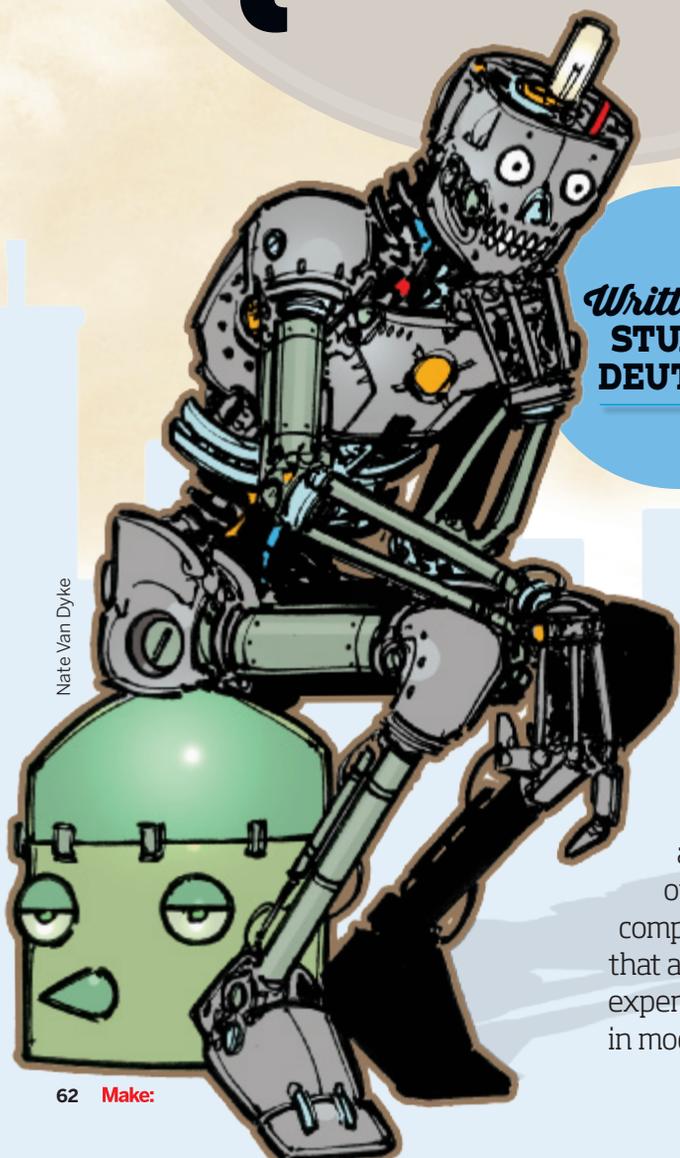
# PROTOTYPING SYSTEMS FOR *Robotics*

*A  
bot-builder's  
guide to bits  
and pieces.*

*Written by*  
**STUART  
DEUTSCH**

All-in-one robot kits, such as MAKE's new Arduino-based Rovera series and Parallax's Boe-Bot system, are designed to provide easy entry into hobby robotics. Popular with beginners as well as intermediate and advanced makers, they often employ fixed chassis components and simple drive trains that allow quick assembly and easy experimentation with sensors, plug-in modules, and control components.

Nate Van Dyke



Prototyping systems, on the other hand, are not necessarily robotics-specific. They require more assembly, but allow for greater customization and are aimed at anyone looking to experiment with electromechanical systems in general. And, as it happens, they can be used to make some pretty sweet bots, too. Here are a few of my personal faves.

## Vex Robotics

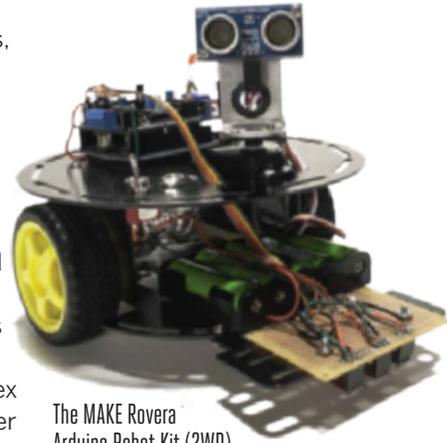
Like Mindstorms, the Vex Robotics Design System is an all-inclusive prototyping platform that includes structural components, drive train parts, actuators, sensors, a branded microcontroller, and remote control equipment. You can work entirely inside the Vex system, or use its structural and mechanical components as a base for third-party microcontrollers or other components.

Building mobile robot and machine prototypes from Vex components is fairly easy, though not Lego-easy. Lego is everywhere on the web, and naturally there are fewer photo galleries, build instructions, and other resources available for Vex, though the company itself does a good job of providing "Inventor's Guides," educational curricula, and other support materials. Add-on

components include treads, chains, sprockets, gears, omni wheels, and many others, allowing for designs of great versatility and complexity.

It's possible to use Vex components with off-brand or improvised structural parts and hardware, but it's usually much easier to stay in-system. Adapting Vex parts could be made simpler with the use of a 3D printer: Vex publishes 3D models for most of their products, enabling users to print individual components or compatible parts of their own design.

If you plan to use your own microcontroller, Vex's \$150 Clawbot Kit (276-2600) is a handy starting bundle. There's also a Radio Control Starter Bundle (276-2310, discontinued but still available) for \$300, which allows

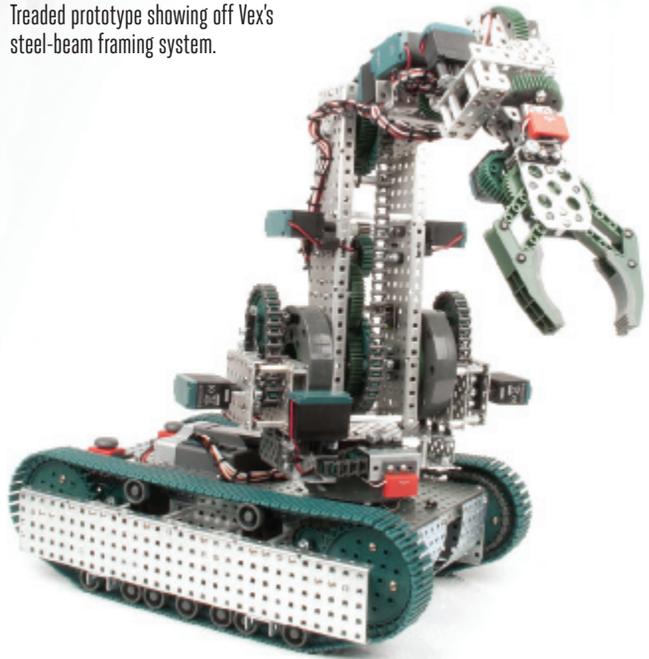


The MAKE Rovera Arduino Robot Kit (2WD).



Mecanum wheels are among the more exotic components in the Vex system.

Treaded prototype showing off Vex's steel-beam framing system.



for quick mechanical prototyping without writing code.

## Makeblock

Many all-in-one commercial prototyping systems, like Lego and Vex, are proprietary and closed source — which is not necessarily a bad thing, but can make it more complicated for users to develop or commercialize their own designs past a certain point.

Personally, I like to create hodgepodge designs using just the components I want, without being locked into one system. Makeblock, a relatively new prototyping platform, seems to be one of the best mechanical design systems to allow this, short of working from scratch.

Makeblock's mechanical and motion kits are designed from the ground up to be used with Arduino and other open source microcontrollers. The basic kits come with wheel assemblies and standard-sized 25mm gearmotors that can be easily

controlled using an H-bridge circuit or motor shield. Larger kits include MXL belts and an assortment of timing pulleys for the creation of more advanced mechanisms.

Perhaps the most interesting aspect of Makeblock's system is the aluminum structural beam design, which features two rows of evenly spaced holes and a middle channel with threaded walls. The threaded channel allows for structural components and other parts to be mounted anywhere along the length of the channel with just machine screws. Care must be used, with steel fasteners, to not damage these threads by overtightening. The latest beams are said to have stronger threads, but I still prefer nylon screws to minimize the risk of damage.

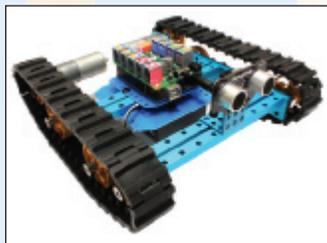
## Lego

Although often thought of as toys, Lego products have established a strong reputation among roboticists. Lego elements are relatively inexpensive, commonplace,

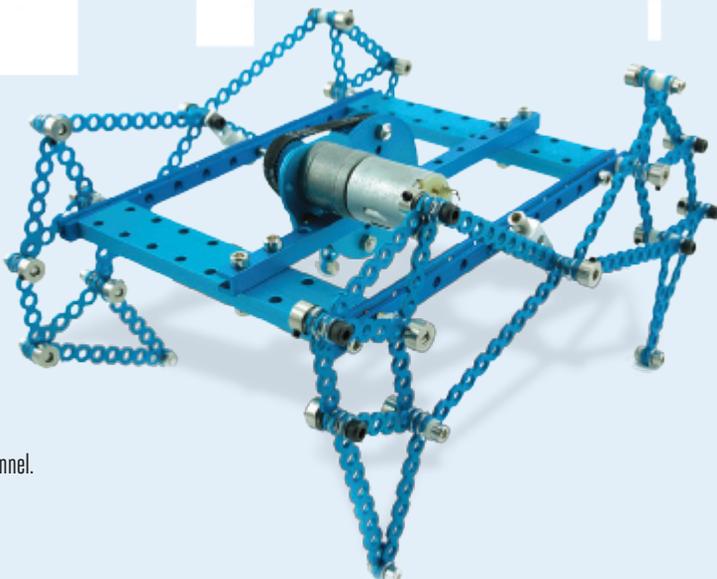
and highly modular, which makes them perfect for serious prototyping.

You may have already heard about Lego's Mindstorms robot invention system, an all-in-one development kit that includes a powerful microcontroller, sensors, and servos. There has been an explosion of wondrous Mindstorms-based robotics in recent years — rovers, walkers, sorting machines. CNC foam milling machines, gripping arms, even a couple of underwater vehicles — that amply demonstrates how useful Legos can be at any level of robot design.

Lego also offers a classic line of Technic building sets and parts, which includes a vast selection of structural and mechanical components. Technic components are compatible with Mindstorms and other elements in the Lego system, including the Power Functions series of electric building components — various sizes and types of DC motors, LED lighting



Makeblock's unique extruded-beam profile features a continuously threaded central channel.



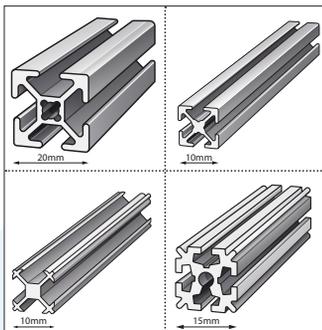
elements, switches, battery boxes, and wiring elements — which are all easy to interface with Arduino and other microcontrollers.

Technic vehicle sets usually feature mechanically realistic actuation and locomotion, making them excellent sources for drive train components, like gears and wheels, as well as linear actuators, pneumatic cylinders, shock absorbers, and of course structural parts. A Technic vehicle can also provide a quick means to get a mobile base working without much trial and error. If you find your design lacking one or more specific components, you can always head over to [bricklink.com](http://bricklink.com) to buy parts a la carte.

There can be downsides to using Lego for building bots. First, Lego robots can be less robust and durable than those made from “serious” construction materials. It is possible to reinforce Lego builds with off-the-shelf parts using velcro, rubber bands, or more permanent means. But the time and effort saved by prototyping with Lego may or may not repay the time needed to convert a Lego-based prototype into a stronger, faster, or scaled-up construction using standard parts and components.

## T-Slot Beams

If you’re just looking for a structural prototyping system, T-slotted aluminum extrusions are a great way to go. There are several



Clockwise from upper left: 80/20 20-2020, MakerBeam, OpenBeam, and MicroRax extrusion profiles.

options on the market, with MicroRax, MakerBeam, and OpenBeam being the three notable small-scale systems, and 80/20 being the oldest, most well-established full-size brand.

MicroRax and MakerBeam extrusions have 10mm×10mm cross-sections, OpenBeam is 15mm×15mm, and 80/20 starts at 20mm×20mm. 80/20 also offers a smaller 12.5mm×25mm extrusion, but with only one T-slot.

Independent of size, T-slot beams are typically square or rectangular with built-in channels on all sides. The channels are shaped so that bolts and other fasteners must be slid in from an open end of the beam. This also means that fixtures can be loosened and slid into new positions on a beam without popping off.

Bolts are used to attach parts and devices directly to T-slots, and lengths of T-slot beam can be affixed to each other using metal brackets and joining plates. Extrusions often come in longer



Rutgers University's 2012 IGVC robot chassis uses 80/20 extrusions extensively.

lengths that can be cut down to custom sizes, but it is also possible to purchase pre-cut beams for easier prototyping.

80/20 is a very popular choice for larger mobile robot bases (even those you can ride on!), 3D printer frames, and CNC machines. Specialty fasteners and brackets allow for more complex configurations and designs, but these often require minor and sometimes multi-stepped machining operations.

T-slot systems, even the smaller-scale ones, require more advanced design skills and a better-equipped toolbox, so they’re not as beginner friendly as other prototyping options. Still, building with T-slotted beams is far quicker and easier than working with stock materials like aluminum channel or steel bar. ■

## BIO

**Stuart Deutsch** enjoys reviewing the latest in hand and power tools at [ToolGuyd.com](http://ToolGuyd.com). He has many maker interests, but is most passionate about robotics and computer casemodding.

# HOW I PRINTED A *Humanoid*



## *Humanoid Evolution*

The DARwIn-OP (Dynamic Anthropomorphic Robot with Intelligence — Open Platform) is a state-of-the-art research and development humanoid robot created by Virginia Tech's Robotics and Mechanisms Laboratory (RoMeLa), led by Dr. Dennis Hong, in collaboration with the University of Pennsylvania, Purdue University, and the South Korean company Robotis, with support from the National Science Foundation.

Weighing in at just 2.9kg and standing 45.5cm tall, the DARwIn-OP has won the gold medal in the autonomous RoboCup Soccer Humanoid League, Kid Size class, in both 2011 and 2012.

*3D-print  
a \$12,000  
humanoid robot  
— for half that  
price.*

*Written by  
MICHAEL  
OVERSTREET*

In recent years I've experimented with 3D-printing the structural brackets for my humanoid robot Boomer. Boomer and I compete at RoboGames and show off at Maker Faires, and people always ask me: Why 3D printing? Why not just make the brackets out of metal like everyone else?

I started to do it just because I could. The advent of cheap DIY 3D printers has given makers a new way to manufacture and customize objects, and I was simply exploring this new process. As I printed more parts for my robot, I realized that it could be done — and done cheaply.

Then I saw the DARwIn-OP at the 2010 International Conference on Humanoid

Robots. After seeing how capable and groundbreaking it was, I wanted one. But how could I afford it? A new DARwIn-OP from Robotis costs \$12,000.

That's how this project got started. My mission was to print as much of the robot as possible using a DIY 3D printer costing \$2,000 or less. DARwIn-OP is an open hardware and software

# Meet the Clone



## » THE TOUGHEST PARTS

A few parts, designed for aluminum or injection-molded plastic, are almost impossible for a DIY printer. The front body cover must be printed at the highest resolution – that's 16 hours on my printer, and a lot can go wrong in 16 hours. I had Shapeways ([shapeways.com](http://shapeways.com)) print the head and body covers, using their laser sintering process. I hope to modify these parts for a DIY printer – or to find one that can handle them.

## » 90% DIY PRINTED

I print my parts in ABS plastic, as PLA is weaker and more brittle. I strongly agree with the review of the Up Plus/Afinia printer in the MAKE Ultimate Guide to 3D Printing ([makezine.com/3dprinting](http://makezine.com/3dprinting)). It's one of the best on the market, and it has printed 90% of my clone: servo brackets, structural framing, and body covers.

## » TOP SERVOS

Robotis Dynamixel digital servomotors are the leading robotics servos in the world – fast, high torque, and very high resolution.



## » GLUES NOT SCREWS

Nuts and bolts are not ideal for plastic. I glue my 3D-printed brackets together using Micro-Mark's liquid plastic welder or an ABS-acetone slurry; it's stronger.



## » TRICKY WIDTHS

Some parts are 1½ or 2½ extruder paths wide instead of 2 or 3. Many DIY printers and slicer programs can't overcome this problem, causing hollow passageways within walls that weaken the part. Also problematic: body covers are barely 1 path wide.

## » OFF-THE-SHELF BRAINS

The DARwIn-OP is controlled by an affordable Fit-PC2 compact PC and a Robotis CM-730 servo controller.



project, so all of the 3D files and plans are free online. I bought 20 Dynamixel MX-28T servos and the complete electronics kit from Robotis.

Today, my DARwIn-OP

clone is fully assembled, and I've spent about \$6,100, not counting the costs of the 3D printers I used. That's still a lot – but it's almost half off the factory price.

## Lessons Learned

### » FREE 3D DESIGN

I had to fine-tune some of the parts, so I used Autodesk's 123D design software to create my STL files, both for its price

(free) and its ease of use (Figure 1).

» **RAFTS AND SUPPORT MATERIAL**

I like the Up Plus 3D printer's accuracy and its automatic generation of both rafts (disposable footings that prevent warping) and support material to prop up overhangs, bridges, and screw holes (Figure 2). I still had to play around with the orientation of parts on the build platform, because this can affect the printing of overhangs and supports (Figures 3 and 4).

» **HEATED PLATFORM**

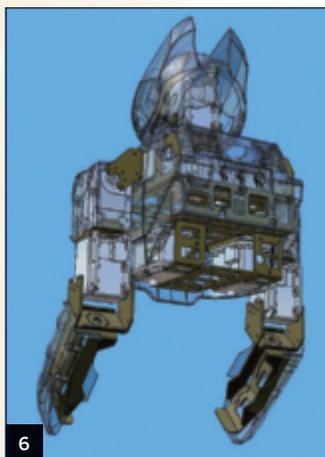
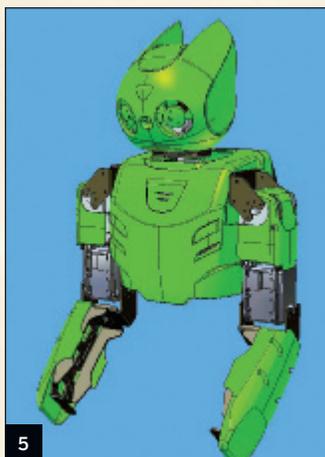
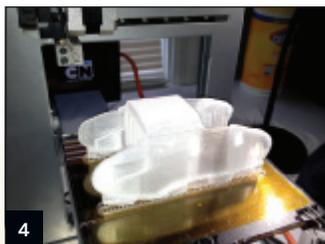
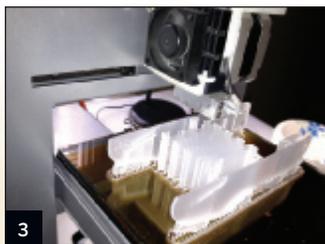
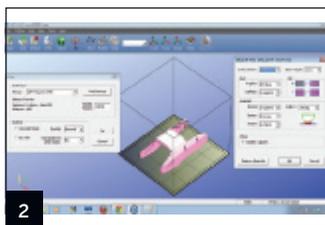
Printing in ABS requires a build platform heated to about 110°F. To improve performance, I upgraded my Up Plus platform to glass covered with Kapton tape for adhesion.

» **LEVELING THE PLATFORM**

Learn the paper leveling trick: if a sheet of paper can freely move between the extruder tip and the build platform, you're OK. If not, then the extruder tip is too close. If it moves too easily or you see a gap, then it's too far away.

» **AWESOME MANUALS**

The open source DARwIn-OP manuals are the most comprehensive and detailed I've ever worked with — they break down the entire assembly into easy steps (Figures 7–10). I thank Dr. J.K. Han of Robotis for the tireless work he must have put into creating them!



» **DIY VS. COMMERCIAL**

To print the whole robot (Figure 11), I used two spools of plastic that cost about \$90 total. Shapeways' price is almost \$1,000. That's close to the price of many DIY 3D printers, and in my opinion the quality of DIY prints is now 70% to 80% of professional prints. Still, I'm considering having all the covers printed by Shapeways for about \$400, as they're the most difficult parts to get right.

*What's Next*

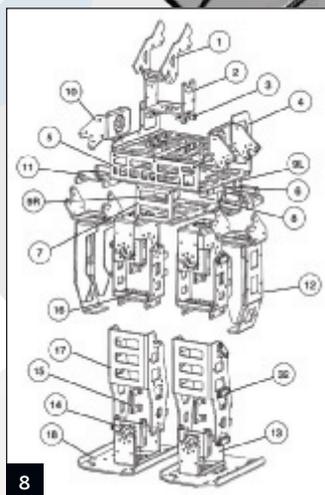
Next I'll download the control

software to the Fit-PC2 and get this robot to walk, talk, and see, with as few modifications to the software and hardware as possible. I may need to redesign some of the brackets and frames, because these were designed for aluminum. My friend Yoshihiro Shibata is helping me analyze DARwIn-OP's structure to find its weak points when printed in plastic (Figures 5 and 6). My plan is to redesign only the parts that break, to make them stronger, as I don't want to add unnecessary weight.

Michael Overstreet; Yoshihiro Shibata (5,6)



7



8



9



10



11

That's one of the great benefits of personal manufacturing: if something doesn't work, just redesign it and print it out. This process is called iterative design and experimentation. You can do it as many times as needed because the cost of a part is only a few dollars and you just have to wait for it to be printed!

After the robot is fully functional, I'll modify its covers to resemble my favorite fictional humanoids Robby, Gort, Atom, or C-3PO, and maybe add a fully

articulating hand with fingers.

But I've come to realize that I may never be fully done with this project. I think the only limit is my imagination. This, I think, is the greatest benefit that we'll get from the personal fabrication movement. It has opened up limitless possibility for an individual to fully explore in solid form their dreams, ideas, and imagination. ▣

Special thanks to Luis Rodriguez, Rob Giseburt, Paul Piong, Roc Terrell, James Rao, and Kayla Kim for their printers and knowledge.



## BIO

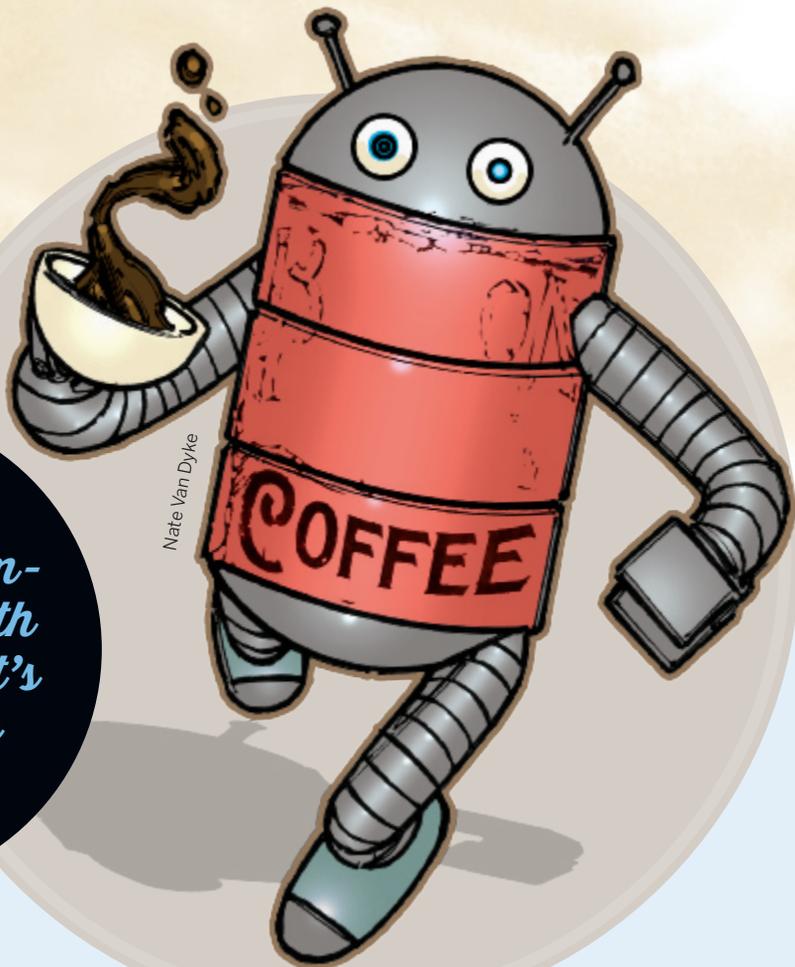
**Michael Overstreet** ([mike-ibioloid.blogspot.com](http://mike-ibioloid.blogspot.com)) is a computer programmer by day and amateur roboticist by night. He and his humanoid robot Boomer have won medals in the last six RoboGames. He's a founding member of the Cowtown Computer Congress hackerspace in Kansas City, Mo., and has attended all of the national Maker Faires.

# HOW TO BUILD

# Coffee Bots

*Written by*  
**JUDY AIME'  
CASTRO**

*Build a  
simple, program-  
mable robot with  
personality that's  
approachable  
for all ages.*





✓ TIME: 8–12 HOURS ✓ COST: \$\$

## MATERIALS

- » **Gearmotors with wheels (2)**  
Solarbotics #GM8 with GMPW wheel deal, [solarbotics.com/product/gmpw\\_deal](http://solarbotics.com/product/gmpw_deal)
- » **Transistors, logic level MOSFET, 12N10L type (2)** such as Jameco #1071214, [jameco.com](http://jameco.com)
- » **Photoresistors, CdS, 250mW, 12kΩ–1MΩ (2)** such as Jameco #120299
- » **Resistors, ¼W, 150kΩ (2)**
- » **Arduino Uno or Leonardo microcontroller board**  
Maker Shed item #MKSP11 or MKSP15, [makershed.com](http://makershed.com)
- » **Battery holder with switch, 9V, with separate coax power plug**  
Maker Shed #MSBAT1
- » **Battery, 9V**
- » **Header, male, 36- or 40-pin**  
such as Jameco #68339 or #160882. You'll break off 20 pins, or 26 if you add an LED.
- » **Wire, solid core** Get 6 or 7 colors, or use colored tape to identify the wires. I use black, red, white, green, blue, yellow, and purple.
- » **Craft sticks, wood, 6"×¾": solid (6) and notched (2)**
- » **Wine corks (2)**
- » **Bottle caps, plastic (2)**
- » **Coffee can, 10oz or 12oz**
- » **Cable ties (10)** aka zip ties
- » **Decorative bits** Use recycled material, broken toys, googly eyes, and other fun bits to personalize your robot.

### OPTIONAL, FOR ADDING LEDs:

- » **LED, jumbo, green** Jameco #2152104
- » **LED, jumbo, red** Jameco #2152112
- » **Resistors, ¼W, 220Ω (2)** such as Jameco #690700

I created CoffeeBots to observe chaotic behavior, by programming a bunch of them with subtle differences and a few choices — for example, how to respond to light sensors — and then turning them loose. To distinguish one from another, I named them after celebrities or historical figures and gave them each their own personality and style. I discovered that their interactions can create patterns that resemble our own social behavior!



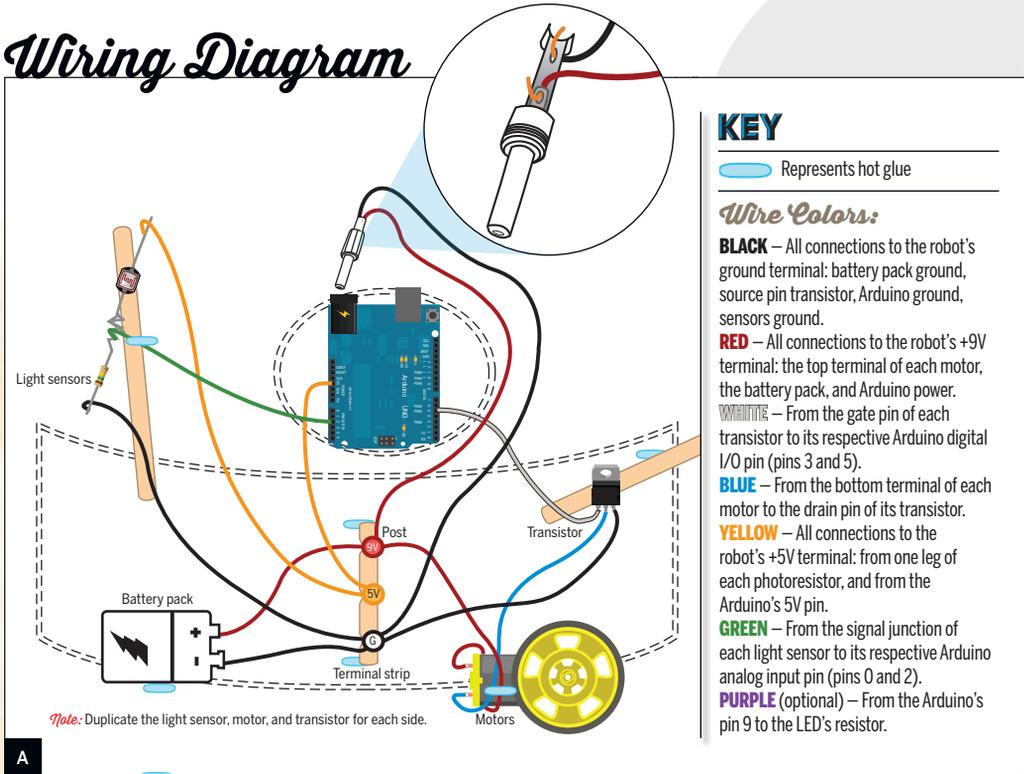
## TOOLS

- » Hot glue gun with glue sticks
- » Soldering iron, fine, with solder
- » Wire strippers
- » Pliers

### OPTIONAL:

- » Helping hands tool
- » Magnifying glass
- » Multimeter
- » Battery, coin cell

# Wiring Diagram



## KEY

 Represents hot glue

### Wire Colors:

**BLACK** – All connections to the robot's ground terminal: battery pack ground, source pin transistor, Arduino ground, sensors ground.

**RED** – All connections to the robot's +9V terminal: the top terminal of each motor, the battery pack, and Arduino power.

**WHITE** – From the gate pin of each transistor to its respective Arduino digital I/O pin (pins 3 and 5).

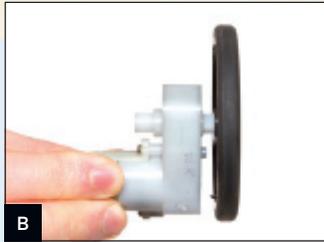
**BLUE** – From the bottom terminal of each motor to the drain pin of its transistor.

**YELLOW** – All connections to the robot's +5V terminal: from one leg of each photoresistor, and from the Arduino's 5V pin.

**GREEN** – From the signal junction of each light sensor to its respective Arduino analog input pin (pins 0 and 2).

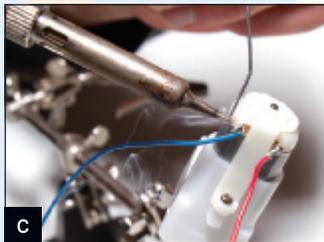
**PURPLE** (optional) – From the Arduino's pin 9 to the LED's resistor.

A



B

Each CoffeeBot is constructed from household materials that give it its own unique characteristics. Functionality comes from motors, sensors, wires, and an Arduino microcontroller for a brain. You can easily program your robot to detect light, to follow it or run away from it, to turn this way or that (by adjusting the timing of the motors), and to blink its LED light in whatever patterns you choose.



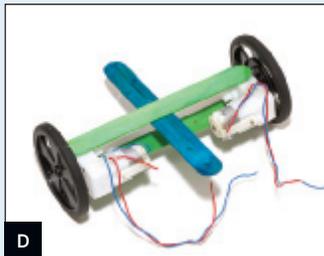
C

This robot was designed to get the most amount of robotic behavior for the least amount of coding, the least amount of money, and the fewest number of parts. And to be built by someone with the least amount of experience, in as little time as possible. You can definitely do this!

## 1. Wire the motors.

Attach a wheel to each motor shaft (Figure B).

Position the motor heads facing each other. Strip the ends of 2 red and 2 blue wires, and hook these into the copper terminals: a blue wire to the bottom and a red wire to the top terminal of each motor. Solder all 4 connections (Figure C). Hot-glue the wires to the motors for strain relief, as shown in the wiring diagram (Figure A).



D

**Caution:** Take care not to rest the hot soldering iron on the plastic motor body, and not to overheat the copper terminals. Also, it's wise to cover connections with electrical tape or heat-shrink tubing to avoid short circuits.

## 2. Build the chassis.

Hot-glue one 6" solid craft stick across the top of both motors, and one across the bottom, for structural support.

For front-and-back stability, hot-glue a third craft stick perpendicular to the first 2 (Figure D). At each end, hot-glue the wine corks and bottle caps as shown in the chassis diagram (Figure E).

**Note:** Make the front cork slightly shorter than the rear cork, and allow the chassis to teeter. This ensures that the wheels will always be in contact with the ground.

Place your favorite coffee can on top of the chassis. Glue additional pieces of craft sticks as necessary to strengthen the connection between the chassis and the can.

## 3. Mount the terminal strip.

This is where multiple connections are made to the positive voltages (+9V and +5V) and to ground. Build the terminal post by gluing 2 small pieces of cork between a notched craft stick and a solid craft stick, then glue the solid stick to the back of the coffee can as shown in (Figure F).

Label the notched stick for the 3 different terminal posts, from top to bottom: +9V, +5V, and Ground.

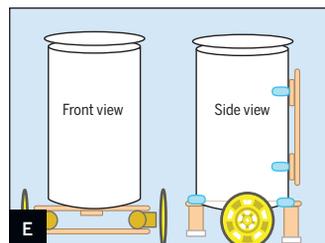
## 4. Make 2 light sensors.

Each sensor is made up of a photoresistor connected in series with a fixed resistor. Twist one leg of each component together, add a green wire, and solder the junction. The green wire will carry the signal from the light sensor.

Now solder the loose leg of the fixed resistor to a black wire, and the loose leg of the photoresistor to a yellow wire (Figure G).

Hot-glue each light sensor to a solid craft stick, then glue the stick to the can to make the robot's arms (Figure H).

**Note:** These resistors aren't polarized, so their orientation doesn't matter when you solder them together. But the assembled light sensor is polarized; you'll connect it in the correct orientation in Steps 8 and 9.



## 5. Wire the transistors.

Look at the component with the tab up, the 3 legs down, and the part numbers facing you.

The left leg of the transistor is called the *gate*. Strip a white wire, twist the stripped end tightly around the gate leg, and solder.

The middle leg is the *drain*. Strip, twist, and solder the blue wire coming from one of the motors.

The right leg is the *source*. Solder it to a black wire.

**Note:** Make sure the wires don't touch; you can bend the legs slightly to separate them (Figure I).

Wire the second transistor and motor the same way.

## 6. Mount the battery pack.

Depending on where you choose to mount the battery pack, you may need to extend its 2 wires to reach the terminal strip; they're typically not very long. Hot-glue the battery pack in place (Figure J).

Wrap the black wire a few times around the Ground terminal location you marked, then strip its end to create your Ground terminal post.

Repeat with the red wire to create your 9V terminal post.

**Important:** Don't put the battery in until you're done wiring the robot and programming the Arduino.

## 7. Solder the power plug.

Unscrew the DC power plug's cover and expose the 2 terminals. Solder a red wire to the inner terminal (+), and connect the other end to the +9V terminal post. Solder a black wire to the outer terminal (-) and connect it to the Ground terminal post (Figure K).

**Caution:** Put electrical tape between the 2 terminals to avoid having them touch and short circuit.

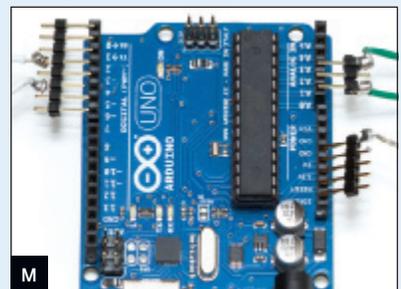
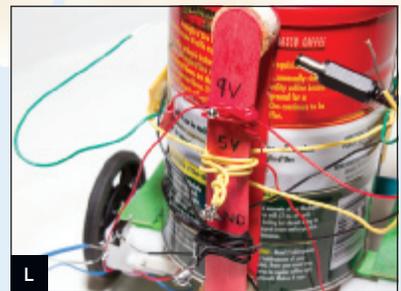
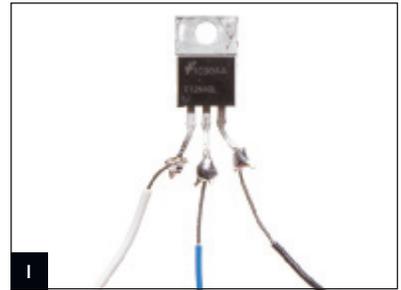
**Important:** Thread the wires through the plug's cover before soldering them to the robot's terminal strip, so that you can screw it back on.

## 8. Connect the terminal posts.

Wire the remaining terminal strip connections, following Figure A. At your 9V terminal post, solder together the red wire from the battery pack, the 2 red wires from the top of the motors, and the red wire from the Arduino's power plug.

For your 5V terminal, solder the 2 yellow wires from the light sensors, as well as a new yellow wire (which you'll connect to the Arduino's 5V pin in just a minute). You can wrap this new wire around the terminal strip to make it stay put.

And at the Ground terminal post, connect the black wire from the battery pack to the 2 black wires from the right legs of the transistors, the 2 black wires from the light sensors, and the black wire from the Arduino's power plug (Figure L).



**Note:** To avoid short circuits from exposed bare wires, only strip as much wire as is necessary to connect to your terminals.

Now you can tidy up your wires using the zip ties, and glue the transistors to the wooden arms if you wish.

## 9. Solder the headers for the Arduino.

Break off 3 strips of male header pins to fit the Arduino board's female headers for Power (6 pins), Analog In (6 pins), and Digital I/O pins 0–7 (8 pins). These male headers have one row of short pins, to which you'll solder your wires, and one row of longer pins, which you'll plug into the Arduino.

In the Power block, solder the free wire from the robot's +5V terminal post to your 5V header pin.

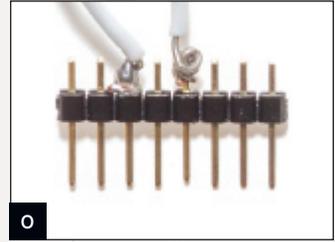
In the Digital block, solder the white wires from the 2 transistor gates to your Digital 3 and 5 header pins.

In the Analog block, solder the green signal wires from the 2 light sensors to your Analog 0 and 2 header pins (Figure M).

The schematic diagram (Figure N) shows

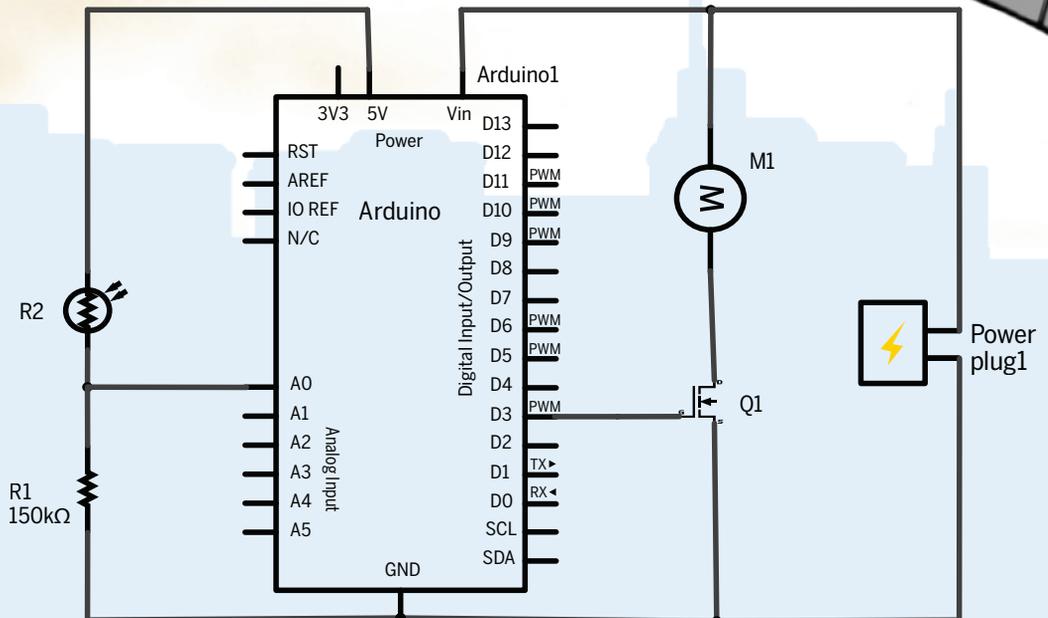
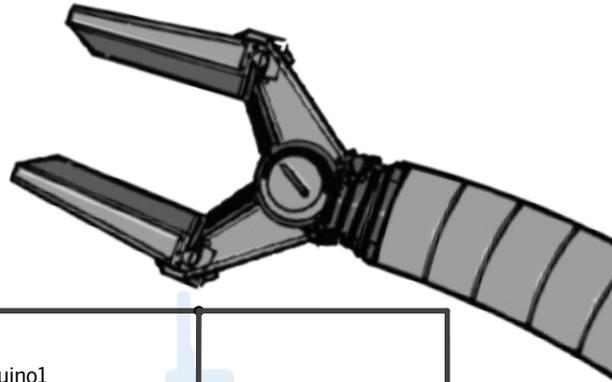
how these connections work (for one side only).

**Tips:** Solder the wires to the headers before you plug the headers into the Arduino.



To avoid short circuits, make sure the wires don't touch adjacent pins; I have intentionally avoided using adjacent pins to give you more room to work.

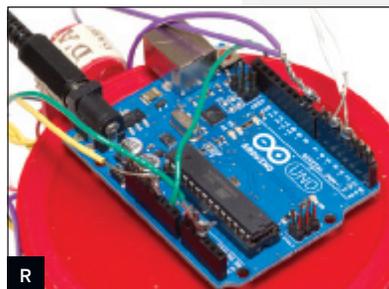
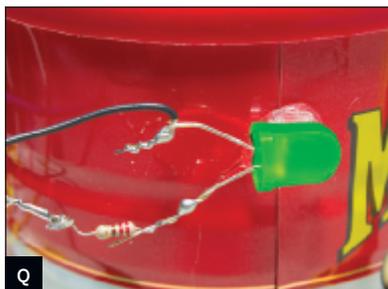
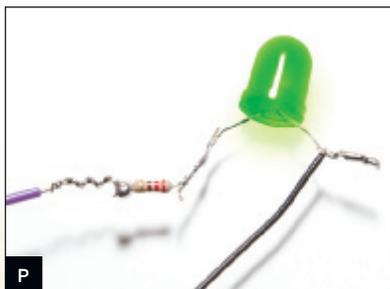
It isn't necessary to twist the wires around the pins; it's best to strip only 1/8", apply solder separately to the wire and the pin, and finally, touch the wire to the pin and remelt the solder to form a good connection (Figure O).



N

Arduino Schematic

Note: This is only for one side



## 10. Add an LED (optional).

Solder a black wire to the negative leg of the LED, typically indicated by a shorter leg and/or a flat spot on the LED's plastic dome.

Solder one end of a 220 $\Omega$  resistor to the positive leg of the LED. Solder a purple wire to the loose end of the 220 $\Omega$  resistor, forming a series circuit (Figure P).

Solder the other end of the wire to a male header pin in the Arduino's Digital block. You might wish to make an additional male header for Digital pins 8–13, and use pin 9 for the LED.

Solder the black (–) wire to the robot's Ground terminal post. Then glue the LED wherever you want it on the robot (Figure Q).

## 11. Program your Arduino.

The Arduino microcontroller will process all the inputs and outputs and control your CoffeeBot. Download and install the Arduino environment on your computer, following the instructions at [arduino.cc/en/Guide/HomePage](http://arduino.cc/en/Guide/HomePage).

Then download the CoffeeBot code from [bit.ly/coffeebot](http://bit.ly/coffeebot), and upload the correct version (with our without an LED) to your board.

## 12. Install the brain.

Use the coffee can's plastic lid as a tray for the Arduino, securing it with zip ties.

If your lid is metal, then make a tray from craft sticks, plastic, or other nonconductive material to avoid short-circuiting the board.

Plug your male headers into the corresponding female headers on the Arduino (Figure R). Now your CoffeeBot has a brain.

## 13. Give it nutty flavor.

CoffeeBots aren't just robots made with a

coffee can and wires. Give them a personality you can see — a wheel that wobbles and drags a little to one side, or an LED that sort of hangs there like a weird antenna!

Now's the time to go nuts with hot glue and googly eyes, pirate flags, or whatever bits you'd like to add to make it unique and fun.

## Use It

Put a battery in, plug the power plug into the Arduino, and switch on the battery pack.

The CoffeeBot Arduino program makes your robot either seek or avoid light, depending on how it's wired up. Shine a flashlight, or hold your hand over a light sensor, to change the robot's behavior.

If you added the optional LED, the program will make the robot's LED light up whenever the sensors measure equal brightness.

Try out this simple code first, and then start modifying it to give your robot the personality you desire. Position the LED so that other CoffeeBots can perceive the light, and see if they'll react to it according to their own programming!

I designed the CoffeeBot as a platform for experimentation by adding other sensors. Maybe you'd like to add bump sensors, or distance measuring sensors, or infrared LEDs and detectors.

With these additional sensors, and suitable programming, it would be possible for robots to identify other robots and to follow, lead, or communicate with them! ▣

## BIO

**Judy Aime' Castro** ([judy@teachmetomake.com](mailto:judy@teachmetomake.com)) is a tinkerer, artist, and collaborator with Teach Me to Make.



## CoffeeBot Code

Here's the basic CoffeeBot code for your Arduino. If you installed the optional LED, get that version of the code at [bit.ly/coffeebot](http://bit.ly/coffeebot):

```
/*
This program makes your robot either seek light or avoid light, depending on how
it is wired up.
Try this program first, and then start modifying it to give your robot the
personality you desire.
Shine a flashlight, or hold your hand over a light sensor, to change the
behavior.
Other examples and suggestions are on our website.
*/
void setup()
{
  // Set the mode of the digital pins to outputs to drive the motors
  // (the analog inputs are automatically inputs and so don't need to be set)
  pinMode( 3, OUTPUT );
  pinMode( 5, OUTPUT );
}

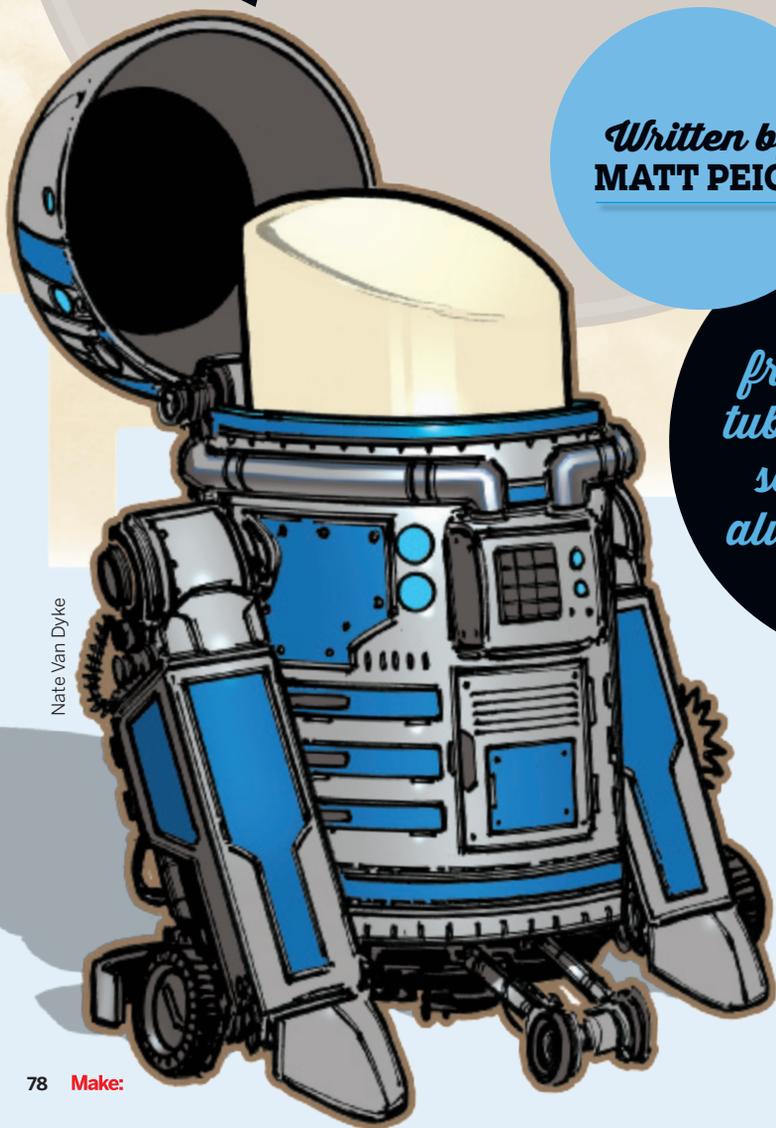
void loop()
{
  // Compare the two light sensors
  if ( analogRead( 0 ) > analogRead( 2 ) )
  // If one light sensor has more light than the other ...
  {
    digitalWrite( 3, LOW ); // turn this motor off ...
    digitalWrite( 5, HIGH ); // and this motor on to turn in one direction
  }
  else // otherwise ...
  {
    digitalWrite( 3, HIGH ); // turn this motor on
    digitalWrite( 5, LOW ); // and this motor off to turn in the other direction
  }
}
```

# THE MIGHTY LIP BALM LINEAR *Actuator*

*Written by*  
**MATT PEICK**

*Make one  
from a Blistex  
tube, mini hobby  
servo, and an  
aluminum shaft.*

Nate Van Dyke



I needed a small linear actuator (a mechanism for creating motion in a straight line) for a project and was finding only oversized or cost-prohibitive solutions. Industrial automation actuators have plenty of muscle but rarely come in small packages. Hobby linear actuators come with a smaller footprint but can be costly. I've often wondered about the load capacity of the screw and nut contained in a standard lip balm tube, so I collected all the lip balm tubes I could find and started testing.

One stood out over all the others and could exert over 10 pounds of thrust with a 1.25" stroke: the mighty Blistex tube. No other lip balm screw-and-nut assembly comes close to carrying the same load as a Blistex tube. Add a magnet to the shaft and a couple of reed switches to the case, and you've got an actuator with limit switches at each end!

⚡ **TIME: A WEEKEND** ⚡ **COST: \$\$**

## MATERIALS

» **Clevis mounts, rear and front**

Make these from ABS plastic, wood, or any material you're comfortable working with. See dimensions in Step 3e.

» **Hobby servo, full rotation**

SparkFun Electronics #ROB-10189, [sparkfun.com](http://sparkfun.com)

» **Blistex lip balm tube** The actuator's drive screw, body tube, drive nut, and cap are all made from it.

» **Proximity sensors, magnetic, NPN, 3-pin (2)** Jameco Electronics #513244, [jameco.com](http://jameco.com)

» **Magnet, 1/8" square** SparkFun #COM-08644

» **Aluminum tube, 3/8" OD x 3"** McMaster-Carr #9056K643, [mcmaster.com](http://mcmaster.com). The shaft can be any nonmagnetic 3/8" OD tube of at least 1/4" ID — even plastic.

» **Threaded insert, #8-32** McMaster #92105A660

» **Threaded shaft, #8-32 x 3/4"** Cut this from any #8-32 bolt.

» **Cable ties, small**

» **Plastic epoxy** J-B Weld works well.

## TOOLS

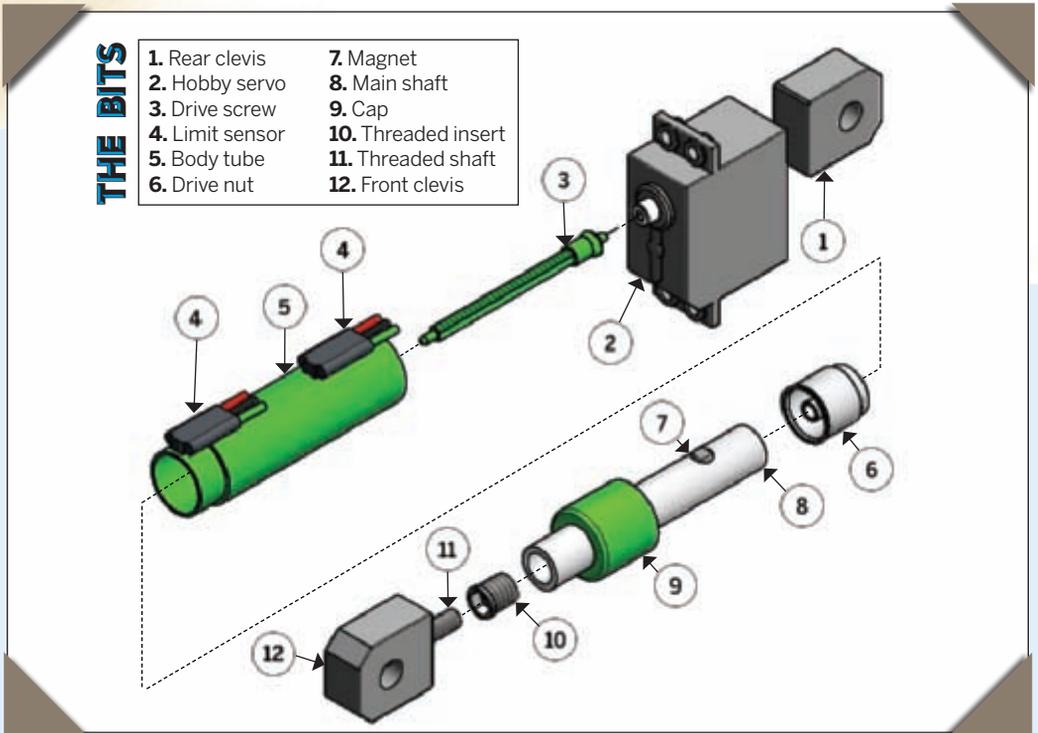
» **Drill and drill bits: 3/8" Forstner, 3/8" brad point, 3/16"**

» **Utility knife**

» **Tubing cutter or hacksaw**

» **File or sandpaper**

» **Screwdriver, flat-blade**





## 1. Prepare the Blistex tube.

**1a.** First you'll need to remove the lip balm. Put the lip balm tube in the refrigerator for 10 minutes. This will solidify the contents and make it easier and cleaner to remove. Then, extend the lip balm all the way and twist the solid block out of the lead screw nut.

The label will peel off cleanly if you do it slowly.

**1b.** Pry the base off the Blistex tube. The leadscrew and base are molded together and will come off as one part. A barbed snap feature holds the base in place. Try not to dent the end of the tube when prying off the base. Eventually you'll glue this bottom surface of the tube to the servo.

**1c.** Clean all the components thoroughly. Getting all the lip balm off the components is critical for good adhesive bonding.

**1d.** Open up the bottom and cut the notch. The bottom of the body tube has a base plate with a small hole; drill it out or cut it out with a utility knife.

The notch is sized to accommodate a feature on the servo and can be cut with a utility knife. Mine was about  $\frac{1}{5}$ " wide and  $\frac{1}{20}$ " deep; cut yours to fit your servo. (If a stepper, DC, or other motor is being used, this step can likely be skipped.)

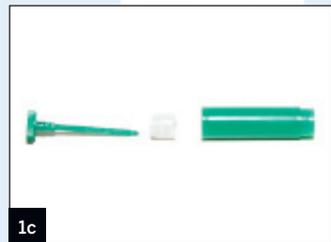
**1e.** Drill the cap. To prevent the main shaft from binding in the cap, it's critical to drill this hole as close to the center of the cap as possible. To find the center, you can use a center-marking jig or just use the molding mark in the center of the cap; it's visible when the cap is viewed from a low angle. Use a fine-tip marker to mark this molding point as your center point for drilling.



1a



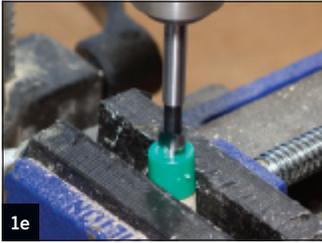
1b



1c



1d



You must use a  $\frac{3}{8}$ " Forstner or brad point bit because a standard twist drill will catch immediately and ruin the cap. Proceed with a slow bit speed and try not to collapse the cap by clamping it too tightly. If necessary, you can use a wooden dowel, fit to the inside of the cap, to back up the cap when you're clamping it.



## ***2. Build the main shaft.***

**2a.** Cut a  $2\frac{3}{4}$ " length of the  $\frac{3}{8}$ " aluminum tubing. A tubing cutter will provide a square, burr-free cut, but a hacksaw will also work fine.

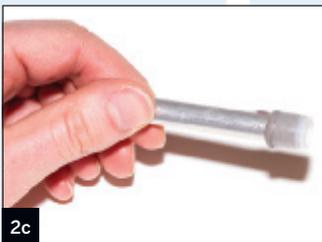
Drill a  $\frac{3}{16}$ "-diameter hole  $\frac{1}{2}$ " from one end. This hole is for mounting the sensor magnet.



**2b.** Using epoxy, glue the  $\frac{1}{8}$ " square magnet into the hole in the main shaft. Ideally, the magnet can be wedged into the hole and secured with epoxy. If the magnet slips through the hole, use a dowel or rod in the main shaft to support it while gluing. The magnet should extend into the  $\frac{1}{16}$ " gap between the main shaft and the body tube, so be sure it protrudes slightly above the surface of the shaft when glued.



**2c.** Epoxy the main shaft into the drive nut. Shaving off the tabs on the drive nut may allow it to slide with less friction. Make sure no glue seeps into the threads of the drive nut. To ensure that the drive nut is square on the end of the shaft, you can use the body tube and cap as a jig to hold the shaft and drive nut in place while the glue sets.



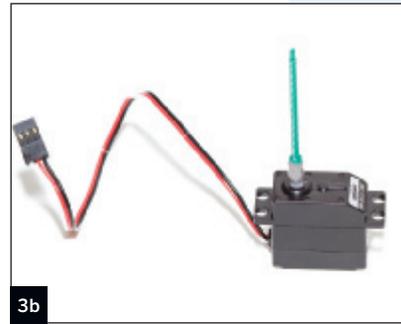
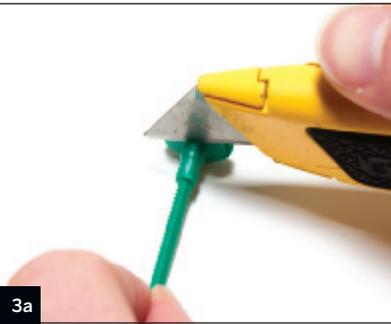
**2d.** Test fit the threaded insert. If the fit is tight, lightly sand or file the inside of the main shaft tube. Epoxy the threaded insert into the end of the main shaft, making sure that no glue gets into the inside threads and that the end of the threaded insert is flush with the end of the main shaft.

## ***3. Assemble the actuator.***

**3a.** Use a utility knife to cut the drive screw off the base. Then trim the end of the drive screw down to create a post that fits into the servo hub.



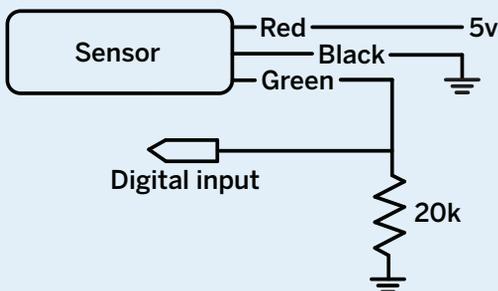
**3b.** Epoxy the drive screw to the servo. Or, if you'd like the option to replace the drive screw, cut the head off one of the attachment screws that came with the servo. Drill a  $\frac{1}{16}$ " hole in the end of the drive screw, then glue the attachment screw into this hole. You can then screw the drive screw into the servo.



**3c.** Epoxy the body tube to the servo. Use the completed main shaft to ensure that the body tube is glued in place concentric to the drive screw. To accomplish this you'll need to have the servo powered up. With the body tube and epoxy in place, but not yet set, power the servo to pull the main shaft down into the body tube about  $\frac{3}{4}$  of the way.

**3d.** Epoxy the limit sensors in place. The front proximity sensor is glued to the cap,  $\frac{1}{8}$ " down from the top. The rear sensor is  $\frac{5}{8}$ " from the bottom of the tube. Lightly sanding the tube first will help the epoxy hold.

Before actually gluing the sensors, do a dry run. Hook up the circuit shown below and run the main shaft in and out using the servo, holding the sensors in place with tape. Mark the axial position where the sensors make contact with the magnet. There are anti-rotation ribs between the drive nut and the body tube, but the main shaft can be completely removed and repositioned to put the magnet where you want it. Positioning the magnet and sensors along the short side of the servo allows the servo mounting holes to be used for routing the sensor wires.



**3e.** Fabricate the front and back clevis mounts out of ABS plastic or wood. The ones shown were 3D-printed in black ABS, and are roughly  $\frac{3}{4}$ " square with a  $\frac{1}{4}$ "-diameter hole. You may want to specifically design yours for the application you have in mind. The rear clevis is glued directly to the back of the servo.

**3f.** The front clevis has a threaded shaft to allow fine adjustments. Use a  $\frac{9}{64}$ " drill bit to drill a hole in the center of the clevis end through to the existing center hole. Thread a  $\frac{3}{4}$ "-long #8-32 threaded shaft into this hole, up to the center hole, and glue it in place.

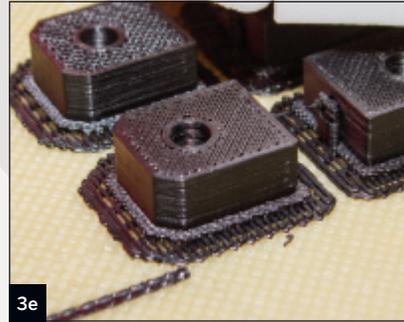
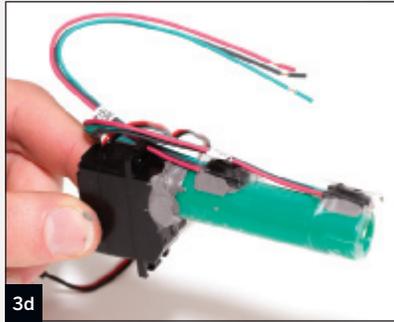
Finally, thread the front clevis into the main shaft, and your linear actuator is complete!

## Put It to Work

To get the most out of your new powerhouse you'll need a microcontroller to power the servo and take input from the limit sensors. The limit sensors work by changing state when the magnet is in close proximity. Normally the input to the microcontroller will be +5V. When the magnet passes by the sensor the input will be pulled down to ground.

The alignment of the magnets to the sensor is a bit precise and may take repositioning of the main shaft in the body tube during the initial setup. To help set up the sensors and test the completed actuator for different uses I made up an Arduino test platform, with one button to extend the actuator and one to retract it. My Arduino program does not allow you to overextend or over-retract; you can find a copy of it at [makezine.com/34](http://makezine.com/34).

To test the full-force capability, I set up a

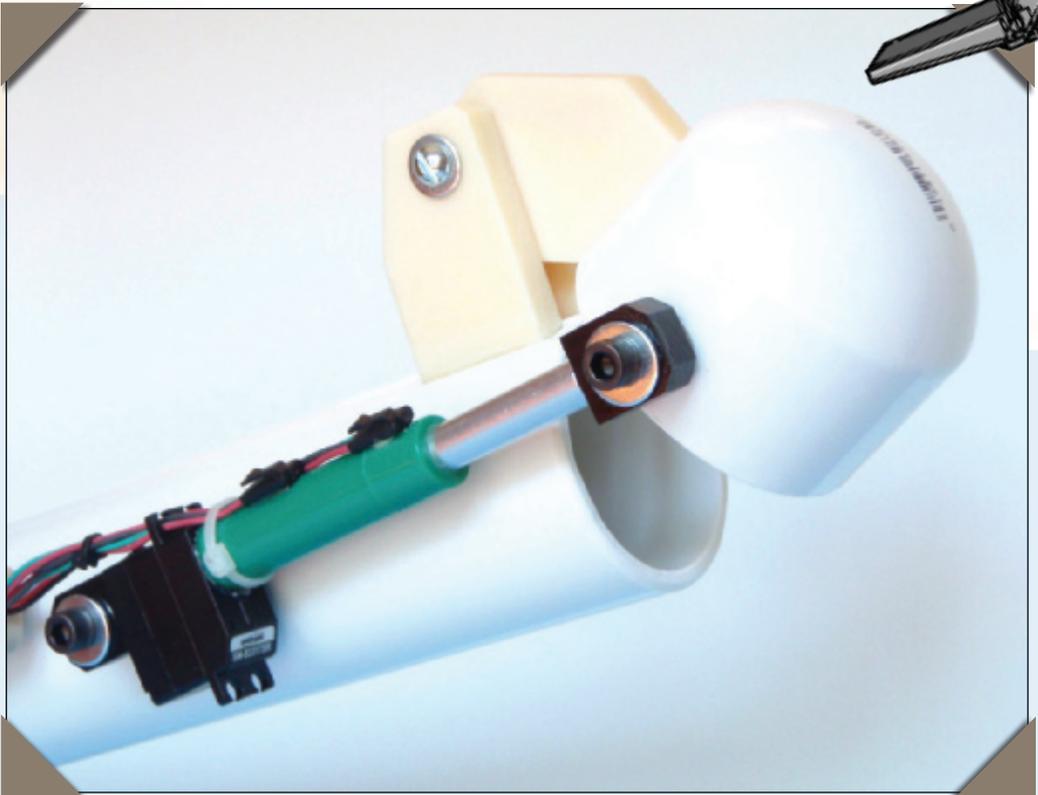
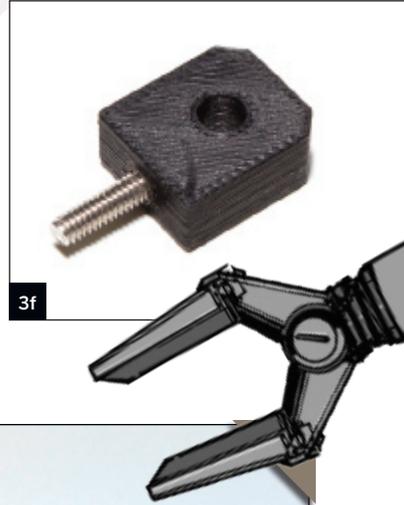


scale that showed the actuator pushing at 5.75kg, or over 12lbs! Two projects I've implemented using this actuator are an automatic vent pipe cap (see below) and a "spurting" action on a Halloween prop.

With over 10lbs of force and a 1¼" stroke, the mighty lip balm linear actuator packs a punch, is cost effective, and may be just what you need for your next project. ▣

## BIO

**Matt Peick** ([matt@thepeicks.com](mailto:matt@thepeicks.com)) is a mechanical engineer and the vice president of engineering at Perbix Machine Company.



## SMARTPHONE

## Servo

*Plug hobby servos straight into your smartphone and control almost anything with a fingertip.*

*Written by*  
**KAZUHISA  
TERASAKI**

Smartphones have become our primary interface to the network world, and increasingly, to the real world as well. I call this project GlueMotor, because it works like “glue” for putting gadgets together under smartphone control, providing a very easy way to build simple servo-controlled machines.

⚡ TIME: 30 MINUTES ⚡ COST: \$\$

**MATERIALS**

- » **Servomotors (2)** Futaba S3003 or other standard hobby servos
- » **Stereo phone plug, 3.5mm (1/8")**, with cable A pair of cheap earbuds is perfect.
- » **Battery holder**, 4×AA, with wires
- » **Hookup wire, 22 AWG solid core** You'll use about 12" each of red, black, and yellow.
- » **Batteries, AA (4)**
- » **Capacitors, ceramic, 0.1μF–0.47μF (2)**
- » **Heat-shrink tubing or electrical tape**
- » **Cable tie, plastic** aka zip tie

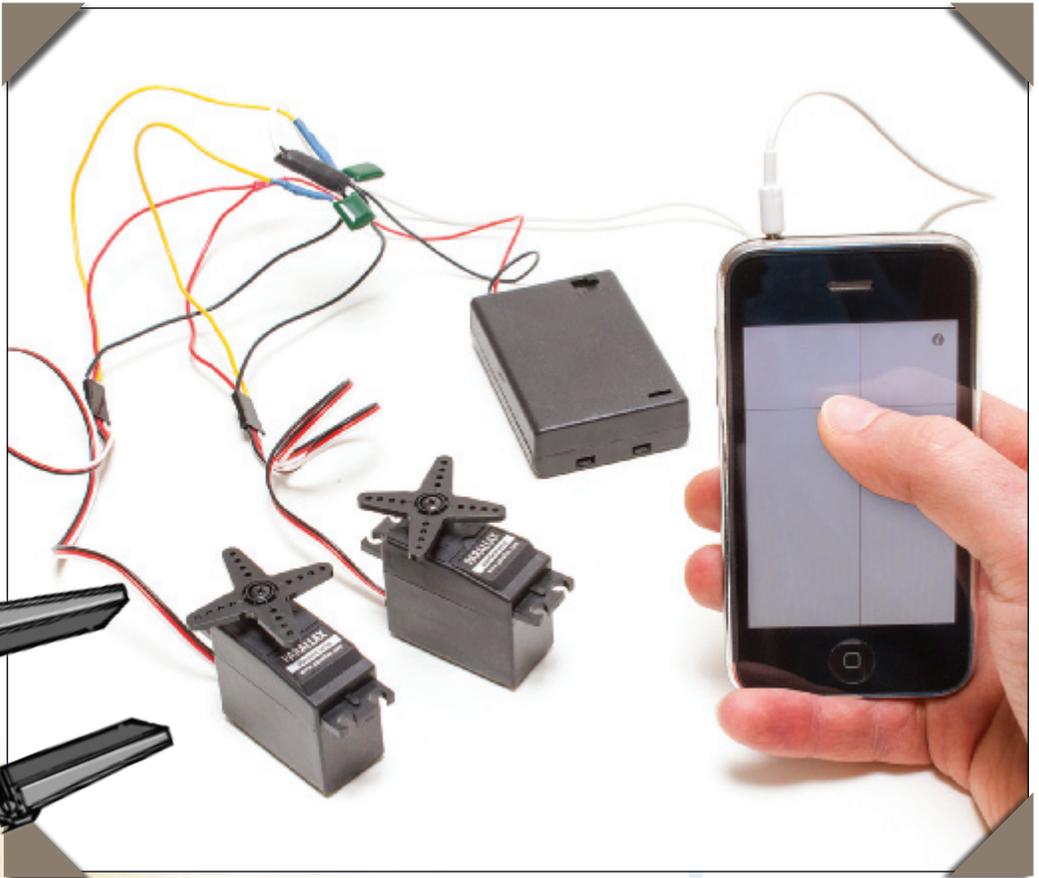
**TOOLS**

- » **Smartphone or tablet** iOS or Android
- » **Wire cutter/stripper**
- » **Lighter or match**
- » **Sandpaper, 400 grit**
- » **Soldering iron and solder**
- » **Multimeter**



To use it, attach any convenient on-hand materials — PVC pipe, chopsticks, Legos, duct tape — to a GlueMotor, then plug it into your smartphone's headphone jack. The GlueMotor app lets you control it with a finger swipe.

The GlueMotor can be attached to your smartphone's headphone jack and used to actuate any convenient materials at hand —



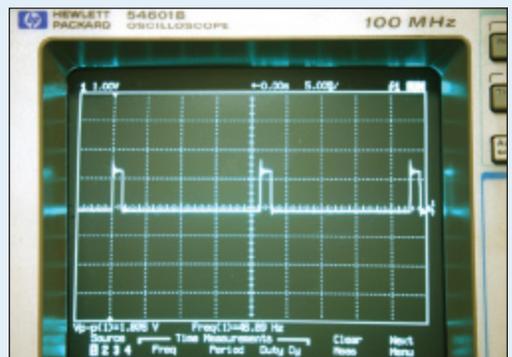
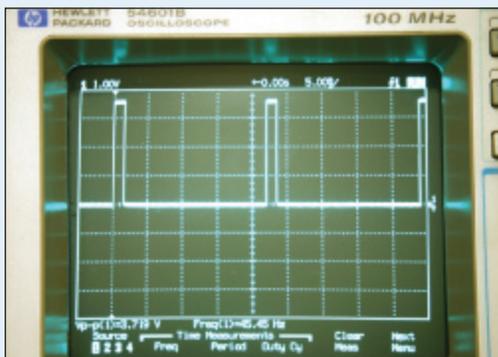
PVC pipe, Legos, duct tape, chopsticks, you name it! The GlueMotor app then lets you control all of this with the swipe of your finger.

### *How It Works*

Controlling a hobby servo-

motor is relatively easy. It requires a single digital pulse-width modulation (PWM) signal at 50Hz, which means one pulse every 20ms. The width of the "high" pulse sets the absolute rotation angle of the servo.

Normally the width of the pulse at center angle is 1.5ms. A longer pulse will set the angle clockwise of center, and a shorter pulse will set it counterclockwise. The maximum and minimum angle will depend on



PWM servo signals generated by an R/C radio receiver, left, and by an iPhone running the GlueMotor app.

the model of servomotor, but usually a range of  $1.5\text{ms} \pm 0.5\text{ms}$  is supported. In a typical R/C car or airplane application, the radio receiver generates the control signal.

But the radio receiver is not strictly necessary. If you can generate the proper PWM signal by whatever means, you can control a servomotor in exactly the same way. The GlueMotor project uses a smartphone to generate the control signal, and outputs it through the headphone jack.

The output from a headphone jack is usually an analog audio signal such as music or voice. If you can create digital sound data that only has “high” and “low” voltage values, then play the data through the headphone jack, you can produce a “nearly” digital signal good enough to control the servo.

To generate this signal, I have developed two applications, one for iOS devices, and another for Android. The user interface is very simple, converting the onscreen coordinates of a touch location to the width of two PWM signals, allowing simultaneous control of two servos. The GlueMotor app is free from the iOS App Store and Google Play.

**Note:** Some devices may not produce enough voltage at maximum volume for this project. To test your device, play a sine wave tone through the headphone jack and measure the output with the AC voltage mode of your multimeter. A reading of 0.6V or higher should work.

## 1. Prep the phone cable.

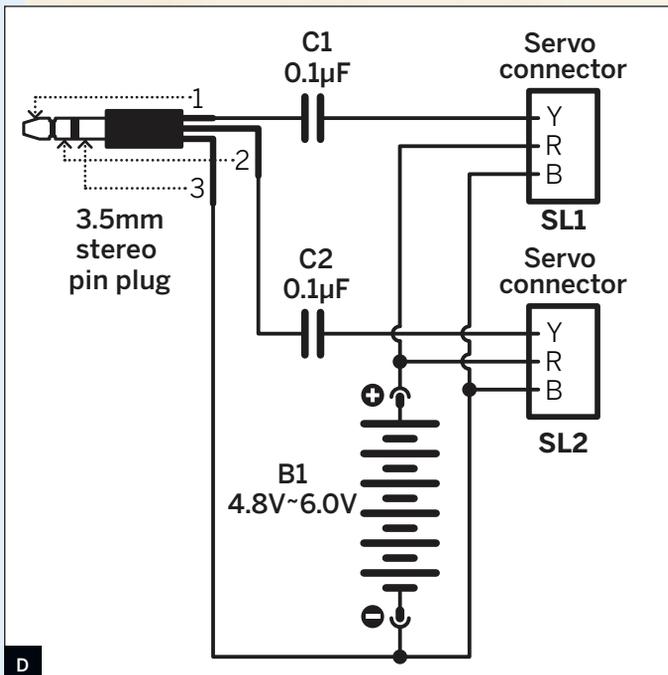
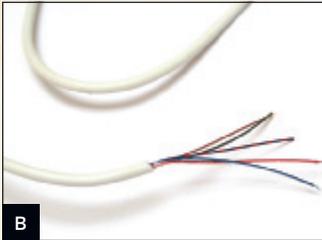
Cut the earbud cable (Figure A), then strip the outer insulation from the side attached to the plug (Figure B).

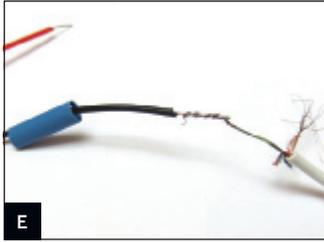
Now strip the 3 wires inside (Figure C) by quickly running them through a small flame to burn off the insulation and strain-relief fibers. Lightly rub the exposed metal wires with 400-grit sandpaper to clean off any residue.

Use the multimeter’s continuity setting to identify which wire corresponds with contact on the phone plug.

## 2. Solder the harness.

Use the schematic in Figure D as a guide. First, solder the black wire from the battery holder to the phone plug ground wire (Figure E). Next, solder a capacitor lead to each of the remaining 2





plug wires (Figure F). These capacitors aren't polarized, so it doesn't matter which lead you solder.

Cut two 6" black hookup wires, strip the ends, and solder them to the ground junction of the battery holder and phone plug (Figure G). Insulate this joint, and the 2 capacitor lead joints, with heat-shrink tubing or electrical tape (Figure H).

Cut two 6" yellow hookup wires, strip the ends, and solder one to each of the free capacitor leads. Cut two 6" red hookup wires, strip the ends, and solder both to the battery pack's red lead, dividing it into 2 parallel leads. Insulate all these connections with heat-shrink tubing or electrical tape (Figure I).

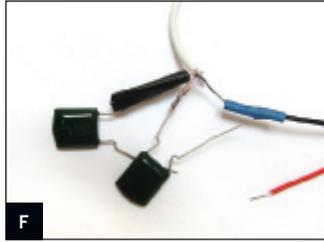
### 3. Install the app.

Go to the Apple iTunes App Store or Google Play, search "GlueMotor" to find the app, and follow the instructions to install it on your device.

### 4. Test it on the servos.

Install the batteries in the holder. If they get hot, disconnect them immediately and check for a wiring error.

Before connecting the servos, insert the phone plug into your device's headphone jack.



Turn the volume all the way up and launch the GlueMotor app. The 2 lines should cross right in the center of the screen. Don't touch the screen yet.

Connect the servos to your wiring harness, as shown in Figure J, by pushing the stripped ends of the wires into the servo cable header sockets. If you've used the wire colors indicated in the steps above, all you have to do is match the colors.

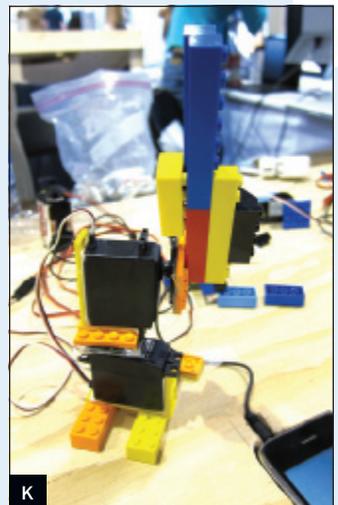
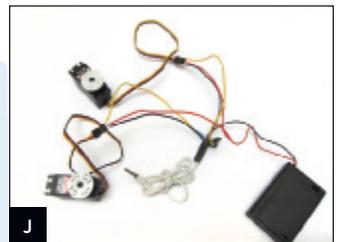
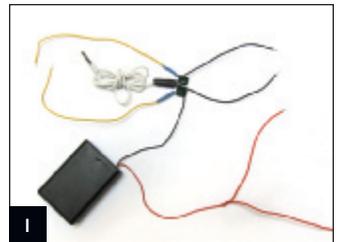
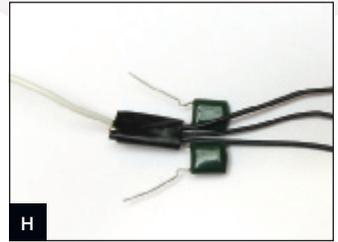
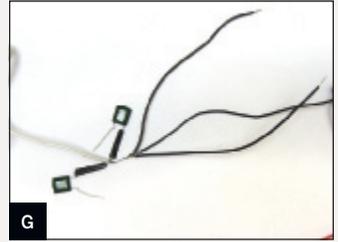
Touch the screen to move the crosshair. The horizontal position controls one servo-motor, and the vertical position the other. Once it's working, use zip ties to tidy up the wiring.

### 5. Get gluing.

For my recent demonstration at Maker Faire, I demonstrated GlueMotor by attaching Lego elements to the servo arms with double-sided tape (Figure K). Lego is a very handy prototyping system for this purpose. ☑



**Kazuhisa "Kazu" Terasaki** is a software engineer who loves prototyping low-tech gadgets out of high-tech junk. He calls this stuff Pachi-Mon, which is Japanese for "not quite real, but works."





Micah Ganske

## Finishing and Post-Processing Your 3D-Printed Objects

Friction-weld, rivet, sand, paint – arm yourself with simple tools and techniques to take your desktop 3D printer to the next level.

Written by **Matthew Griffin** Photographed by **Andrew Baker**

## PEOPLE OFTEN CLAIM 3D PRINTERS CAN “MAKE YOU ANYTHING YOU CAN IMAGINE.”

Dial up the digital model you want, hit “Go,” and the machine hums to work, producing an object, accurately and repeatably. But as an astute 8-year-old pointed out to me when I handed her two of my favorite printed models at Maker Faire Bay Area last year, the results don’t always match your intentions.

“That octopus is *red*! A TARDIS is not *supposed* to be yellow!” she wailed and knocked my offerings away.

While overall shape and mechanical fit are valued more highly than surface treatment in today’s desktop 3D printing, it’s sometimes worth judging a print by its cover.

I’m reminded of advice I got from a pair of industrial design professors at Pratt, after I showed them my print of a fluorescent-green clockwork mechanism: “It is worth enormous effort to make prototypes *look* like they were created from real-world materials.” Even the most creative engineers and businesspeople will have difficulty seeing your prototype as a “machine” when it looks like a toy.

The domain of finishing techniques (i.e., everything that takes place after printing) is the craftsman’s workshop, where patience, tools, skills, and experience can transform the raw products of these machines into fully realized models. Like builders of dollhouses and model trains, many 3D printer jocks appreciate a loving and accurate rendering of a miniature world.

The results are impressive, but why should you tackle these craft skills when you could spend that time printing more plastic objects?

Makers who have mastered finishing techniques are granted wizard status by fellow 3D practitioners. Take artist Cosmo Wenman, who creates pieces that accurately mimic distressed metals and stones. And sculptor Jason Bakutis, whose sanded, painted, and polished faux marble and jade prints look remarkably like the real thing. Through careful work, pieces printed in crazy pink, green, and translucent filaments are made to resemble

## TOOLS & MATERIALS

- » **Benchtop vise** e.g., PanaVise
- » **Pliers, combination** aka lineman’s pliers
- » **Pliers, needlenose**
- » **Multitool**
- » **Safety goggles** I like DeWalt’s DPG82-11C clear anti-fog model.
- » **Respirator for sanding/particulates** I use 3M’s 8511 particulate respirator.

### FRICION WELDING:

- » **High-speed rotary tool with 1/8" and 3/32" collets** e.g., a Dremel
- » **Filament for 3D printer, ABS or PLA**

### HEATING/REWORKING:

- » **Hot air SMD rework station** (pictured below) or other small heat gun
- » **Soldering iron and solder**
- » **Brass tube** to fit snugly over your soldering iron tip
- » **Metal plate or mirror (optional)** for fast cooling
- » **Nail, steel, large** for cooling/pressing

### TRIMMING/GRINDING:

- » **Deburring tool** I use Noga’s heavy duty NG-1 model.
- » **Flush cutters** aka diagonal pliers or wire cutters
- » **Files, narrow, diamond grit**
- » **Coffee/spice grinder**, for grinding filament

### SANDING/POLISHING:

- » **Sandpaper: 80/100, 150, 220, 320, and 500 grits**
- » **3M Wetordry Polishing Papers**
- » **Micro-Mesh Soft Touch Pads and Colored Sanding Sticks**
- » **Sanding/polishing/buffing disks** for rotary tool
- » **Novus Plastic Polish Kit**

### FILLING/GLUING/PAINTING/SEALING:

- » **Acetone** for use with ABS objects (not PLA)
- » **Resealable container, acetone-resistant**
- » **Enamel hobby paints** such as Testors
- » **Acrylic paints**
- » **Clear-coat spray paints** I use Krylon Crystal Clear Acrylic, Matte Finish, and Triple Thick Crystal Clear Glaze; and Rust-Oleum Matte Clear and Gloss Clear.





clay, stone, metal, and wood. How do they do that?

The desktop 3D printing community has a lot to learn from the sculptors, model railroad builders, and tabletop gamers now joining their ranks. And as my professors pointed out, these extra steps aren't just cosmetic. Your capacity to transform your models into "magical" replicas is a crucial means of communicating your inventions.

### TRICKS OF THE TRADE

Desktop 3D printing has yet to spawn third-party finishing services like commercial 3D printing did a decade ago. So, without access to acetone cloud chambers, multi-axis enamel jet robots, agitating chemical baths, and industrial tumblers and polishers, makers have rolled up their sleeves and discovered a host of finishing solutions using inexpensive tools and materials. These methods not only affect a print in post-production, but can often change the way we think about a digital model back in the initial design stages.

In researching my upcoming book *Design for 3D Printing* (Make: Books, Sept. 2013), I've interviewed a wide range of members of the desktop 3D printer community. I'd like to share some of their promising tools and techniques. In turn I hope that those of you refining new methods and sourcing better, safer, and cheaper products and techniques will also share. Post your ideas and thoughts in the comments section at [makezine.com/go/3dprint-finishing](http://makezine.com/go/3dprint-finishing).



## FRICTION WELDING

The world may have forgotten the Spin Welder toy sold by Mattel in the mid-1970s, but Fran Blanche of Frantone Electronics did a great job of re-creating the experience in her 2012 video "Build Your Own Friction Welder." Using an inexpensive rotary tool, Fran was able to spin a styrene rod fast enough to create a strong weld between two pieces of plastic that was difficult to break apart by hand. With the Spin Welder toy, children assembled the frames of helicopters, motorcycles, and other projects by fusing together beams and struts, then used plastic rivets to fasten the outer shell. Sure, it was potentially one of the most dangerous toys of all time, but I agree with Fran's conclusion: why haven't tools like these joined the maker's toolbox?

Unlike adhesives or traditional welding, *friction welding* fuses metal or thermoplastic objects together by quickly spinning or vibrating one piece against another. Mechanical friction creates a melt zone shared by both parts, fusing them into one solid piece. In *friction surfacing* — a variant of friction welding — a piece rotated at high speeds is moved across an edge or surface under gentle pressure to weld seams, patch gaps, or smooth surfaces.

These techniques are common for plastics and aluminum in the automotive and aerospace industries, but the tools are expensive. Sophisticated spin welders can spin parts at hundreds of thousands of RPMs for short bursts of even single-digit rotations,



parking the fused part at a precise orientation. Where are the cheap, hand-tool equivalents?

As it turns out, many of us already have the equipment to experiment with friction welding. Dremels and similar high-speed rotary tools spin fast enough to melt 3D printer plastics, and printer filament can be used as welding “rod” to solidly fuse parts or close seams. These tools can also spin-weld 3D-printed rivets. And while it takes them a second or two to spin down again, the melting points are comparatively low, allowing for some manipulation after the fact to reposition the joined part.

I think both approaches — welding and riveting — are killer tools for 3D print finishing, particularly for “blind riveting” into the side of objects, and for joining parts made of PLA, which is typically much harder to glue than ABS.

## Friction-Welding Mismatched Surfaces

I spent some time with Chris Hackett from the Madagascar Institute learning how ideas from traditional metal welding might apply to friction-welding 3D-printed parts. We experimented with the rotary tools in his workshop and came up with the following approach for creating a nice welded seam

in plastic, similar to a traditional metal weld. When two printed parts don't mate perfectly due to warp or poor planning, you can friction-weld them together as securely as if they were a single printed part. Here I'll demonstrate with ABS parts and ABS filament. It works with PLA too.

### 1. PREPARE THE ROTARY TOOL

**1a.** Select the collet you need for trapping the filament you'll be using. For 1.8mm filament, use a  $\frac{3}{32}$ " collet as shown here (3 rings) and for 3mm filament use a  $\frac{1}{8}$ " collet (0 rings).

**1b.** Insert a short length of filament into the collet jaws and tighten down the collet nut to secure it in place.

**1c.** Trim the filament about  $\frac{1}{2}$ " from the collet. Short pieces are easier to control, and they spin on a tighter axis. (With experience you can use longer pieces, pressed gently at an angle, to make longer welds. You may need to straighten them by reforming them with a heat gun.)

### 2. PREPARE 2 PARTS FOR WELDING

**2a.** After scraping and sanding, these 2 watch body cases meet with a gap that varies between 0.1mm and 2mm around the edges. That's too sloppy for gluing, so I'll weld them.

**2b.** Use a deburring tool or razor blade to bevel the top edges of the seam where the parts meet, forming a narrow, V-shaped channel. Your goal is to create enough room for 3 welding layers, from the bottom of the bevel up to just above the surface of the 2 parts. This method gives a stronger bond than a weld that sits just on the surface.





**2c.** Warm both parts with low heat from a heat gun. This helps them receive the weld to the same depth. If one part is much larger than the other, focus extra attention on warming the larger piece.

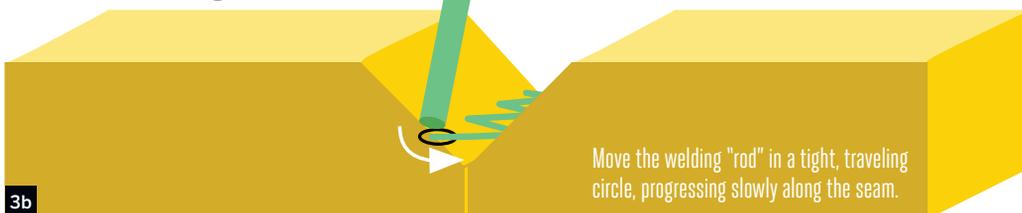
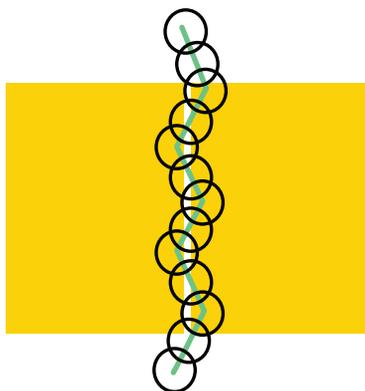
### 3. TACK-WELD THE PARTS IN POSITION

**3a.** Now you'll tack the parts together with a series of short spot welds, moving around the joint while holding the parts steady.

Spin up the rotary tool, and lower it until the spinning filament grazes both surfaces of the seam. When the tip of the filament begins to deform, apply a little pressure.

**3b.** Moving the spinning filament in tight little circles, widen the melt zone slightly into the side of both parts, making a little forward progress with each circuit, until you've created a small spot weld.

**3c.** Tack in 3 or more places along the seam and let the parts cool. They should be tacked tight, difficult to separate by hand.



Move the welding "rod" in a tight, traveling circle, progressing slowly along the seam.



## 4. PLUG GAPS WITH FILAMENT

**4a.** Gaps that are wider than half the width of your welding filament should be filled before welding a clean seam. Soften a short scrap of filament to use as filler, by using the low setting on a heat gun or by warming to 100°C on your printer's heated build platform.

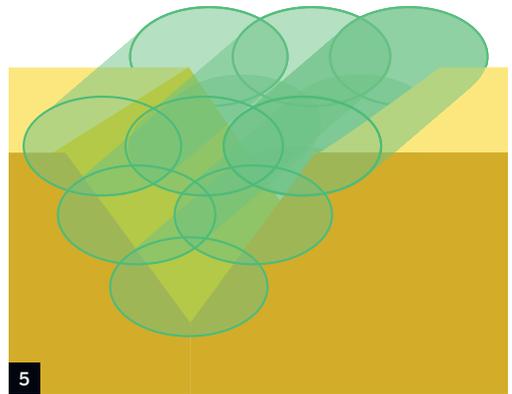
**4b.** Press the softened filament into the widest gaps between the 2 parts, making quick tack-welds if necessary to pin it in place.

## 5. FRICTION-WELD THE SEAM

Now weld the whole seam in 2 or 3 layers, as shown in the diagram. A single weld would probably bond the parts at the surface only, allowing the seam to be broken if the parts are torqued.

To hide the weld, you can sand it back flush and then paint or seal the surface.

Punctured mysteriously by the TSA, a part from Micah Ganske's sculpture *Industrial Ring Habitat* (page 88), needs a patch. We'll use red filament to make the friction weld easily visible.



In this idealized diagram, we weld one bead at the bottom of the seam, 2 beads on a second layer, and 3 on a third (top) layer, fusing the parts through their entire thickness.

# Friction-Welding to Repair a PLA Model

PLA is prone to cracking and splitting, and it's typically difficult to repair. Solvents such as acetone have little effect. ABS glue or super glue merely cement the parts by surface tension, rather than offering a chemical weld — meaning that the seam can easily be rebroken.

With friction welding, you can form solid joints that are difficult to break.

**1.** Press the patch or broken part into place and hold it securely.





**2.** Tack-weld the patch in place in a few different positions.

**3.** PLA is workable at lower temperatures than ABS, so use a gentle touch to melt and weld the 2 parts. Too much pressure can create a puncture. It takes a bit of practice.

**4.** Move around the seam, changing direction as necessary for handling and control. For prettier welds, take frequent breaks to let the parts cool.

**5.** Let the completed seam cool to room temperature before sanding and sealing.



## RIVETING

### Friction-Welding Blind Rivets

A rotary tool can also be used to permanently fuse a spinning part to a fixed one, using a one-sided “blind rivet.” Blind rivets have one huge advantage over ordinary solid rivets: you don’t need access to both sides of an assembly to rivet its parts in place.

This method works well for attaching plastic panels to the outside of objects when access to the interior is awkward or impossible. It also lets you construct massive objects from multiple panels, each panel printed close to the bed of the printer for optimal printing.



Shown here are two 3D-printed blind rivets, next to a brass solid rivet and 3 aluminum blind rivets. Notice that the printed rivets, like the aluminum ones, have a “mandrel” that extends well beyond the rivet’s head. This is the part that’s gripped in the rotary tool. You’ll clip it off after the rivet is firmly in place. I designed the printed rivets to be gripped by the 1/8” collet, the standard size for most Dremel accessory bits.

Plastic rivets need not be perfectly cylindrical for friction welding, so I designed



them “three-quarters” round, for printing flat on the platform. This way, the horizontal “grain” of the printed rivet helps strengthen it.

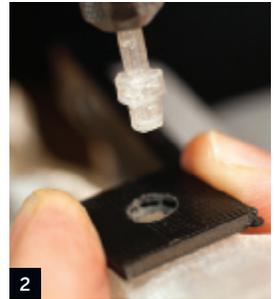
I’ll demonstrate by riveting a small panel to the outside of another part. To print your own rivets, get the 3D files at [thingiverse.com/thing:61510](https://thingiverse.com/thing:61510).



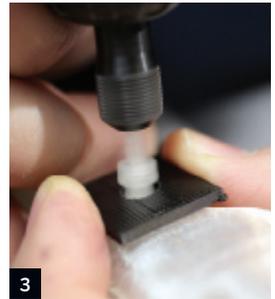
**1.** With the proper collet in place, loosen the collet nut and insert a plastic rivet.



**2.** Drill or design in mounting holes in your panel to provide clearance for the shaft of the rivet to pass through to the base part where it will be fixed. The hole should be narrow enough that the rivet’s head will pin the panel in place.



Pre-drilling (or designing) a pilot hole in the base part can help prevent your rivet from mounting off target.



**3.** Spin up the rotary tool and gently insert the shaft of the rivet through the mounting hole until it contacts the mounting position. Continue spinning until the shaft of the rivet begins to melt and deform — then press it gently down into place.



**4.** Stop the rotary tool and hold it steady in a fixed position at a right angle to the work, while applying a little downward pressure. It can help to use a piece of cardboard or foam as a friction brake to stop the rotation quickly. (Unlike a professional spin-welding tool, most rotary tools need a second or two to spin down.)



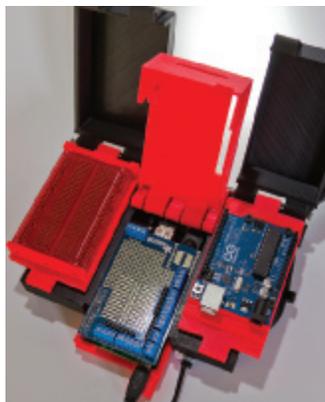
**5.** Loosen the collet nut and slip the mandrel of the blind rivet out of the rotary tool. If the rivet is still cooling, hold it in position until it's fully cooled (at which point it should be entirely fused with its mounting point).

**6.** Using a flush cutter, snip off the mandrel, leaving the head intact.

**7.** If the rivet head protrudes too far, has a sharp ridge, or seems too narrow to secure the panel in place, warm it with a heat gun and use the head of a steel nail to press it flat.

Arduino Lab ([thingiverse.com/thing:32839](https://thingiverse.com/thing:32839), shown here) and Pi Command Center ([thing:38965](https://thingiverse.com/thing:38965)) each use filament “spikes” to create rivets and hinges.

Essentially, Welsh uses heat to reform pieces of filament into straight rivets, flattening one head before inserting the rivet and the other head after



the rivet is firmly in place. As with any solid rivet, you need access to both sides of the assembly, but the advantage of this method is the creation of strong fastenings that can be completely removed later using a flush cutter.

While you can make spikes with any filament, I recommend 3mm PLA based on my experiences building Welsh's project. PLA is easier to soften and work with a heat gun, and 3mm spikes remain straighter and more rigid than 1.75mm spikes after cooling. If you don't have 3mm filament, you can accomplish the same goal with 1.75mm filament by using more rivets to distribute the load.

## 1. PREPARE THE SPIKES

**1a.** With a heat gun set to low, evenly warm a 4"–6" length of filament until it becomes limp. (Several minutes on a heated build platform works, too.)

**1b.** While the filament is still hot, straighten it by rolling it on a table, or better yet, on a piece of glass that will quickly cool it. Gently move both hands away from each other while rolling, to keep the filament straight as it cools.

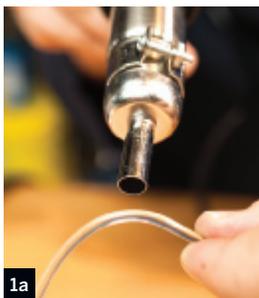
**1c.** Soften one end using a heat gun on a low setting. (A soldering iron, heated brass nozzle, or heated build platform can work in a pinch.)

**TIP:** It's possible to fuse ABS rivets to PLA, and vice versa, but you'll need to find the "feel" for the initial friction stage before pressing down the body of the rivet. Before mounting delicate parts, test-rivet the materials you'll be using.

## Using Filament to Make Solid Rivets and Hinges

People have used rivets since the Bronze Age to fasten together tools, art, bridges, and buildings, so it's no surprise that 3D printer users are experimenting with riveting techniques. We've seen a number of projects using pieces of filament as pins to hold together large assemblies.

Just recently, 3D artist and instructor Jason Welsh demonstrated a method for building his DIY electronics cases that promises to become a new power technique. His Folding



**1d.** Tap the soft end of the spike on a flat, cool surface until it deforms into a flat rivet head. I tend to use a steel nail head, but any flat surface that can cool the filament rapidly will work.



**1e.** Your rivet should have a nice flat head, wide enough to rest firmly on the edge of the mounting hole. In rivet lingo, this is the “factory head,” as opposed to the second head or “shop head” you’ll create on the other end when installing the rivet.

## 2. INSTALL THE RIVET

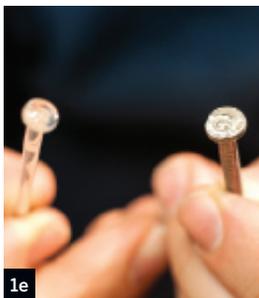


**2a.** Insert the rivet into the mounting point until the factory head is flush, then clip the tail a little ways beyond where you need the second head of the rivet.



**2b.** Use a heat gun to soften the protruding tail of the rivet until it begins to deform.

**2c.** Use a flat, smooth surface to press down and deform (“buck”) the tail, creating the rivet’s shop head. I find that a large steel nail head works best — it’s easy to handle and it cools the shop head quickly.



**2d.** Continue to press tight against the shop head as it cools, making sure it doesn’t relax away from the mounting point.

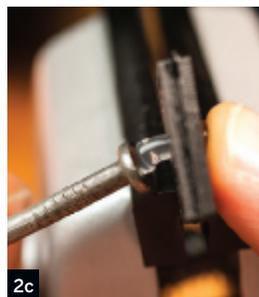
Don’t apply force to the assembly until both the rivet and the parts being assembled cool to room temperature.

## 3. USE A RIVET AS A HINGE

Installation of a hinge rivet follows the same procedure, except at the very end.

After pressing the shop head, move the parts gently as they cool to ensure that the joint has enough play for the hinge to open and close easily.

In the completed assembly shown here, the 2 black ABS plates can spin easily on the hinge without coming free.



**TWO MATERIALS, TWO APPROACHES TO FINISHING TECH**

ABS and PLA plastics have very different physical properties. ABS is printed at a higher temperature (typically 215°C–235°C), is more durable and flexible, and dissolves in industrial solvents like acetone. PLA can print at lower temperatures (starting at 180°C), wears down faster, can be brittle or shatter, and won't dissolve in acetone. (The chemicals used to dissolve PLA are highly toxic.)

**TIP:** If you'd rather use a soldering iron than a heat gun, find a brass tube that fits snugly over your iron. Use the brass tube to work the plastic, and keep your soldering tip clean. Make sure to clean your tube thoroughly so the plastic doesn't stick to the brass.



**TIP:** Tape the factory head of the rivet in place when you need both hands to soften and flatten the shop head.



**GLUING AND FILLING**  
**Creating ABS Slurry for Filler and Glue**

While “super glue” (cyanoacrylate) and plastic model glues do an excellent job of bonding ABS parts, many 3D-printed model builders have switched to using “ABS slurry” for both glue and filler material, because this substance can



Artist Micah Ganske used ABS slurry glue to assemble his ground-breaking sculpture *Industrial Ring Habitat* from 1,000 3D-printed ABS parts. He also uses it to glue PLA parts to ABS— even though acetone doesn't dissolve PLA, the slurry seeps into cracks and crevices to mechanically bond the PLA part to the ABS base.

weld parts together more permanently, and can be exactly color-matched to the printed parts. ABS slurry is simply ground-up ABS filament dissolved in acetone.

Applied in the open air, acetone melts the surface of ABS plastic (and many similar styrene plastics), creates a goopy sludge, and then — after some time — evaporates, leaving behind just the reformed ABS plastic. By sealing up this process in an airtight container that the acetone cannot easily escape, you can prepare a thick, even acetone/ABS mix similar to acrylic gel medium.

There are a variety of methods for preparing ABS slurry. I like ProtoParadigm's recipe ([thing:14490](#)) — 1 part ABS to 2 parts acetone, mixed in fingernail polish containers or similar. Use a cheap coffee/spice grinder to shred ABS filament and scraps as needed. Smaller pieces dissolve faster and make it easier to gauge the mix ratio.

**WARNING:** Observe proper handling precautions when working with acetone and ABS slurry. Wear gloves and goggles and do not work without proper ventilation or in the presence of open flames. Besides being highly flammable, ABS slurry sticks to anything and burns with a foul-smelling smoke that is widely regarded as toxic. Be very careful or you'll create a tiny batch of “napalm” that will need to be treated like a chemical fire.

Apply ABS slurry with an inexpensive natural-hair paintbrush (synthetic brushes will dissolve in acetone!) to either fill small cracks or glue 2 pieces together. Leave it to air-dry until the acetone completely evaporates, and your final part will have a joint or patch made only of ABS plastic.

Your exposure to acetone is greatest while applying ABS glue and immediately after, so pin your parts to a piece of cardboard or a tray that you can immediately move to a well-ventilated area away from your workspace. If you move them outside, protect them with a cardboard box to keep leaves, dust, and grime out of the still-goopy slurry.

**TIP:** While acetone can “weld” the edges of ABS parts to bond them, this joint lacks the shear resistance of parts printed together, because the “melt zone” doesn't extend deep into the surface. If an assembly needs mechanical strength, design an interlocking joint with lots of surface area — or use hardware.



# SANDING

## Sanding 3D-Printed Plastic Parts



When I first learned the basics of woodworking, I proved a lazy, inept sander of splintery plywood tool-boxes and lopsided Pinewood Derby cars. My father suggested I forget about “sanded” as a goal, and focus

on “sanding” as an activity. You cycle from coarse-grit sizes down to finer-grit papers until the surface is as smooth as you intend.

Same goes for sanding 3D-printed plastics. With ABS and PLA, you can work your way down to very fine papers indeed — 3M gem-polishing papers and Micro-Mesh sanding tools with single-digit micron grits that create scoring patterns invisible to the naked eye.

Still, well-sanded 3D-printed projects seem few and far between, for two good reasons. First, ABS and PLA are softer than the wood we’re used to sanding. Second, the tricky horizontal “grain” created by 3D printing reflects light differently than sanded surfaces or the glossy heated base (in ABS printing), and this grain cannot be tooled back into the surface easily — encouraging an all-or-



### ABOUT SAFETY

Friction welding involves the use of high-speed rotating tools and should not be attempted without ANSI-approved safety glasses. Welding and other operations that heat, soften, and melt plastic may release hazardous chemical vapors and should not be attempted without proper ventilation. Sanding and other dust-producing operations should not be attempted without a NIOSH N95-approved particulate respirator. Acetone and other volatile solvents should not be handled without proper ventilation, safety goggles, protective clothing, and latex or nitrile gloves.

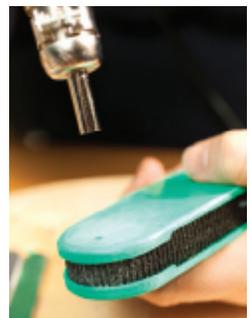
nothing approach to sanding the object.

The basic rule of thumb is to sand 3D-printed pieces like you’d sand a gummy hardwood. Focus on “sanding” and don’t rush toward “sanded”: start with 100- or 150-grit papers or Dremel wheels, then 220, then 320 fine, then 500 super fine, and *then* tackle the micron-grade grits to eliminate sanding marks. Many 3D makers tend to skimp on the earlier papers to their detriment: these coarser grits are capable of stripping away the peaks of the layer lines. Go too fine too fast and you’ll just round over the peaks without flattening them.

After you’ve sanded a surface to your satisfaction, you can use a heat gun to gently warm the surface until it melts slightly, which will erase many of the smaller scratches and restore the original printed color. Practice on scrap until you get the feel of it.

You can also use the Novus plastic polishing system to get a remarkably smooth, polished surface on ABS prints, but most 3D modelers opt to just paint their prints instead.

For tips on polishing, painting, and sealing your 3D-printed objects (and a slideshow of finished 3D prints), visit [makezine.com/34](http://makezine.com/34). ▣



MonoBox is a small, inexpensive powered speaker that amplifies the output of your headphone music player. It's little but it's loud! All the circuit parts are available from RadioShack, while the speaker and cabinet are left to your preference.

You'll learn how to assemble and solder an audio power amplifier using an integrated circuit (IC) chip, and how to choose a speaker and install it in a cabinet with the amplifier.

The core of MonoBox is a compact and efficient audio amplifier based on the LM386 power amp chip. It will run on 200mA of current using power supplies from 6V-15V DC. This gives you the flexibility to power it from a wall adapter, a 9V battery, or a car accessory outlet.

You're probably thinking, "Sure, but it's so small. Does it rock?" Fair question. The prototype has been exhaustively tested and it does indeed rock. Maximum volume output is 90dB, and with the added bass boost, your socks will be rocked clean off!

✓ TIME: 6 HOURS ✓ COST: \$\$

# MonoBox Powered Speaker

Gregory Hayes

**Build an amp and  
speaker for your  
music player. It's  
little but it's loud!**

Written by  
**Ross Hershberger**



# MATERIALS

For links to all RadioShack parts on this list, visit [makezine.com/34](http://makezine.com/34).

- » Power jack, DC, size N coaxial, panel-mount
- » Printed circuit board, general purpose, for ICs
- » Audio jack, stereo, 1/8", panel-mount
- » Audio amplifier IC chip, LM386, low voltage, 8-pin DIP package
- » IC socket, 8-pin
- » Resistors: 10 $\Omega$ , 1/4W, 5% (R3); 10k $\Omega$ , 1/8 W (R2); 100 $\Omega$ , 1/8 W (R1)
- » Capacitors, 50V, 10%, PC mount: 0.01 $\mu$ F (for C1), 0.047 $\mu$ F (C2), and 0.022 $\mu$ F (also C1)
- » Capacitors, electrolytic, 35V 20%, radial lead: 100 $\mu$ F (C4) and 470 $\mu$ F (C3)
- » AC adapter, 300mA, 6V–12V DC output, with type N center-positive plug such as RadioShack Enercell 9V/300mA
- » Loudspeaker driver, full range, 6 $\Omega$ –12 $\Omega$ , <150Hz resonance, >87dB sensitivity
- » Wire, solid core, 22–24 gauge, various colors
- » Box or other enclosure, about 1/4 cu. ft. volume See Step 1, below.
- » Dacron pillow filling, about 1/4 cu. ft.
- » Fabric or screen, acoustically transparent
- » Machine screws, with nuts and washers: #6-32 $\times$ 1 1/2" (2), and a second size (4–6) to mount the circuit board and the speaker, respectively
- » Standoffs, plastic, 3/4" long for the #6-32

- screws. I made mine from 1/4" plastic tubing.
- » Sheet cork, solid cardboard, or foamcore board (optional) to fabricate a speaker gasket if needed
- » Audio cable, 1/8" stereo plugs

*Optional, for battery power:*

- » Battery and battery holder, 9V
- » Battery snap connector, 9V, heavy duty
- » Power plug, DC, size N, coaxial

# TOOLS

- » Soldering iron, fine point, with solder
- » Wire cutter/stripper
- » Helping hands tool aka third hand tool
- » Pliers, needlenose
- » Magnifying glass
- » Hobby knife and scissors
- » Marking pen, fine-tipped
- » Crayon and paper
- » Ruler
- » Rotary tool with cutoff wheel, or small saw such as a Dremel, or a scroll saw
- » Sandpaper, 100 grit, half sheet
- » Drill with bits: 1/8" or 4mm, 6mm, and 10mm
- » File, round, tapered, small
- » Screwdriver(s) to match your screws
- » Hot glue gun or caulking gun (optional) if needed to seal the speaker box

## 1. Select your cabinet.

There are many options for housing your MonoBox. RadioShack sells project boxes made of black ABS plastic, which is very easy to work. Good sizes for this project are 7"×5"×3" (model 270-1807) or 8"×6"×3" (270-1809). I've used nice old wooden cigar boxes; you could also use a lunch box, small toolbox, or plastic kitchen storage container.

Choose something between 1/8 and 1/4 cubic foot (equal to 6"×6"×6" and 6"×6"×12", respectively). Make sure it is deep enough for your desired speaker, and has one surface suitable to mount your speaker on. A box that can be tightly sealed against air leaks will provide the best bass sound.

Wood and plastic are good cabinet materials, as they're easy to work. Metal is more challenging. Almost anything relatively rigid can be used. Construct a box from cardboard in any shape you like, and cover it with colored duct tape!

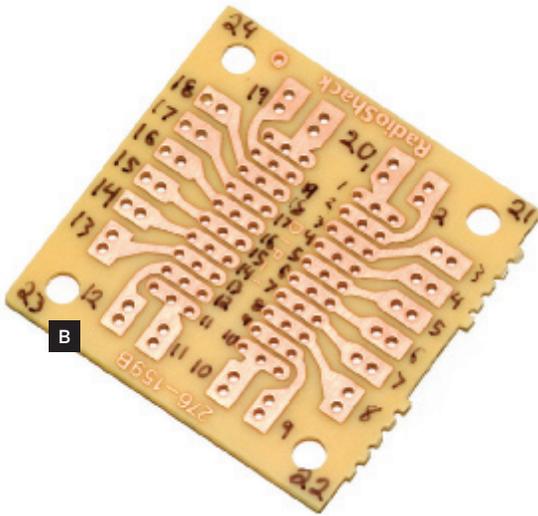
## 2. Choose your speaker.

The driver (loudspeaker) will determine the sound quality to a great extent. Good-quality drivers are available cheap as manufacturing surplus. Look for a driver at least 3" in size that's described as "full range." This type will reproduce the entire frequency range of sound from one driver.

Good online sources of drivers include Parts Express, Madisound, and any websites that sell overstock or surplus parts. Look in the Specials, Closeouts, or Bargains sections for



**TIP** Test a speaker's bass by temporarily mounting it in a cardboard box, or in the middle of a panel of cardboard at least 20" square (Figure A). Connect it to any stereo. The panel, or "test baffle," will separate the front and rear bass waves, allowing you to hear what it will sound like in a finished cabinet.



**B**

great deals. The driver I used in my prototype only cost \$0.98 from Parts Express and it sounds great.

If specifications for the driver are stated, the impedance should be between  $6\Omega$  and  $12\Omega$ . Resonance frequency should be below 150Hz for good bass. High frequency range should extend to at least 8,000Hz (8kHz). And sensitivity of 87dB or higher will provide better volume output.

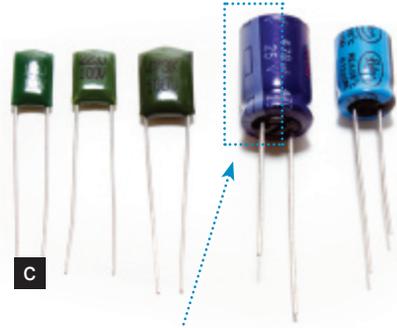
Drivers repurposed from table radios, computer speakers, etc. are often perfectly acceptable for DIY projects. Car speakers work, too.

### 3. Mark the circuit board.

Now you'll build the guts of the MonoBox: the amplifier circuit board. The board has 20 copper traces, each with 5 holes connected together. Eight of these traces will be used for the chip socket. Others will be used for component interconnections and off-board wires.

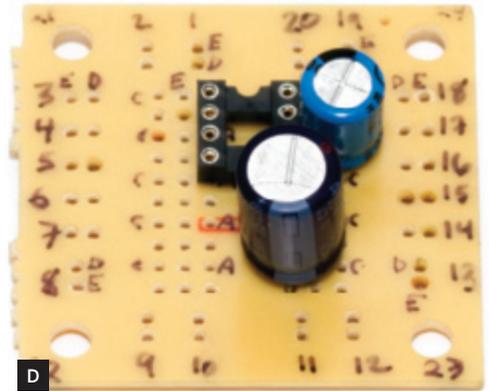
Mark the hole designations on your board before installing components, because it can be difficult to tell the holes apart once some of them are obstructed. On the soldering side of the board (with the copper traces), use a fine-tipped marker to label the traces, from 1 at the upper right clockwise to 20 at the upper left (**Figure B**).

Flip the board over to the component side (without the copper), and label the traces from 1 through 20 on this side too. Note that the handedness reverses when you flip the board.



**C**

**NOTE** The electrolytic capacitors are polarized and must be installed in the proper orientation. The negative (-) lead is identified by a vertical band on the housing as shown in **Figure C**, above.



**D**

Now label the 5 holes of each trace A through E, with A at the center of the board and E at the outer edge. Thus the inner hole on the trace at the upper left is 1A and the outer hole of the trace at the upper right is 20E. (You can see the component side labels in **Figure D**, above.)

### 4. Solder the socket and caps.

Insert the DIP-8 socket for the amp chip into holes 2A–5A and 19A–16A, orienting the notch in the socket body toward 2A and 19A (up). Flip the board over and solder the socket leads to the traces.

Insert capacitor C3's ( $470\mu\text{F}$ ) negative lead into hole 11A and bend its positive lead over to hole 16B. Insert capacitor C4's ( $100\mu\text{F}$ ) negative lead into hole 20C and bend its positive lead over to hole 17C (**Figure D**). Solder and clip the leads.

Insert capacitor C2 (0.047 $\mu$ F) into hole 13D and bend the other lead to hole 15D. (The film caps aren't polarized, so it doesn't matter which lead is which.) Solder and clip the leads.

Capacitor C1 (0.033 $\mu$ F) consists of 0.010 $\mu$ F and 0.022 $\mu$ F capacitors in parallel. Install them together by inserting one lead of each into holes 16C and 14C (**Figure E**). Solder and clip the leads.

## 5. Add resistors and jumpers.

Insert resistor R3 (10 $\Omega$ ) into holes 15E and 16E. Insert resistor R2 (10k $\Omega$ ) into holes 1D and 2B. Insert resistor R1 (100 $\Omega$ ) into holes 4B and 5B. Solder and clip leads.

Insert a short narrow-gauge jumper wire, such as a cut-off lead, from hole 3C to 5C. For all other wires, solid-core insulated wire is recommended for ease of working.

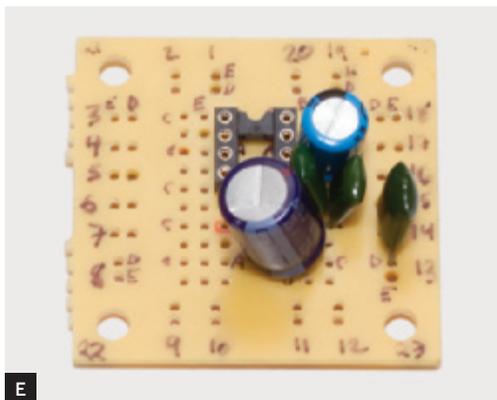
Cut a 5cm jumper wire, strip 3mm at each end, and run it from hole 1E to 14E, passing around 19 and 20 as shown in **Figure F**.

Cut a 5cm jumper wire, strip 3mm at each end, and run it from hole 13E to 5C, passing around 8 and 9 as shown.

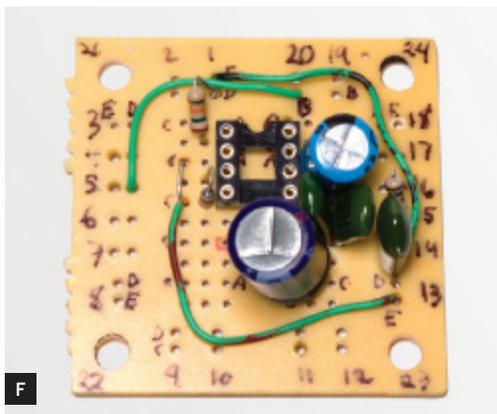
Cut a 4cm jumper wire, strip 3mm at each end, and run it from hole 20D to 5D, passing around 1 and 2 as shown.

## 6. Connect the off-board wires.

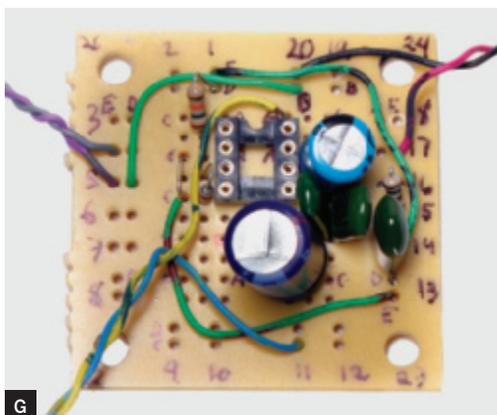
Wires to reach the power input



**E**



**F**



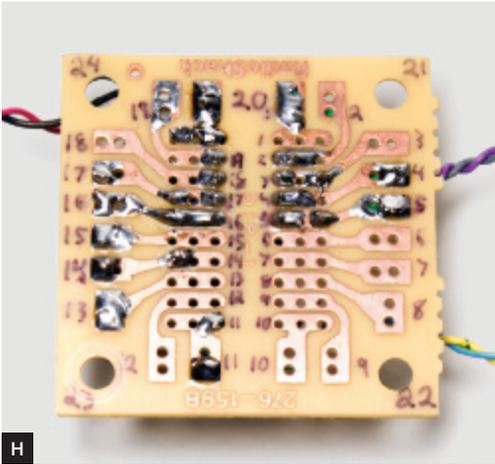
**G**

socket, shown red and black (**Figure G**), are soldered to holes 20E (black, -) and 17E (red, +).

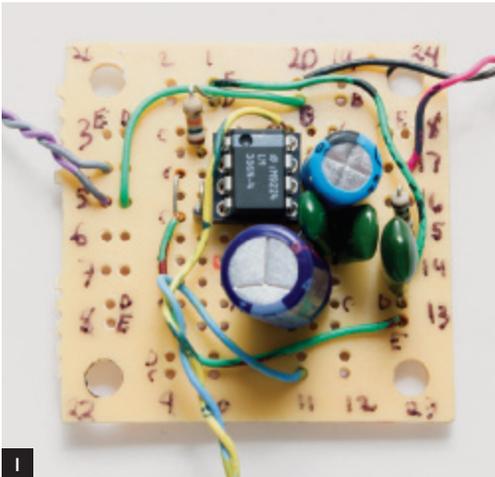
Wires to reach the signal input socket, shown purple and gray, are soldered to holes 4E (gray, signal) and 5E (purple, ground). Wires for the speaker, shown blue and yellow, are soldered to holes 11E (blue, +) and 20A (yellow, -).

**NOTE** If you have a film capacitor with a value of 0.030 $\mu$ F to 0.035 $\mu$ F, you can use that for C1 in place of the 2 in parallel.

**TIP** Where a resistor body is longer than the distance between its holes, stand it vertically on one hole and bend the other lead down toward the second hole.



H



I

## 7. Check your work.

Carefully examine both sides of the board. On the component side, check the connection holes against the assembly instructions.

On the solder side, use a magnifier to look for missed solder joints, cold joints, or accidental solder shorts between traces (**Figure H**). This is a tiny board and problems are easily overlooked by the naked eye.

If you think you see a solder bridge between traces, run a knife point between them to scrape it away.

## 8. Add the amp chip.

Carefully plug the LM386 amp chip into the socket. Note the orientation of the dot on the back of the chip (**Figure I**).

The amplifier circuit is now complete.

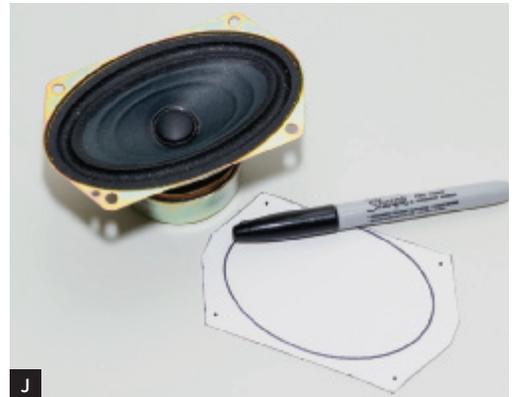
## 9. Cut and drill the cabinet.

Trace the shape of the speaker on paper using a pen or crayon. Cut out your tracing and use it as a template to mark the box surface for cutting (**Figure J**).

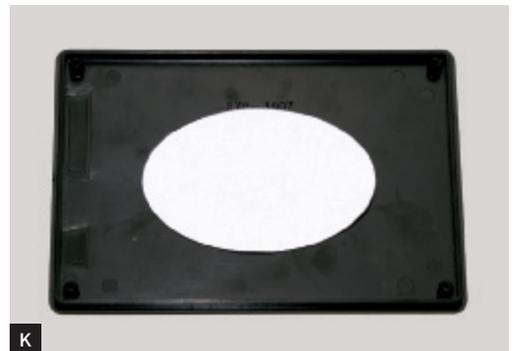
Place the speaker on the box and mark its mounting holes. How you cut the box will depend on the material. For my wooden cabinet, I roughed out the speaker hole with a 50mm×1mm Dremel cutoff disk, then finished it to size with a 2" sanding drum followed by 100-grit sandpaper. For the plastic box shown here, we used a laser cutter, but a Dremel works too (**Figure K**).

In a rear corner, locate and cut a 10mm hole for the power socket and a 6mm hole for the audio signal input jack (**Figure L**, following page). My box was so thick I needed to cut a little relief inside so the power jack would reach through.

Position the circuit board on the inside cabinet surface and mark mounting hole locations through 2 of its corner holes. For #6 screws, drill these using a 1/8" bit.



J



K

## 10. Finish the box (optional).

If you've got a box that wants paint or varnish, now's the time. Krylon Fusion spray paint is made for plastics; it's easy to apply to ABS and gives a great finish on project boxes (**Figure M**).

## 11. Install the amp and jacks.

Solder the audio ground wire (gray) to the outer tab of the audio input jack. Solder the audio signal wire (purple) to both left and right jack signal tabs.

The power jack mounts from the outside. Thread the black/red power wires through the power jack's nut and washer, then pass the wires out through the cabinet power jack mounting hole. Solder the black wire to the outer power jack tab and the red wire to the inner tab (**Figure N**).

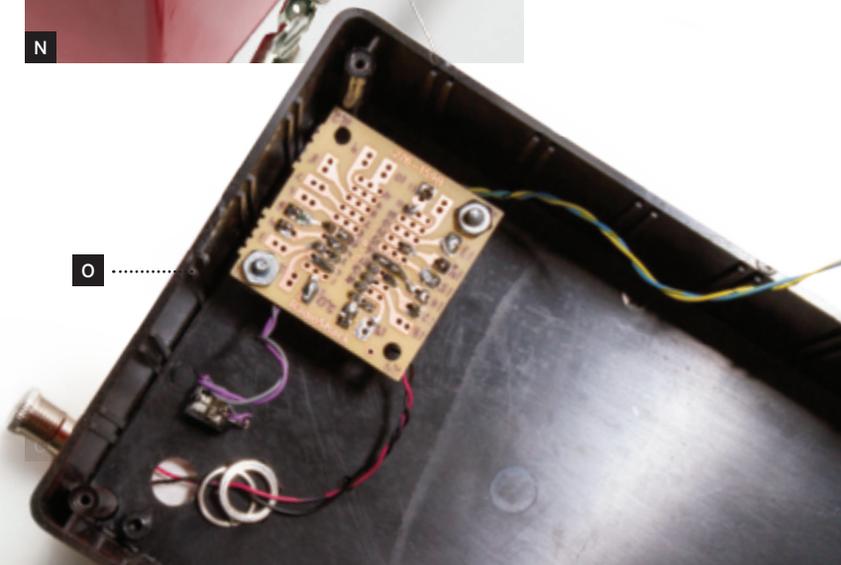
The circuit board requires standoffs to give it about 1" of clearance from the cabinet. I used sections of 1/4" plastic tubing. Pass two #6-32x1 1/2" screws through from the outside, and slip the standoffs onto them inside. Slide the circuit board onto the screws and install the nuts (**Figure O**).

Put the audio jack through the 6mm hole and secure it with a nut on the outside. Pull the power jack through its hole and secure it with a nut on the inside.



**TIPS** Place the jacks in a corner so the cords will be low whether the box is placed vertically or horizontally.

Drill an undersized hole, test-fit the part or fastener, then use a small round file to adjust hole size and position. This gives you a chance to second-guess and adjust the hole rather than having to drill precisely and accurately in one try.



## 12. Make the speaker grille.

The speaker needs an acoustically transparent fabric grille to protect it. You can use a variety of materials including speaker grille cloth, cane material, metal screen, or anything else that will pass sound through.

My speaker needed a gasket to keep the cone from hitting the grille. I recommend sheet cork. You can use pasteboard, foamcore, thin wood, plastic, or other stiff foams, but soft foams and corrugated cardboard won't work.

Use the speaker frame as a template for the outer edge of the gasket, and the cabinet speaker hole as a template for the inner edge. Drill screw holes in the gasket as needed (**Figure P**).

## 13. Install the speaker.

I used #6-32 flat-head brass screws and finishing washers because they look good with my wooden box. Steel hardware looks nice with a plastic box. Again, use a  $\frac{1}{8}$ " drill bit for #6-32 screws (**Figure Q**).

After mounting your speaker, solder its + terminal to the blue (+) wire from the amplifier and its - terminal to the yellow (-) wire.

For best bass performance, seal any gaps or air leaks in the box with hot glue or caulk, then fill the box with lightly packed Dacron pillow stuffing (**Figure R**). Fiberglass insulation works well too, but it's an irritant and should be handled carefully.

If you don't want to permanently seal your box, you can apply felt or adhesive foam to the lid rim to stop air leakage.

Done! Cool! Now we just have to arrange for power and signal connections, and your MonoBox will be ready to play.

## 14. Power up your MonoBox.

Your power source needs at least 300mA of current capacity. Voltage as low as 6V works for driving  $4\Omega$  speakers, but 12V is best for  $16\Omega$  speakers, so 9V is a good compromise.

RadioShack's Enercell 9V/300mA AC adapter is ideal. Install the type N power plug with the center (tip) positive. Now you can plug your MonoBox into wall power.

To build a battery adapter, solder the red



**TIP** After screwing the power plug's body together, you can fill it with hot glue to secure the wires in place.

**T**



**NOTE** The MonoBox has no power switch. To turn it off, unplug the power from the back. Leaving a battery plugged in will drain it overnight even if no music is playing.

(+) lead of a 9V battery snap connector to the center contact of a size N coaxial DC power plug. Solder the black (-) lead to the outer contact. Attach the battery to the back of the cabinet with the 9V battery holder (**Figure T**).

To use a car or boat's 12V power system, make an adapter for the accessory "cigarette lighter" socket. Again, use a size N coax power plug and solder the negative lead to the outer contact, positive lead to inner contact.

Other DC power supplies can be used the same way, but make sure the voltage does not exceed 15V DC.

## 15. Hook up the music.

Audio signal input will depend on your music player. Purchase or make a signal cable suitable for your player with a 1/8" stereo plug on one end to plug into your MonoBox. Most smartphones and MP3 players accept a 1/8" plug in their headphone jack.

Plug in the power source and the audio signal cable. Set your music player's volume to minimum, start the player, and increase the volume until you hear sound from MonoBox.

Crank it up! MonoBox has no volume knob, so just use your music player's volume control. Also use any tone controls or equalization on the music player to adjust the tone of the sound to your liking. ▣

➤ For video instructions, links to materials, schematics, and reader comments, visit [makezine.com/34](http://makezine.com/34).

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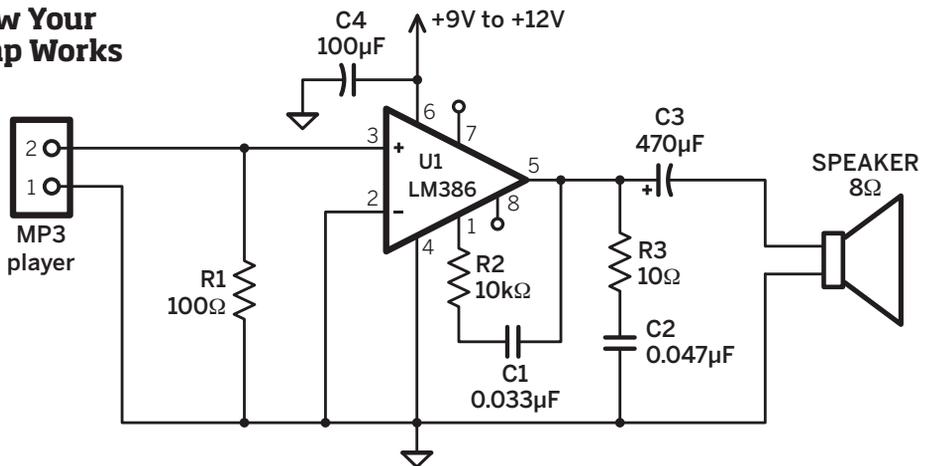
Ross Hershberger is the author of "Econowave Speakers" in MAKE Volume 20 and "Squelette, the Bare Bones Amplifier" in Volume 23. Formerly a mainframe systems analyst, a restorer of vintage tube audio components, and a tooling machinist, he is now a field service engineer for high-powered industrial lasers.

# GOING FURTHER



What if you really want stereo? Make 2 MonoBoxes! In each, connect only one channel (left or right) of the input jack directly to the amplifier circuit board, and use a SPST switch to connect or disconnect the other channel, so each box has its own mono (or 1-channel) selector switch. Set both boxes to 1-channel, then use a stereo headphone splitter to connect both MonoBoxes to your music player.

## How Your Amp Works



» The amplifier circuit is designed to be fed by a headphone output, so the input impedance set by R1 is a relatively low 100Ω. This helps load down the source and eliminate noise. Use a 10kΩ resistor for R1 if you're driving your MonoBox from a line-level source like a home stereo CD player.

» Most small speakers need bass boost. R2 and C1 provide a high-pass feedback loop to boost bass

by reducing frequencies above 200Hz. If the sound is too bassy for your speaker, R2/C1 can be eliminated or disconnected.

» For the best bass from a 4Ω speaker, C3 can be increased to 1,000μF. For a 16Ω speaker, C3 can be reduced to 250μF without losing bass performance.

» R1 provides a load for the signal source and ground reference for the chip input. C4 decouples

and filters the power supply. R3/C2 is a Zobel network to ensure a low impedance load at high frequencies and to damp oscillations.

» Pin 5 is the audio output of the IC chip. This pin has a DC voltage of 4.5V added to the audio signal. Capacitor C3 blocks the DC voltage from reaching the speaker and passes only the audio signal.

## TOOLS & MATERIALS

» **Table saw, chop saw with 12" cut capacity, and handsaw**

» **Drill**

» **Drill bits,  $\frac{7}{64}$  or  $\frac{3}{32}$ , and countersink, or #6 counterbore** I used a Makita #784815.

» **Acid brush**

» **Tape measure**

» **Adjustable square**

» **Small clamps, 2 or more** I used two 6" and four 12".

» **Low horses** optional but helpful

» **Wood, pine or cedar: 1x12 (4') and 1x8 (8')**

» **Screws or nail equivalent:  $1\frac{3}{8}$ " trim-head (36),  $1\frac{1}{4}$ " (16)**

I used drywall screws.

» **Wood glue**

## NOTES

As with all woodworking projects, there are many ways to accomplish the same task. The tools and techniques I show here should be viewed as one option, not the only way. Use whatever tools, methods, and materials make sense to you.

You can avoid a lot of frustration by selecting the best boards you can find. Look for pieces that are straight, flat, and free of twist. Sometimes that means going through every board they have; sometimes that means getting 2 boards so you can cut around flaws.

# Japanese Toolbox

✓ TIME: 4 HOURS ✓ COST: \$\$

**Build this strong wood box with a clever lift-out lid.**

Written and photographed by  
**Len Cullum**

The first time I came across a box like this, it was housing a circular saw. It was made from rec room paneling, scrap pine, and roofing nails. While not much to look at, it was strong, and the action of the lift-out lid fascinated me.

A couple of months later I learned that this is also the common design for a Japanese carpenter's toolbox. I knew I had to make one, so with some 1×12s in hand, I had it.

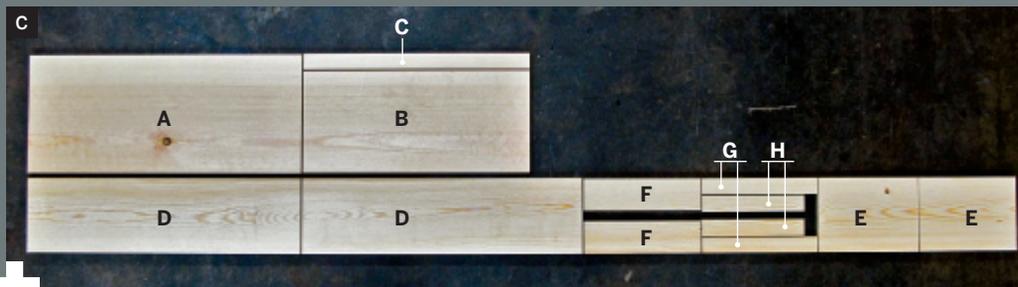
In the last 15 years, the box has carried my tools to nearly every big job. The trouble is, because I built it to fit in my hatchback instead of to fit my tools, it's kind of big for what I need on most jobs. So instead of continuing to stuff tools into my old messenger bag, I figured it was time to build a new, smaller one.

## + Sizing

The first step was deciding how big I needed the box to be. Since I like the width of my old toolbox, I used the same 1×12 bottom. Generally, you want the box to accept your longest tool, which in this case is my saw. I found 23" to be a comfortable fit (**Figure A**).

With the length established, it was time to stack some tools. All together, they measured just over 5" high (**Figure B**), and since we lose a little height from the thickness of the lid (and you never know what else you'll want to stuff in there) I went with 1×8 sides. After doing some math and a quick chalk layout, I determined that, with careful cutting, I could get all of my parts out of 2 boards.





## Cutting the Wood

Since I wanted to squeeze everything out of 2 boards, the layout was especially important.

**Figure C** shows where each piece came from. Download the cutting diagram from [makezine.com/34](http://makezine.com/34).

From the 1×12:

- A:** 11¼"×26" (bottom)
- B:** 9¼"×21⅛" (lid)
- C:** 1⅜"×21⅛" (lid brace)

From the 1×8 (2 each):

- D:** 7¼"×26" (sides)
- E:** 7¼"×9¾" (ends)
- F:** 3"×11¼" (top ends)
- G:** 1½"×11¼" (lid supports)
- H:** 1½"×9¾" (grips)



**TIP** Whenever possible, I try to cut all like-sized pieces at the same time, which ensures that everything will line up properly.

Starting with the 1×12, use a chop saw to trim away about ¼" to get rid of the factory end (**Figure D**); this will give you a cleaner, squarer, more reliable edge. Measure 21⅛" from the fresh end and make the cut.

The bottom and sides are all 26", so to ensure they match, I set up a stop. On the 1×12, mark a line at 26" and align the board on the saw. Place a scrap piece against the cut end and clamp it in place. Check the cut alignment one more time and then make the cut.

Take the 1×8, trim ¼" from the end, slide it carefully up against the stop (you don't want to whack it out of position), and cut the 2 side pieces. Next, lay out 11¼", reset the stop, and cut 2 of those, and then the two 9¾" ends. Leave the stop in this position because you will use it again (**Figure E**).

Next are a couple of rip cuts. On a table saw, rip the lid piece to 9¼" wide, saving the offcut for the lid brace. From one 11¼" piece, rip two 3"-wide pieces. Lastly, from the other 11¼" piece, rip four 1½"-wide sticks. Of these 4 sticks, take 2 back to the





chop saw, and using the 9¾" stop, cut the 2 grip pieces (keep these offcuts as well). And that's it — you're ready to assemble.

The method of assembly has a lot of options. Over the years I've constructed boxes using screws, nails, glue, joinery, and combinations of the four, all with good results. The point is to approach this however feels right to you. If you prefer nails, great! If you like cutting sliding dovetails, go for it!

The only thing that I would specifically recommend is to try to orient all of the boards with the bark side out (**Figure F**). This side of the board will generally remain smoother and will help keep the outside from developing snaggy bits when you sand or plane it.

Apply a bead of glue and then spread it across the surface (**Figure G**). Don't spread it so thin that it dries before you assemble, but also don't make it so thick that your parts are sliding around and a lot of glue is squeezing out (a little is okay).

## 1. Attach the grips to the ends.

It's important that the edges are all flush, so check the fit beforehand and take your time adjusting them before you fasten. Apply the glue and then lightly clamp the parts together (**Figure H**). Get them exactly where you want them before you fully tighten the clamps.

Flip the clamped pieces over. Mark the 3 holes ¾" in from the edge: 1" from each side and one centered. Drill and countersink, then fasten using 1¼" screws (**Figures I, J, and K**).



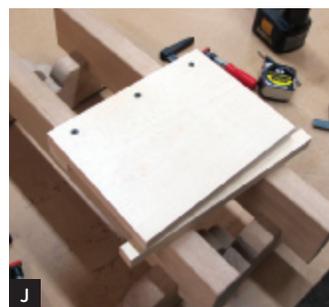
For gluing I like to use an acid brush cut back to about half an inch long.



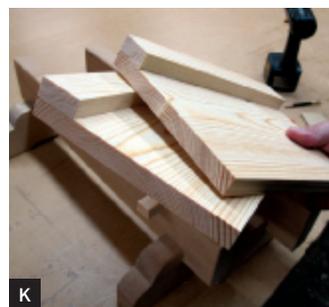
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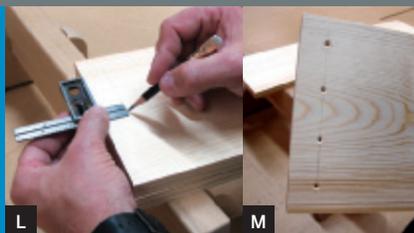
J



K

**TIPS** Slipping a scrap piece under the other end will help keep it stable when adding the screws.

Because I like the look of evenly spaced fasteners, I always make layout lines. Aside from helping make sure I don't miss the board I'm trying to fasten to, it also keeps fasteners from conflicting in the corners.



**TIP** Putting the other end assembly loosely in place will help keep the sides from shifting.



## 2. Make the body.

Using an adjustable square set to  $1\frac{1}{8}$ ", strike a line parallel to the ends, on the outside of both side pieces (**Figure L**). Then measure in from each edge and mark at 1" and  $2\frac{3}{4}$ ". Pre-drill and countersink all 16 holes (**Figure M**).

Apply glue to the ends of one end assembly and clamp in place. Again, make sure that everything is properly aligned before clamping tight. To make sure the bottom is set back the proper distance, I use one of those cutoffs from the grips (you saved those, right?) as a guide (**Figure N**).

When everything is in its place, fasten with eight  $1\frac{5}{8}$ " screws. Because my clamp pads are in the way, I fasten the 2 center screws on each side first, then remove the clamps and drive the rest (**Figures O and P**). Repeat on the other end, making sure that the grips are both facing outward in the same direction.



## 3. Attach the bottom.

Flip the frame so that the grip side is down, and place the bottom. Lay out the fastener locations: for the sides at  $\frac{3}{8}$ " from the edge, 1", 7", and 13" from either end. For the ends, the first one is at 2" (to avoid hitting side screws) and the center one is at  $5\frac{5}{8}$ ". Drill.

Glue and clamp the bottom in place, making sure everything aligns, then fasten using  $1\frac{5}{8}$ " screws (**Figure Q**). Don't be surprised if the bottom seems a little wider than the sides. It happens. No one knows why. You can sand or plane it flush later.



## 4. Attach the top ends.

Following the same procedure, drill, glue, clamp, and fasten the top ends (**Figure R**). Be especially careful when screwing or nailing the outer corners, as the wood is easy to split here. Pre-drilling is highly recommended. My screws are  $\frac{1}{2}$ " from the end, but  $\frac{3}{4}$ " would be safer.

## 5. Make the lid.

For the lid to work right, make sure everything is positioned accurately. To start, make sure the lid board fits between the sides. It's much easier to make adjustments to it now, before attaching the supports. It should be about  $\frac{1}{16}$ " narrower than the opening and  $1\frac{1}{8}$ " longer.

On top of the lid board, mark a line  $1\frac{1}{4}$ " in from one end — this is the long tab. Apply glue to one lid support (stopping about 1" from either end), and lightly clamp it along the line. Using those 2 grip cutoffs again, center the support along the line; it should slightly overhang the scraps (**Figure S**). Tighten the clamps, flip the board, and fasten using three  $1\frac{1}{4}$ " screws.

On the other end, mark a line  $\frac{5}{8}$ " from the end (the short tab) and repeat the process. At this point, you can test the lid. Tilt the long tab in first, slide it in until it stops, drop the other end down, then slide it back.

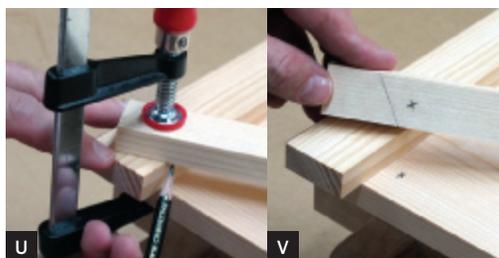
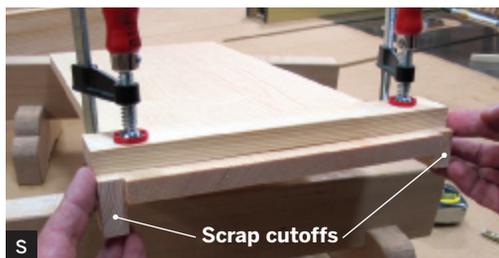
Adding the diagonal is optional. I add it because I like the look, and it makes the lid stiffer and acts as a handle.

To add the lid brace, position it from corner to corner between the lid supports, and clamp it in place (**Figure T**). Using a sharp pencil, scribe a line on the underside (**Figure U**). To keep track of the orientation, after removing the clamps, make a reference mark at one end of both the brace and lid (**Figure V**). This is important because it often only fits one way.

To save the hassle of adjusting the chop saw for these 2 cuts, I prefer to use a handsaw. I place a straight piece of scrap along the line, hold it tight, and run the saw against it (**Figures W and X**). Before cutting the other end, position the brace back on the lid to double check that the cut line is still good. Glue and fasten it in place.

## 6. Wrap it up.

From here on the rest is up to you. Erase the lines or leave them, flush up the bottom if it needs it (mine did), round edges with sandpaper, and then fill it with tools (**Figure Y**). Or books. Or cupcakes! As for mine, I will stop here, slide it under the bench next to the larger one, and wait for the next job. 🍷



Len Cullum ([shokunin-do.com](http://shokunin-do.com)) is a Seattle-based woodworker in the Japanese style. He makes shoji doors and windows, Japanese garden structures, and architectural elements.

**Easy, efficient,  
and effective.**

Written and  
photographed by  
**Charles Platt**



⚡ TIME: A WEEKEND ⚡ COST: \$\$

# LED Photo Lights

**+** I often have to take photographs of small objects – for example, when I’m selling items on eBay. Electronic flash is overkill for this kind of work, and video lights are bulky and hot. I decided to build miniature photo lights from small, efficient LEDs.

On eBay I found complete LED reflector bulbs for just \$3 each. They are plug-compatible and identical in size and packaging to the little 12V quartz-halogen spotlights often used in track lighting (although the LEDs have a cooler light temperature of 6,000° Kelvin – very similar to cloudy daylight). All the distributors were in China, but I’ve never had any problems ordering components from Chinese sources. Sure enough, within 10 days I received my lights.

## MATERIALS

- » **Oak, 3½"×¾"×24"**
- » **Aluminum angle, ½"×¾"×24", ¼" thick**
- » **Wood screws, flat head, #10×1¼" (12)**
- » **Sheet metal screws, pan head, #8×⅝" (24)**
- » **Bolts, flat head, ⅜"×2" (2)**
- » **Wing nuts, ⅜" (2)**
- » **Washers, #10 (8)**
- » **Dual-conductor stranded wire, 14 gauge, 40'** 16 gauge will work. Extension cord wire or loudspeaker wire is good. You can save money by buying an extension cord and cutting off its plug and socket.
- » **"Cool white" LED spotlights, 4W at 12V, 6,000°K, MR16 type (10)** By the time you read this you may be able to buy LED reflector bulbs that are more powerful than those I found on eBay. Just be sure your AC adapter is appropriately rated (or use a separate adapter for each set of lights).
- » **12V DC power supply, 50W or better**
- » **Heat-shrink tubing or electrical tape**

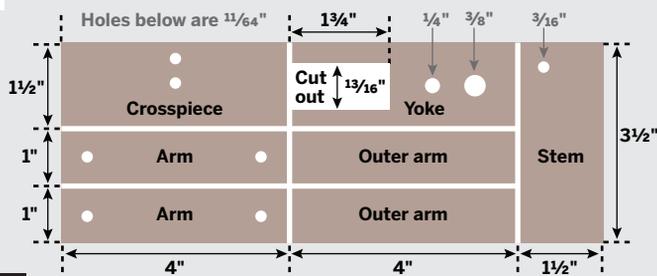
## TOOLS

- » **Drill press or hand drill**
- » **Drill bits: 7/64", 11/64", ⅜", ¼", 5/16", ⅜"**
- » **Vise, bench-top**
- » **Band saw or jigsaw** If you don't have power tools, you'll need a panel saw, keyhole saw, hacksaw, and bench clamps.
- » **Belt sander or sandpaper**
- » **Countersink, awl, clamps, screwdrivers, wire stripper**
- » **Pliers, needlenose**
- » **File, flat, metal**
- » **Soldering iron, 30W, and solder** A lower-wattage iron will have insufficient heat capacity.
- » **Alligator clips, copper** for soldering heat sinks
- » **9V battery and battery holder** terminating in stripped wires, for testing each light
- » **Heat gun**
- » **Epoxy, 5-minute** for securing bulbs (optional)

A



B



**NOTE** You can download a full-size cutting and drilling template from [makezine.com/34](http://makezine.com/34).

**CAUTION** Some AC adapters of this type deliver much more than 12V when not fully loaded. Therefore, avoid powering just one light at a time.

Since each unit was rated at 4W, I needed a 12V DC adapter that could supply at least 40W. Fortunately this kind of switching power supply is commonly available as a power source for laptops and LED displays. I found a 50W unit for \$5.

How to mount the lights? I wanted to use them in 2 sets of 5, so I could position each set on opposite sides of a subject. The angle of each light had to be adjustable, so I could focus their beams tightly around a smaller, closer object, or more widely toward a larger, more distant object. I also wanted to be able to angle the lights up and down, or even turn them backward to reflect against a photographic umbrella for diffuse, shadowless illumination.

My design uses jointed arms (**Figure A**) made from  $\frac{3}{4}$ " oak and small aluminum angle brackets. My photographic light stands have  $\frac{3}{8}$ " brass mounting pegs, so I simply drilled matching holes in the yokes to provide push-fit attachment. If your stands have threaded terminations, install a matching T-nut in each

yoke and secure it, from the top, using a washer and a short bolt ( $\frac{3}{8}$ " or less) of the same thread.

I chose oak as my construction material because I wanted to use wood screws to secure the joints, and the screws would tend to work loose in softer wood. You can get an affordable piece of  $3\frac{1}{2}$ " $\times$  $\frac{3}{4}$ " oak from The Home Depot, which also carries aluminum angles for making the brackets.

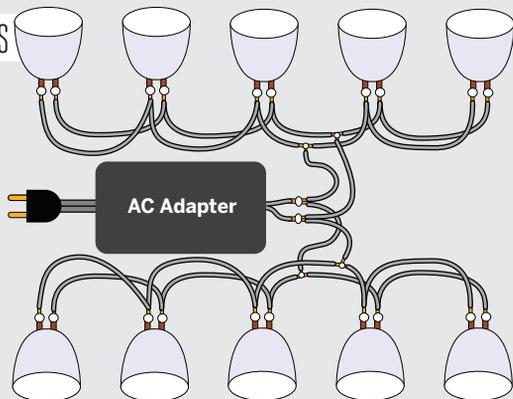
## 1. Shape the parts.

**Figure B** shows how to cut the wooden parts for one set of lights from a  $3\frac{1}{2}$ " oak strip. The dimensions don't have to be precise, so I didn't bother to allow for the thickness of the saw cuts. I used a chop saw, but this requires great care when cutting relatively small pieces. A band saw would be safer. A handsaw is the safest, but will be slow as oak is hard to cut.

To fabricate the yoke section, make 2 parallel cuts, then a series of angled cuts to remove the notch in little triangular fragments. A band saw or jigsaw is good for this. A handheld



C



D



E

**TIP** If you want the option of adding a photographic umbrella, drill a 5/16" hole in the front edge of the stem section, and insert the shaft of the umbrella. Alternatively, you can diffuse the light by shining it through a piece of textured transparent lighting panel, as in Figure U.



F



G

keyhole saw will work if you're persistent. A chisel won't work well, as oak is too tough.

A drill press will ensure that each hole is drilled at precisely 90°. If you use a hand drill, secure each workpiece with a clamp or vise. Again, oak is tough, and these small pieces can easily spin out of control if you try to hold them by hand. Countersink each hole to accept the flat heads of the wood screws.

Cut 10 pieces from the aluminum angle, each 1½" long, and remove a rectangular notch about ⅜" wide from their centers (**Figure C**). This notch engages with grooves molded into the base of each light. If your lights are different, adjust the notch width to fit. Drill two ⅜" mounting holes in each bracket.

**Figure D** shows how the lights are wired. The actual wire lengths are up to you; you can cut them now or later when you wire the lamps in Step 3. See Figures N and O for actual wire usage.

## 2. Build the stands.

In this step, locate holes by using an awl to mark through each drilled hole, then follow with a 7/64" bit to create a pilot hole for the screw itself.

Attach the crosspiece to the stem as shown in **Figure E**. The screws are offset to avoid fouling the hole through the stem below.

Drill 3/16" holes through the yoke (**Figure F**), and countersink one hole.

Use a bolt and wing nut to attach the yoke to the stem as in **Figure G**. Pack with washers if necessary, on one side only, so there is wood-to-wood contact (providing friction) at the other side. The assembly should feel sticky when you turn it around the bolt.

Round the ends of the arms with a file, then use 5/8" screws to attach a bracket to each, and to the central crosspiece. Insert the lights into the brackets, securing with epoxy if needed. Then attach the wooden arms to the central crosspiece (**Figure H**). One light set is

now ready for wiring. Repeat this step to assemble the second set.

### 3. Wire the lamps.

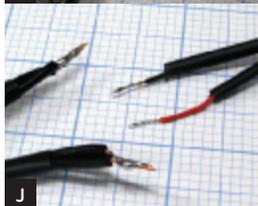
Your power supply probably has a plug on the end of its output cable. Chop it off and strip the wires (**Figure I**).

Cut, strip, and tin wire as needed to make the wiring harness connections and to attach the power supply. If you are using heat-shrink tubing, be sure to slide it over the wire before soldering (**Figure J**). Melt the solder to join the leads, then slide the tubing over the soldered joints and apply heat to shrink.

Tin each lamp pin before soldering. Use a copper alligator clip at the base of the pin as a heat sink (**Figure K**). Make sure the solder bonds well. Use a chisel tip for better heat transfer.

Strip and tin the lamp wire lead, slip heat-shrink tubing over it, and solder it to the pin (**Figure L**). Remove the heat sink and proceed to the next pin. Solder the lower row first, then the upper row.

Test the lights, then slide the heat-shrink tubing over the soldered pin connections and apply heat (**Figure M**).



**NOTE** The spotlights I used are not sensitive to polarity. Double-check yours using a 9V battery and battery holder terminating in stripped wires. Touch the wires to the pins very briefly. If your spotlights only work with positive voltage on one side and negative on the other, they're polarized. The molded pattern on one side of your dual-conductor wire will help you to maintain consistent polarity throughout the circuit.

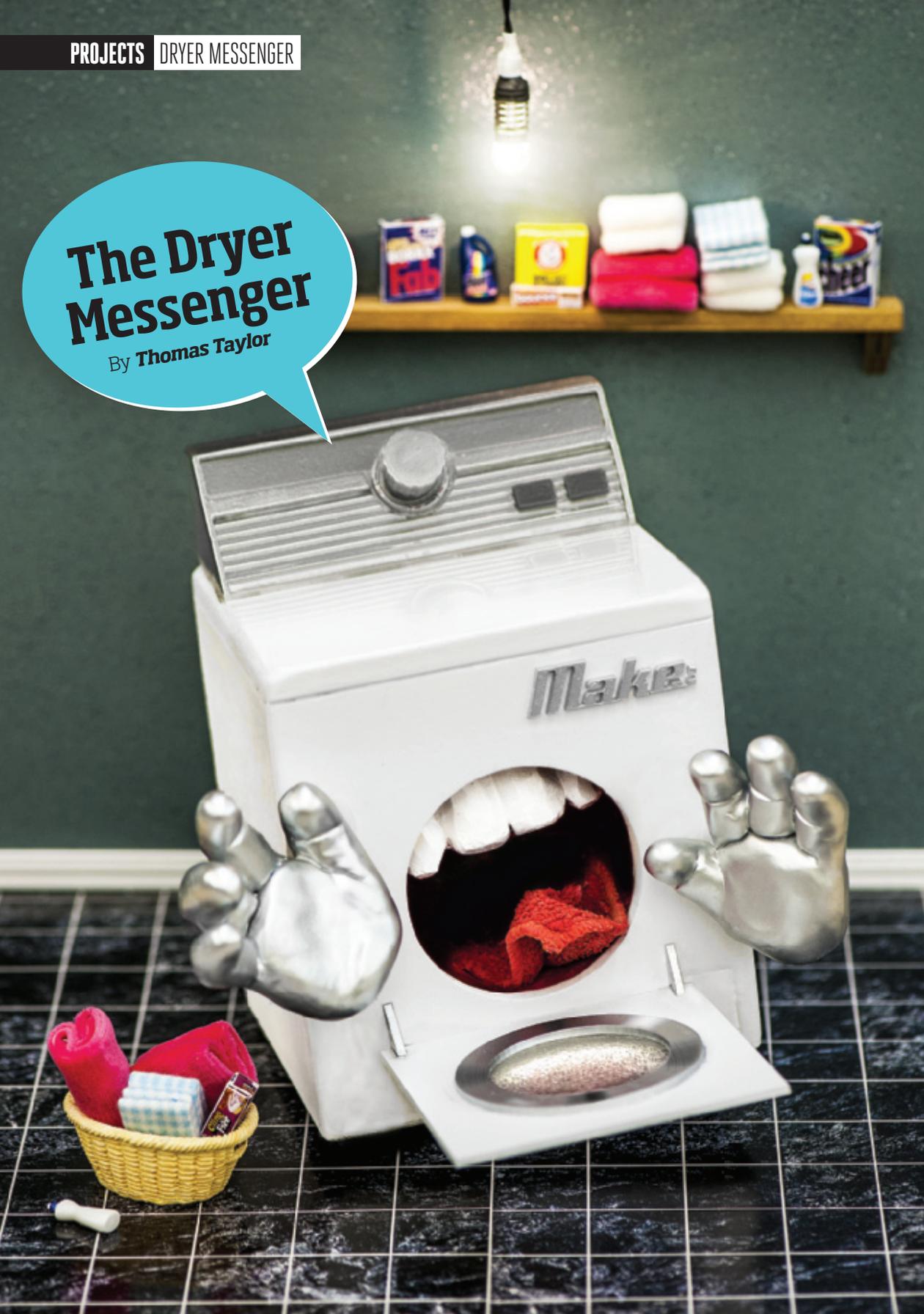


Your finished lights should look something like **Figure N**. You can build a diffuser attachment (**Figure O**) using a prismatic plastic panel from a fluorescent light fixture. ▣

Charles Platt is the author of *Make: Electronics*, an introductory guide for all ages. He is completing a sequel, *Make: More Electronics*, and is also the author of Volume One of the *Encyclopedia of Electronic Components*. Volumes Two and Three are in preparation. [makershed.com/platt](http://makershed.com/platt)

# The Dryer Messenger

By Thomas Taylor



The dryer in our house is in an out-of-the-way corner where it's hard to hear the buzzer. When we miss it, the clothes sit in the dryer getting wrinkly, so we start the dryer again, don't hear the buzzer again ... it's an endless cycle. After what seemed like the thousandth time, my wife quipped, "I wish the dryer could just tell us when it's done."



I had just started playing with Arduino, so I thought a Dryer Messenger would be a good first project. When I ran the idea by my wife, she was enthusiastic but didn't want me disassembling the dryer or voiding its warranty, since it was only months old. We decided to use SMS

since our phones are usually nearby.

Fast-forward a week or two and the dryer was texting us like a household assistant. We haven't forgotten a load of laundry since.

## Overview

The Dryer Messenger consists of 3 main components: a current sensor, the Arduino Pro Mini, and a Wi-Fi module. The current sensor is clipped around a power wire on the back of the dryer where, by electromagnetic induction, it outputs a low current that's a small fraction of the current from the dryer. A burden resistor is needed across the terminals of the sensor to obtain a voltage that can be sampled by the Arduino; the sensor I used has this burden resistor built in.

Since the dryer runs on AC, current flows in both directions, causing the voltage to swing

positive and negative. The Arduino can only sample positive voltages, so I used a voltage divider to bias the sensor's output. The voltage divider uses two 10K resistors (R1 and R2) to obtain 1.65V from the 3.3V supply.

The current sensor has a fairly linear output up to 1V at 30A, which means the Arduino will read 0.65V or 2.65V when the sensor sees 30A. Capacitor C1 goes between the sensor and the Arduino to filter out noise.

The Arduino monitors the dryer's current consumption and sends notification messages when it has determined the dryer has finished a cycle.

Since the Arduino Pro Mini has only one hardware serial port for both programming and debugging at 115,200 baud, I connected the Wi-Fi module to the Arduino digital pins and used the SoftwareSerial and WiFlySerial libraries to emulate a serial port and talk to the WiFly at 9,600 baud.

The Wi-Fi module connects to the local wireless network and sends notifications as tweets using NeoCat's Twitter Library for Arduino. The dryer has a Twitter account both my wife and I follow, and by activating mobile notifications for the dryer's tweets we can receive its updates as text messages on our phones.

## MATERIALS & TOOLS

» **Non-invasive current sensor, 30A** YHDC model SCT-013-030

» **Microcontroller, Arduino Pro Mini 328, 3.3V, 8MHz** SparkFun Electronics #DEV-11114, [sparkfun.com](http://sparkfun.com)

» **Wi-Fi module, Roving Networks WiFly RN-XV**

» **Breakout board for XBee module** SparkFun #BOB-08276

» **XBee sockets, 2mm, 10-pin (2)** SparkFun #PRT-08272

» **Protoboard**

» **Enclosure** Digi-Key #HM1068-ND, [digkey.com](http://digkey.com)

» **Capacitor, 10µF**

» **Resistors: 330Ω (2), 10kΩ (2)**

» **LEDs: green (1), red (1)**

» **Headers, 40-pin breakaway, 0.1" spacing (2)** SparkFun #PRT-00116

» **Stereo jack, 3.5mm** SparkFun #PRT-08032 has pins with breadboard spacing.

» **DC barrel jack, 5mm×2.1mm** SparkFun #PRT-10811 has

pins with breadboard spacing.

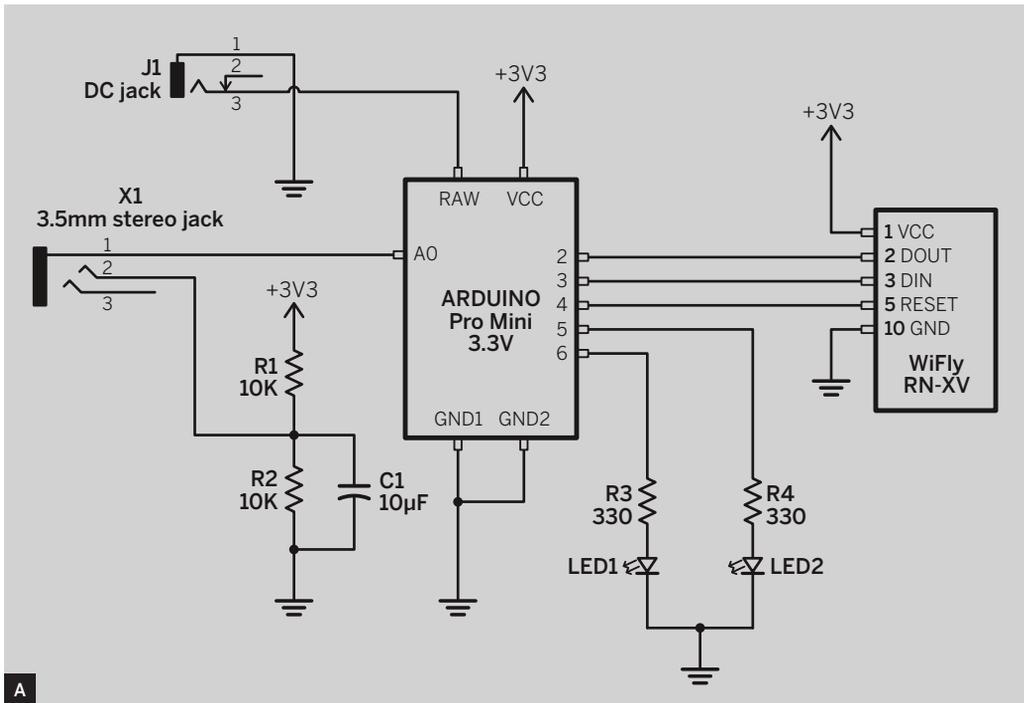
» **Hookup wire**

» **Wall adapter, 9V 650mA**

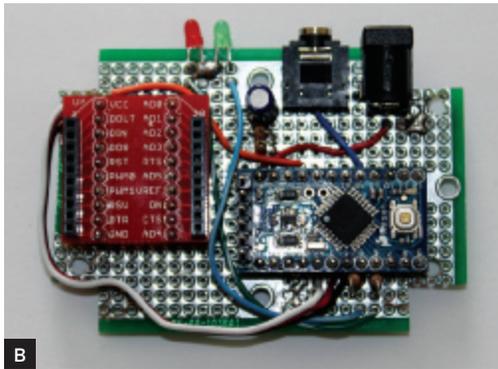
» **Computer with Arduino IDE software** free from [arduino.cc](http://arduino.cc)

» **FTDI programmer** such as FTDI Friend, Maker Shed #MKAD22, [makershed.com](http://makershed.com), or FTDI Basic Breakout 3.3V, SparkFun #DEV-09873

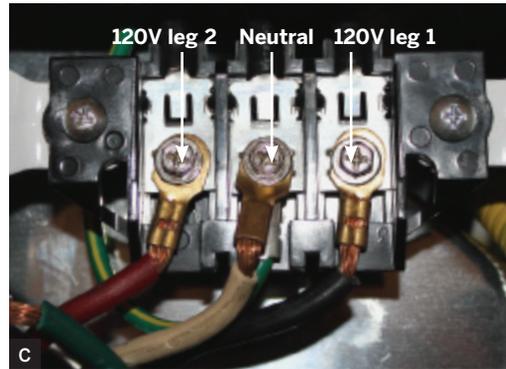
» **Soldering iron and solder**



A



B



C

## 1. Build the circuit.

Solder the circuit shown in the schematic diagram (**Figure A**) on a protoboard. LED1 is green, LED2 is red. My board had a copper pour on the back that I was able to use as a ground plane.

Since the Wi-Fi module has 2mm headers, it can't be directly mounted on the protoboard. Use the breakout board to adapt it to the protoboard's 0.1" grid. **Figure B** shows how I arranged the components on my protoboard.

Plug the Wi-Fi module into the breakout board, and then mount the protoboard in your enclosure.

## 2. Attach the transformer to the dryer.

Unplug the dryer from the wall and remove the back panel to access the terminal block where the power cord is connected. **Figure C** shows the terminal block on my dryer.

The current sensor needs to measure motor current. Use trial and error to determine which leg of the terminal block connections powers the motor.

Clip the current sensor around the appropriate wire (**Figure D**), and run its output cable out the back of the dryer. Replace the panel and plug the dryer back into the wall.



### 3. Get your dryer on Twitter.

Create a new Twitter account for your dryer. Adjust the privacy settings to keep it out of public view, if you prefer. Visit [arduino-tweet.appspot.com](http://arduino-tweet.appspot.com) and follow the instructions to set up your device to send tweets. You will be redirected to Twitter to authorize the Twitter Library's use of the dryer's account. Make sure you're granting access to the right account. Save the token you're given to paste into your Arduino sketch, as explained below.

Now, follow the dryer from your personal Twitter account. Turn on mobile notifications for the dryer's updates, and you should be able to receive text messages on your phone when it tweets.

### 4. Install and tweak the software.

Download the 3 libraries and the Arduino sketch *DryerMessenger.ino* from [makezine.com/34](http://makezine.com/34). Move the libraries to your Arduino libraries folder. Leave the *.h* and *.cpp* files in the same folder as *DryerMessenger.ino*.

Open *DryerMessenger.ino* in the Arduino editor, click the *Credentials.h* tab, and set the following parameters at the top of the file:

- » Change *ssid* and *passphrase* to your network SSID and passphrase.

- » Paste the token into *twitter\_token*.

Adjust the following parameters at the top of the Arduino sketch to suit your application:

- » The *CURRENT\_THRESHOLD* parameter is set to 1 amp by default, which should be low enough to detect when the dryer motor is running. You can adjust this value based on your particular dryer.

- » *WAITONTIME* is how long the *CURRENT\_*

*THRESHOLD* value must be exceeded before the Arduino moves to the dryer *RUNNING* state.

- » *WAITOFFTIME* is how long the dryer must be off before sending the notification. A longer time here allows for momentary interruption of the dryer cycle to insert more clothes or fabric softener (which I always forget).

- » The *messages* array can be edited for more personalized texts, if you prefer.

After you've set the parameters as you like, upload the code to your Arduino using the FTDI module. Make sure it's set to 3.3V mode.

### 5. Use your Dryer Messenger.

Plug the current transformer's stereo plug into the Dryer Messenger's 3.5mm jack, and plug the AC adapter into the wall. Both LEDs should turn on. After successful start-up and connection to the wireless network, the red LED will turn off and the green one will stay lit.

If you leave the FTDI cable plugged in, debug information (such as the software state and the current measured by the sensor) will be displayed.

From now on, when your dryer finishes the cycle, you'll be notified via SMS. No more forgotten, wrinkled clothes!

### Modify It!

With the Arduino's digital and analog inputs, it can monitor and send a notification when triggered by any detectable event. Since the software is a simple state machine, it could be easily adapted to monitor a digital line or a different analog voltage source. A temperature probe might be attached to monitor the temperature of a room or walk-in freezer. A momentary switch on a mailbox could alert you to the mail delivery, or a magnetic switch on a door could let you know when it's been opened. The possibilities are endless! ■

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Thomas Taylor is an electronics engineer in Fort Walton Beach, Fla., who enjoys creating embedded systems to make everyday life easier and integrating them with his wife's crafting projects. He's always on the lookout for new ways to apply technology. Reach him at [thomas07@gmail.com](mailto:thomas07@gmail.com).

# Hand-Crank Geiger Counter

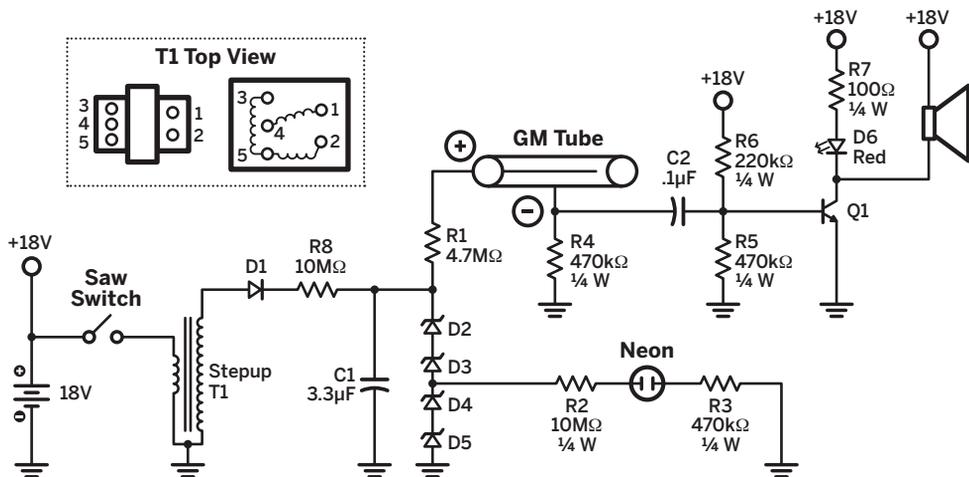
Charge a high voltage tube using a simple mechanical oscillator.

Written by *John Iovine*

I like mechanical systems. Even when it's not the most efficient solution, a machine with moving parts has flair that electronics often lack.



# HOW THE ELECTRONICS WORK



» The circuit applies 18V (from two 9V batteries wired in series) to the primary windings of the step-up transformer through the saw switch.

» The on-off cycling of power to the transformer creates inductive high voltage in the secondary winding, which passes through diode D1 and charges capacitor C1. The Zener diodes D2, D3, D4, and D5 regulate the voltage to 450V for the GM tube.

» When the capacitor is charged, we can siphon off 150V from the junction of D3 and D4 to light a neon bulb. The neon bulb indicates when the capacitor is fully charged and optimum power is going to the GM tube, at which point we can stop rotating the saw switch.

## MATERIALS

- » **Diode, 1N4007** designated D1 in schematic
- » **Zener diode, 200V, 1N5281B** D2
- » **Zener diodes, 100V, 1N5271B (2)** D3, D4
- » **Zener diode, 51V, 1N5262B** D5
- » **LED, subminiature, red** D6
- » **Transistor, NPN, TIP120** Q1
- » **Neon bulb, 150V activation**
- » **Speaker, 16Ω**
- » **Capacitor, 2.2μF–3.3μF, 450V, film or equivalent** C1
- » **Resistors, ¼W: 10MΩ (2), 4.7MΩ (1), 470kΩ (3), 220kΩ (1), 100Ω (1)**
- » **Prototyping printed circuit board (PCB), about 2"×3"** such as RadioShack #276-150, [radioshack.com](http://radioshack.com)
- » **Hookup wire, 22 gauge, stranded**
- » **Wood or plastic box, 5"×3½"×2"** Make one, or shop for a "steampunk" box online.
- » **Plastic "saw" cut from ¼" acrylic** part #PLSAW-01 from

Images Scientific Instruments ([imagesco.com](http://imagesco.com)), \$8, or cut your own using the template at [makezine.com/34](http://makezine.com/34)

- » **Mini step-up transformer** Images SI part #HVT-06, \$8
- » **Geiger-Müller tube, 350V–475V, type SBM-20** Images SI #GMT-03, \$60
- » **Lever switch, 250V 5A** such as Mouser Electronics #540-D43L-R1ML, [mouser.com](http://mouser.com)
- » **Decorative brass gear (optional)**
- » **Thrust bearing, ¼" ID, ⅝" OD** #TB-025 or equivalent
- » **Brass or copper tubing, ¼" OD** length to fit your machine screw
- » **Machine screw, #8-32** length depends on your enclosure
- » **Nuts, #8-32 (2)**
- » **Flat washer, #8**
- » **Split lock washer, #8**
- » **Brass knob, small**
- » **Binding post with screw** to fit your knob

- » **Cable, 2-conductor, 16 or 18 gauge, 600V rating, cloth-covered** such as Sundial Wire part #W182CTBKKXMMNF, [sundialwire.com](http://sundialwire.com)
- » **Clear plastic tube, ¾" OD, ½" ID or greater, about 5" long**
- » **Copper pipe fittings: cap, ¾" ID (1); reducer, ¾" to ¼" (1)**
- » **Copper tubing, ⅛" diameter, about 24" total length**
- » **Switch, SPST on-off toggle**
- » **Battery snap connectors, 9V (2)**
- » **Batteries, 9V (2)**

## TOOLS

- » **Drill and drill bits**
- » **Hand saw or laser cutter (optional)** if you're cutting your own plastic "saw" for the switch
- » **Soldering iron and solder**

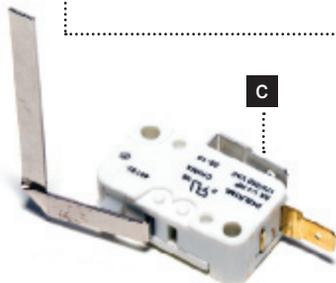
⚡ TIME: A WEEKEND ⚡ COST: \$\$



## Saw Switch Oscillator

Geiger-Müller (GM) tubes require high voltage on the order of 400V-600V, depending on your tube. In modern Geiger counters, a timer or oscillator circuit switches the electrical current to the primary winding (coil) of a step-up transformer on and off in rapid succession. The inductive high voltage thus created in the secondary windings of the transformer is tapped to power the tube.

I replaced the oscillator circuit with a manual switch I call a "saw switch." It switches the electrical current on and off rapidly, but mechanically, instead of electronically. The saw is about 3" in diameter, cut from ¼" acrylic. As it rotates, the teeth engage a lever switch, alternately closing and opening it in rapid succession. The faster you rotate the saw, the faster you switch the current on and off.



## MY HAND-CRANK GEIGER COUNTER IS

not a truly historical design, but it does use an anachronistic "saw switch" as a mechanical oscillator. While I couldn't remove all modern semiconductors from the circuit, I kept them to a minimum and used no integrated circuits.

### 1. Get a stylish enclosure.

Buy or build one. I found a "steampunk" style jewelry box for \$22 on eBay.

### 2. Build the saw switch.

To create the free-spinning saw, I assembled the following parts: the acrylic saw, a top brass gear (for decoration only), an 8-32 machine screw of suitable length, two 8-32 nuts, a #8 split lock washer, a flat washer, a ¼" brass tube for the 8-32 machine screw to pass through, and a thrust bearing (**Figure A**).

Mount the small brass knob to the saw's face using the binding post and screw, to serve as a cranking handle.

Locate a position for the saw on your enclosure's lid, and drill a ¼" hole to accept the brass tube. Mount the saw temporarily in the hole, securing it with the nuts and washers inside the case.

Now pinpoint a spot for the hole for the lever switch (**Figure B**). You're mounting the switch on the bottom of the lid, so you'll need to bend the lever so it will pass up through this hole. (**Figure C**). Position it so that when the saw is rotated clockwise, the lever is cleanly engaged and released by each tooth.



Gunther Kirsch



D



E

Remove the saw assembly and drill the hole. Reattach the saw and test-fit the lever of the switch (**Figures D and E**). You may need to widen the hole to allow clearance for the lever to operate cleanly.

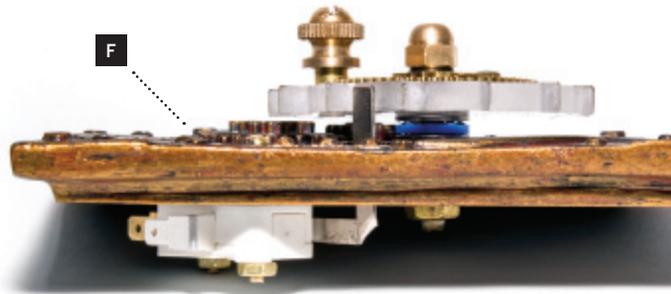
When the hole is the right size and you've found the right position for the switch to engage the saw, mark the position of the switch and drill 2 holes for mounting bolts. Mount the switch, secure it with nuts, reassemble the saw, and check the operation of the whole mechanism (**Figure F**).

### 3. Build the detector wand.

For my detector wand, I used a Russian SBM-20 Geiger tube. Its stainless steel wall looks like copper and fits well with my design. The positive (+) terminal (for the central anode) is marked on the tube.

To connect the wand to the Geiger counter, I opted for a fabric-covered 2-conductor cable that has a nice antique look.

The wand is built from a 4" plastic tube with  $\frac{1}{2}$ " inside and  $\frac{3}{4}$ " outside diameters, two  $\frac{3}{4}$ " ID copper pipe fit-



F

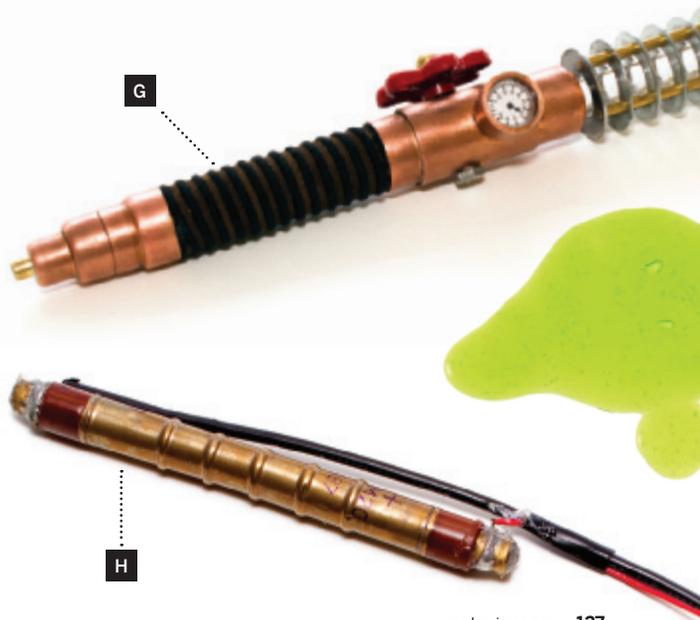
tings that fit the plastic tube, and various decorative bits 'n' pieces. The assembled wand, minus the GM tube, is shown in **Figure G**.

Solder the GM tube to the ends of the 2 cable wires. Cover the connections and the tube ends with clear silicone, for insulation, and let it dry overnight (**Figure H**).

Thread the cable through the wand fittings, as necessary, and place the GM tube into the clear plastic part of the wand assembly. Secure the copper pieces with a little glue, epoxy, or silicone. Silicone is a good choice if you want to disassemble the wand for later upgrades or repair.

### 4. Assemble the Geiger counter.

Assemble the electronics on a prototyping PC board, following the schematic on page 125.



G

H

Drill a hole in the case to accept the wand cable, or the socket if you're using one. If you use a socket, be sure to connect it to the circuit's ground.

If you're not using a socket, tie a strain-relief knot in the wand cable inside the case. Then connect the wand's (+) wire to resistor R1 on the circuit board, and its (-) wire to R4 and capacitor C2, as shown in the schematic.

Drill holes in the lid to mount your LED, neon bulb, and speaker. Space is tight, so measure carefully before you drill. Finally, drill a hole in the side of the case for your on-off switch, and stuff everything into the box (**Figure I**).

## Operation

Turn on the power from the batteries. Rotate the saw switch at a medium pace for 1 minute or so until the neon bulb lights up (**Figure J**). Bring the wand close to a radioactive source. You should see the LED pulse and hear the speaker click every time a radioactive particle is detected.

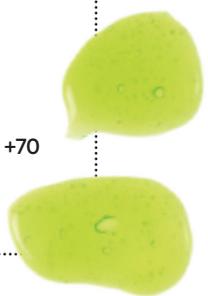
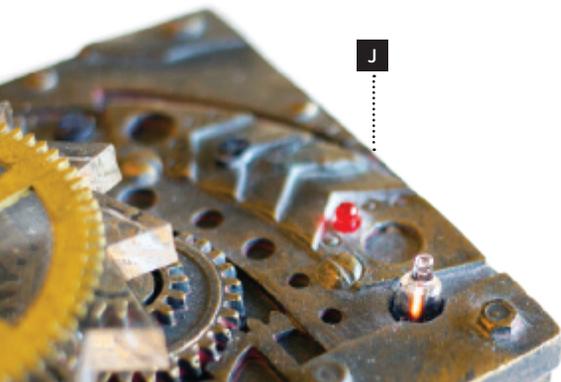
When the neon light goes out, the counter will still have enough voltage on the capacitor to power the GM tube, but it's not as reliable. Crank it up again with the saw switch. When you're done cranking, be sure to turn off the power to avoid draining the batteries. ▣

John Iovine is a science and electronics tinkerer and author who owns and operates Images SI Inc., a small science company. He resides in Staten Island, N.Y., with his wife and two children, their dog, Chansey, and their tabby cat, Squeaks.



## SBM-20 Geiger-Müller Tube Specifications

Gas filling: Ne + Br<sub>2</sub> + Ar  
 Cathode material: Stainless steel  
 Maximum length (mm): 108 / 101  
 Effective length (mm): 91.0 / 83.5  
 Maximum diameter (mm): 11  
 Effective diameter (mm): 10  
 Operating temperature range, °C: -60 to +70  
 Minimum anode resistor: 1.0MΩ  
 Recommended anode resistor: 4.7MΩ  
 Operating voltage range: 350V-475V



# 1.2.3

# Rear-View Power Socket

By **Doug Watson** Illustrations by **Julie West**

**A GPS UNIT IS A GREAT CAR ACCESSORY**, but the power cord hanging across the dashboard is an eyesore. Many vehicles have 12V power at the rear-view mirror, with a 2-wire plug. Tap into it to straighten up your view.

## 1. Wire your socket.

Unscrew the Philmore lighter socket to reveal the lugs. Strip  $\frac{1}{4}$ " of insulation off all ends of your wire pair. Solder one wire to the center lug (+), and the other wire to one of the outer lugs (-). Reassemble the socket.

## 2. Check polarity of the mirror plug wires.

Make sure your car is turned off. Use your ohmmeter to find continuity between a ground (such as the metal housing of the 12V socket in your dash) and one of the existing wires at the 12V mirror plug. The wire with zero resistance is the ground (-).

## 3. Connect your socket.

Push your socket wires into the mirror plug, (-) to (-) and (+) to (+), making sure they make good contact. Zip-tie them to the plug wires so they stay put. (For a permanent connection, you could solder them.) Finally, zip-tie your new 12V socket securely in its hiding place. » Your new 12V socket behind the mirror is ready to power your GPS navigation unit, radar detector, or other gadgets that are suction-cupped to the windshield.

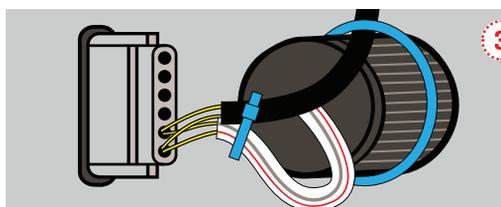
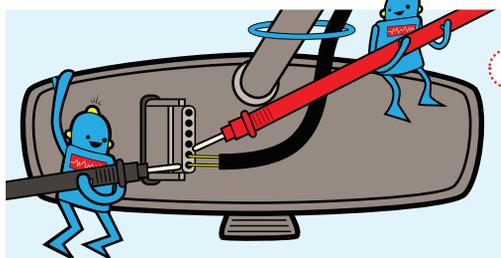
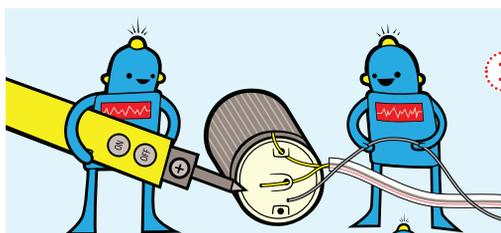
## Going Further

To mount a gadget permanently, you could solder its wires to the plug, with no socket. But I wanted my GPS to be removable. 

Doug Watson ([planithome@mindspring.com](mailto:planithome@mindspring.com)) is a fixer of all things broken; sometimes they're even improved. He recently turned 52, and his brother thinks he's finally playing with a full deck.

### YOU WILL NEED: 12V power receptacle

I used the Philmore TC600 cigarette lighter plug socket. » **Wire, 2-conductor, insulated, 20-gauge solid, 6"** such as bell wire. Or 2 lengths of single-conductor wire. » **Cable ties (5)** aka zip ties » **Wire cutter/stripper** » **Soldering iron and solder** » **Ohmmeter or multimeter**



**NOTE:** If your mirror lacks a plug, try tapping into a courtesy light near the mirror.



## Make a sneaky compartment that's easy to reach but hard to find.

Written and photographed by  
**Sean Michael Ragan**

# DOOR-TOP STASH

✓ TIME: 1 HOUR ✓ COST: \$

What does the top edge of your closet door look like? I bet you've never seen it, even if you've lived in your home for a while. Though there's not a lot of room inside a door, if you're like me, the stuff you want to hide is usually small. Not many think of the door itself as a hiding spot, but it's easy to reach when you need it. And it's devious enough that, yes, I think this trick will still be effective even after this article is published.

### 1. Drill the cap hole and countersink the washer.

Mark the center of the cigar tube cap with a Sharpie. Put a small dimple on the mark with a thumbtack, to guide the drill. Using a brad-point bit, drill a  $\frac{1}{8}$ " hole in the center of the cap (**Figure A**).

Temporarily fix the 1" flat washer to a scrap

of wood by driving 3 small nails around its rim. Countersink the mounted washer slightly, so your flat-head bolt will sit flush against it. Remove the nails and recover the washer (**Figure B**).

### 2. Assemble the cap and the stash.

Put the bolt into the washer, and invert it on the bench top. Guide the bolt through the hole in the cigar tube lid.

Then add the  $\frac{1}{2}$ " flat washer inside the lid and add the split washer above the  $\frac{1}{2}$ " washer. Moisten the threads of the bolt with a dab of thread adhesive.

Finally, thread the nut onto the bolt and tighten it using a nut driver on one side and a screwdriver on the other. Don't overtighten. Set the cap aside and let the adhesive dry (**Figure C**).

When the adhesive on the cap is dry, screw the lid onto the cigar tube (**Figure D**). Verify that the hardware inside the lid does not interfere with the closing of the lid.



## MATERIALS

- » Washers, flat: 1" OD,  $\frac{3}{16}$ " ID (1) and  $\frac{1}{2}$ " OD,  $\frac{3}{16}$ " ID (1)
- » Washer, split,  $\frac{3}{16}$ " ID
- » Bolt, flat-head,  $\frac{1}{4}$ "-diameter head,  $\frac{1}{2}$ " long
- » Nut, hex to fit bolt
- » Cigar tube, aluminum,  $\frac{3}{4}$ " OD, 6" long

## TOOLS

- » Adhesive, thread-lock
- » Bowl, stainless steel, small
- » Countersink
- » Drill
- » Drill bits: 1" spade,  $\frac{1}{4}$ " brad point,  $\frac{1}{8}$ " brad point,  $\frac{3}{4}$ " spade
- » File, round, rattail
- » Hammer
- » Nails, small (3)
- » Wood scrap
- » Thumbtack
- » Work gloves
- » Sharpie marker
- » Screwdriver and nut driver to fit bolt and nut

### 3. Mark and drill the pilot hole.

Select a hollow-core interior door to conceal your stash. It should be a door you can access with some expectation of privacy. Position the stash closer to the hinge than the knob. It will undergo less acceleration in this position, when the door is opened or closed, and be less likely to rattle.

Measure the thickness of the door, and mark the halfway point. Being careful to keep the axis of the drill plumb, drill a  $\frac{1}{4}$ " pilot hole, as deep as you can, on the mark (**Figure E**). A brad-point bit is less likely to wander.

### 4. Counter-bore the door.

Using a 1" spade bit, with the pilot hole as a guide, counter-bore a circular recess about  $\frac{1}{8}$ " deep in the top of the door. The purpose of this recess is to provide clearance for the washer you mounted to the lid of the cigar tube, so it will sit flush with the top of the door. Thus, you don't need to counter-bore any deeper than the thickness of the washer.

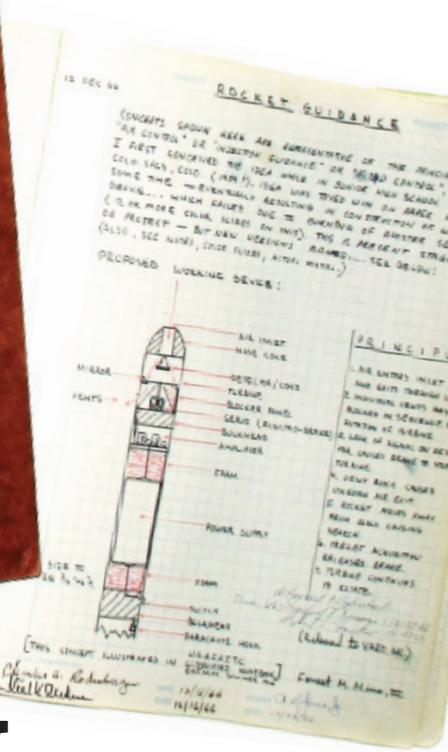
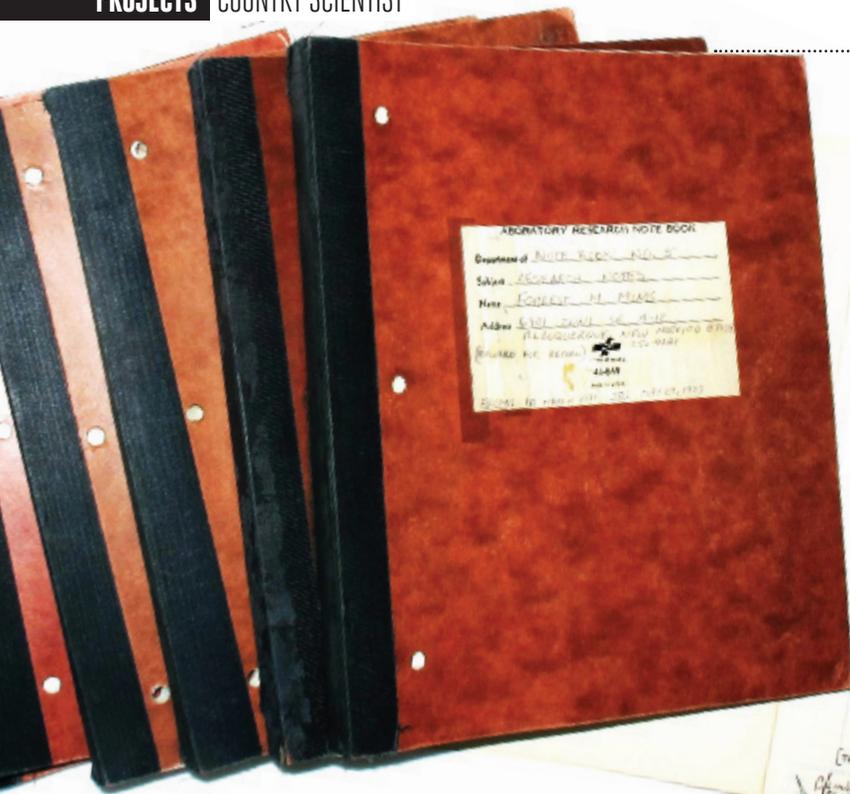
### 5. Drill and shape the opening.

Switch to a  $\frac{3}{4}$ " spade bit and, using the pilot hole as a guide, drill straight down into the door until your bit breaks through into the hollow space inside. This should be about 3"–4" down. Then use a rattail file to shape the opening to fit the tube. If your cigar tube is like mine, you'll need to expand the opening a bit to accommodate the threaded portion at the top (**Figure F**).

### 6. Use it!

The washer attached to the top of the stash should fit flush with the upper surface of the door (**Figures G and H**). The fit should be loose enough to lift out easily, but not so loose as to rattle when the door is moved. A small magnet can be used to easily lift the stash clear of the door. ■

Sean Michael Ragan is technical editor of MAKE magazine. His work has appeared in *ReadyMade*, *c't – Magazin für Computertechnik*, and *The Wall Street Journal*.



# COUNTRY Scientist

## How to Document What You Make or Discover

By **Forrest M. Mims III**

Every issue of **MAKE** provides more proof that today's generation of makers is creating an amazing array of inventions, gadgets, circuits, and projects. Some of these creations even appear sufficiently novel to qualify for patent protection.

No matter what you plan to make, invent, or discover, one of the best steps you can take is to keep a detailed record of your progress. The traditional mechanism for documenting

inventions and projects is a paper notebook, preferably one that is bound to assure that pages have not been added or removed. While paper notebooks remain very popular and are



The lab notebook Holt gave me became the first in a series of 100-page, store-bought lab notebooks. From 1966 to 1996, I kept a record of many projects in these traditional lab notebooks. In addition to the projects described in the 1966 spiral notebook, topics included semiconductor lasers, remotely controlled cameras for making aerial photos from kites and balloons, and instruments that measured haze, water vapor, and the ozone layer. Also included were details about using LEDs and laser diodes as dual-purpose emitters and detectors of audio- and pulse-modulated light beams.

A completely unexpected spinoff from those lab notebooks occurred in 1979 when David Gunzel, then RadioShack's technical editor, came up with a new book idea. Gunzel suggested an idea for a hand-lettered book filled with electronic circuits that would resemble my lab notebooks. Engineer's Notebook sprang from Gunzel's idea and became the first of a series of 19 hand-lettered and illustrated books that sold millions of copies.



**Fig. C:** The entire contents of Mims' lab notebooks, thousands of pages of his atmospheric data (5 of 24 years shown at right), many thousands of scientific photographs, and much more can be easily saved on just one of the flash drives shown at right or on a small fraction of the portable hard drive at center bottom.

## Keeping a Virtual Notebook

Paper notebooks retain important advantages, particularly when inventions are described on pages dated and signed by the

inventor and witnesses. But when projects are best illustrated with photographs and charts, an electronic notebook provides far more flexibility.

### Here are some tips for keeping an electronic notebook:

- Develop an organized virtual notebook containing separate folders for various projects, ideas, resources, expenses, and so forth.
- Save everything related to each project, including photos, videos, charts, data files, illustrations, circuit diagrams, and CAD files.
- Include plenty of detail about your experiment or project.
- Explore various ways for you and witnesses to digitally sign your entries.
- While you can create your own electronic notebook using standard office software, consider an online search to explore commercial or free electronic notebooks.

## Going Further

Whether you keep a paper or electronic notebook — or both — be sure to carefully safeguard your notes by backing them up. Carbon paper may be old-fashioned, but it works well for backing up paper notebook pages. You can also photograph or scan paper notebook pages and save them electronically. That's what I'm doing with all my old notebooks (**Figure C**).

As for electronic backups, I suggest storing your electronic notebooks on at least two external flash or hard drives.

An online search will provide many more tips about keeping a laboratory notebook. Try searching "keeping a laboratory notebook." Our hardbound, gridded *Maker's Notebook* is a perfect paper option: [makezine.com/go/notebook](http://makezine.com/go/notebook). ■

Forrest M. Mims III ([forrestmims.org](http://forrestmims.org)), an amateur scientist and Rolex Award winner, was named by *Discover* magazine as one of the "50 Best Brains in Science." His books have sold more than 7 million copies.

# 1.2.3

# Give Old Work Jeans New Legs

By **Gregory Hayes** Illustrations by **Julie West**

**DON'T LET A TORN SEAM DOOM YOUR VETERAN WORK JEANS** to the landfill. With just a few stitches, they can return to the workshop with honor as a handsome, durable tool wrap for wrenches, chisels, and the like.

## 1. Cut 'em.

Starting at the pant cuff, cut up the length of the inseam, staying quite close to the tucked edge of the seam. When you reach the crotch seam, turn 90° and cut around the leg; take care not to cut through any pockets in case you decide to repurpose more than just the legs.

## 2. Fit 'em.

With one flap of the leg material open, lay out your tools evenly with elbowroom for easy rolling, then peg between them with straight pins. If the leg's too long for all your tools, trim the excess (or get more tools).

## 3. Stitch 'em.

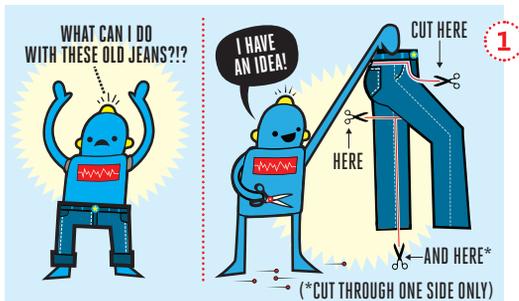
Remove the tools, then straight stitch on your sewing machine in the places you pinned, using upholstery thread. To get the top flap to always fold the same way, stitch along the folded top edge. If the pockets are too deep for some tools, add a stitch to shallow those pockets. For added finish and durability, fold over and stitch all edges; for a rough look, don't stitch anything you don't need to.

## Going Further

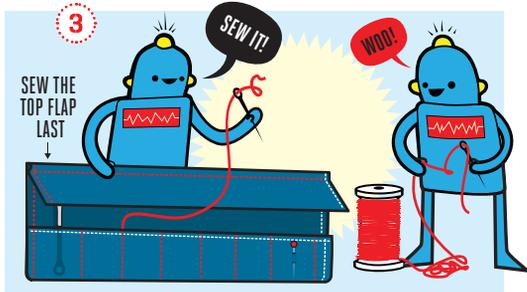
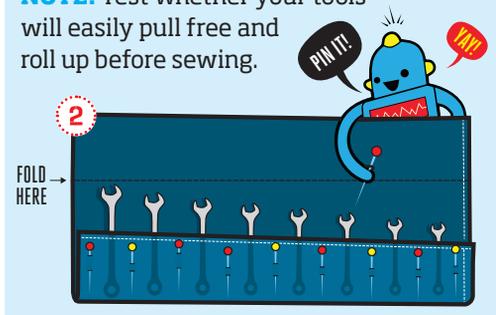
Trim out the waistband (including zipper) to create a buttoning strap to secure the roll around its top. For more ideas visit [makezine.com/34](http://makezine.com/34). 

Gregory Hayes wrangles photos for MAKE and knows lots of other ways to destroy good jeans.

**YOU WILL NEED:** Pair of jeans » Fabric scissors » **Straight pins** » Sewing machine » **Upholstery thread**



**NOTE:** Test whether your tools will easily pull free and roll up before sewing.





**It's easy to open this padlocked box, once you know the secret.**

Written by **Paul Boon**

## MATERIALS

- » **Box** to be modified. See Step 1.
- » **Padlock, small**
- » **Hasp and staple set** such as Everbilt 2½" safety or Schlage decorative sets
- » **Wood screws, brass, flat-head Phillips, #4×¾" (5)**
- » **Felt pads or protective "feet" (4)**
- » **Magnets, rare earth (NdFeB), ½" long × ¼" or ⅜" diameter (2)** depending on your box's wall thickness, Applied Magnets item #ND015 or #ND010, [magnet4less.com](http://magnet4less.com)
- » **Varnish or paint (optional)**

## TOOLS

- » **Drill and drill bits: ⅜", ¼", or ⅜"** A drill press is recommended, though a handheld drill can also work if you're very careful.
- » **Tape measure or ruler**
- » **Pencil**
- » **Glue**
- » **Screwdrivers, small**
- » **Safety glasses**
- » **Brush (optional)**

Paul Boon has been a scuba diver, welder, portrait painter, magician, truck loader, and sailboat crew member and has constructed three electric vehicles, started two successful small businesses, and been awarded two patents.

# Puzzle Treasure Box

⚡ **TIME: 1-2 HOUR** ⚡ **COST: \$**

Given as a gift, this puzzle box provides a few minutes of entertainment while the recipient solves the puzzle of how to open the locked box (which they've been given without a key). The obvious lock, hasp, and staple misdirect their attention from the secret: nonfunctional hinges and hidden magnets.

Leave the box in plain view on a desk, nightstand, or table to hold small items you'd like to keep inaccessible or unknown to the hoi polloi but readily available to the trusted few.

## 1. Obtain a suitable box.

For previous projects, I've purchased amazingly carved wooden boxes at import chain stores. This time I struck out, so I got boxes from Michaels and Big Lots for about \$5. You might also try other craft stores, garage sales, second-hand stores, and flea markets.

Make sure the box is big enough to attractively mount the hasp you intend to use. I recommend you avoid boxes with the hinge screws exposed, because the puzzle aspect of the box can be bypassed if screws can be removed. Also, I prefer somewhat distressed wood — any damage I cause can go undetected.

## 2. Remove screws and glue the hinges.

Remove screws from one side of the hinges. Save the screws! Maybe you can use them to install the hasp.

Apply a drop of glue inside each hinge (**Figure A**) to hold the 2 leaves together. This prevents them from opening at an inopportune time and interfering with the closing of the box.

## 3. Apply finish (optional).

If your box is unfinished, now's the time to paint or varnish it. Wait for everything to dry — don't attempt to remove sawdust or fingerprints from tacky varnish.

## 4. Attach the hasp and staple.

Look for a location and orientation that please your artistic sensibilities. Mark the hasp and staple mounting holes with your pencil.

Drill  $\frac{1}{16}$ " mounting holes that are less than  $\frac{1}{4}$ " deep. Mount your hasp and staple using the brass wood screws (**Figure B**).

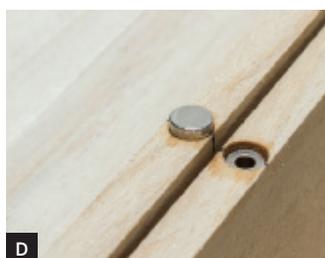
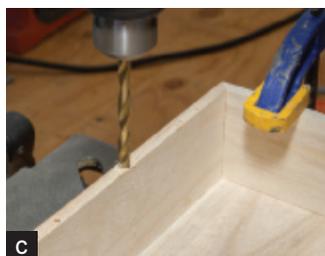
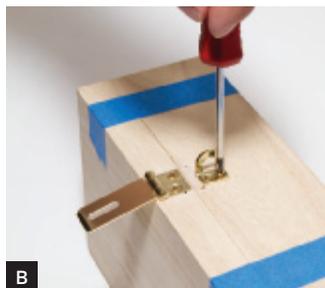
## 5. Install magnets.

Mark an X for the magnet holes in the exact center of the hinged side of the lid and the opposing side of the box.

I prefer to use  $\frac{1}{4}$ " magnets because they require about 6lbs of force to pull apart. This makes it more difficult to find the secret method of opening. But before drilling  $\frac{1}{4}$ " holes, look carefully at the box panel you'll be drilling into. If your panel is near  $\frac{1}{4}$ " thick, you might end up splitting it or drilling through it with a  $\frac{1}{4}$ " drill bit. In that case, downsize to  $\frac{3}{16}$ ". Whatever size you choose, drill the holes  $\frac{3}{4}$ " deep (**Figure C**).

Apply a drop of glue to each hole, then push the first magnet into its hole. Speaking with the (embarrassed) voice of experience, I advise you to allow the second magnet to attach to the one you've already installed. Then ensure that its opposite end is the one you push into the second hole.

I made one magnet stand  $\frac{1}{16}$ " proud while the other is recessed  $\frac{1}{16}$ " (**Figure D**).



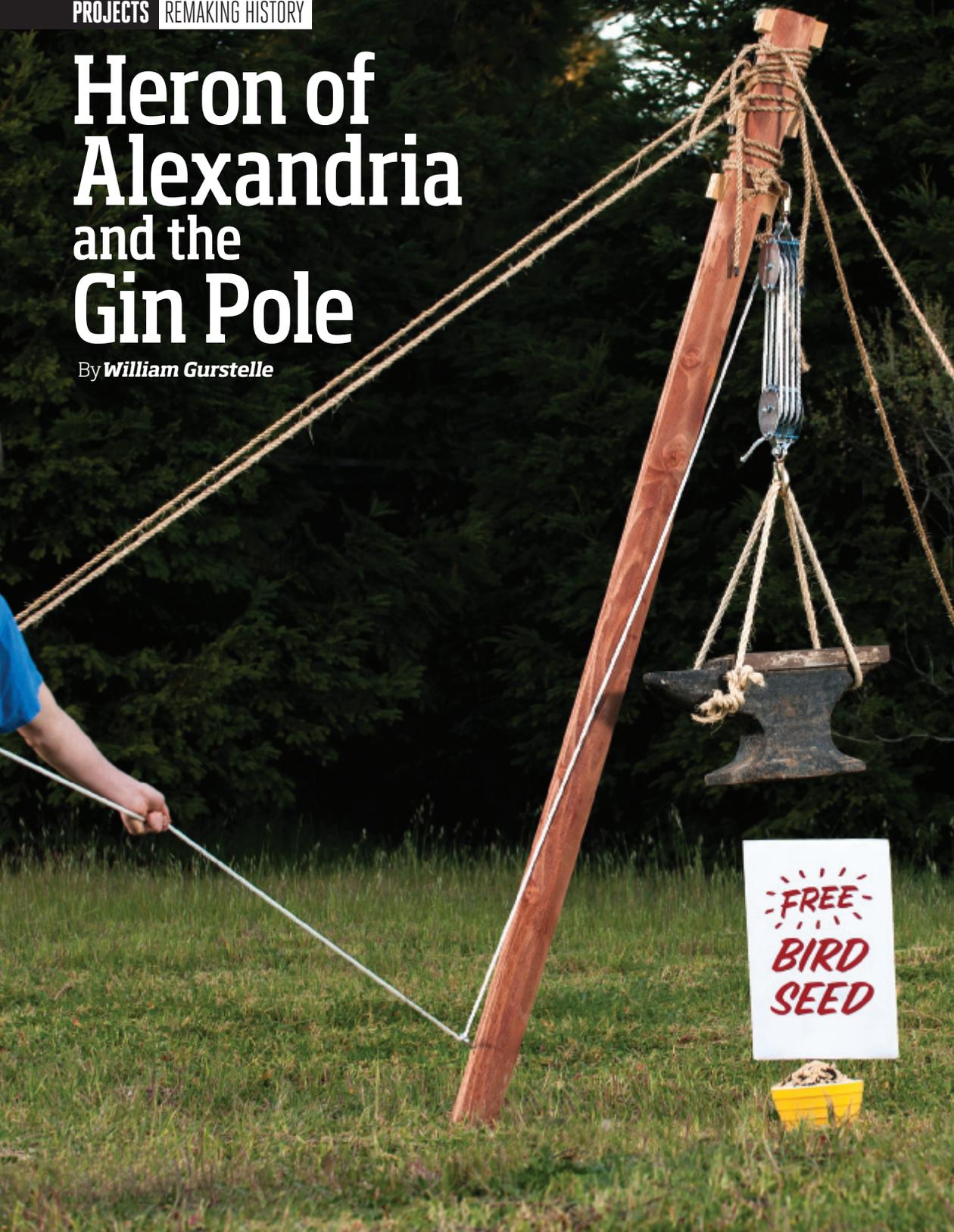
## 6. Finishing touches.

Apply foot pads to protect your furniture. Put the lid in place, close the hasp, lock the lock, and throw away the key!

But wait — you're not finished yet. My dear friend Dr. David Schultz tells me that gift puzzle boxes must always be filled with a treat or treasure. Although I settled for candy, you may choose gold doubloons, jewels, or the latest issue of MAKE! ▣

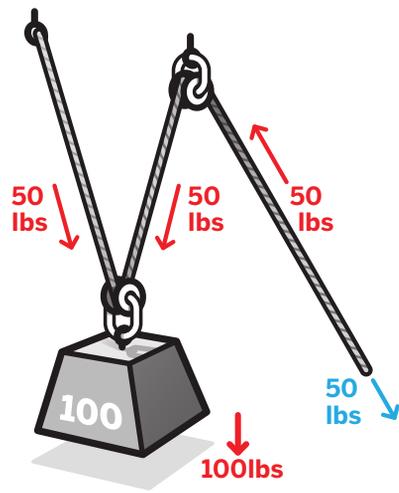
# Heron of Alexandria and the Gin Pole

By **William Gurstelle**



## CAUTION

The amount of weight that your gin pole can handle will depend on the length and thickness of the pole, the capacity of the rope, the quality of your knots, and the holding power of the stakes. Take it easy to begin with as you learn the capability of your rig.



In antiquity, the only way to raise a heavy object was to put a rope on it, climb a ladder, and pull, or if you had enough time, build a ramp.

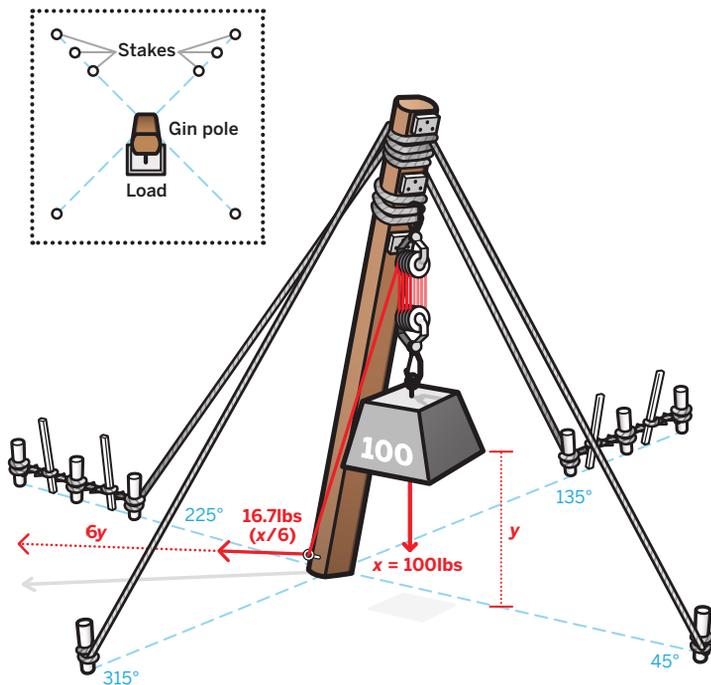
The ancient Egyptians much favored the ramp technique, and the Great Pyramids show that very worthy things could be built this way. Later the Egyptians came up with better ways to hoist stuff. Around 1500 B.C., Nile farmers invented a counterbalanced lever called a shadouf or swape, to use in irrigating their crops. With a shadouf, buckets of water or baskets of rocks could be lifted to a height of nearly 15 feet.

But 15 feet was more or less the limit for machine-assisted lifting for 1,000 years, until the Greeks mounted a pulley on the end of a pole and invented the construction crane in the 6th century B.C. They soon realized that with such a device, the sky's the limit.

Who engineered those first cranes? Their names are lost; only their marks remain on the stones of the classical Greek temples. It is through Heron (Hero) of Alexandria (c. A.D. 10–70), a Greek engineer living in Roman Egypt, that we first become well acquainted with the ancient construction cranes.

Some modern historians put Heron's scientific contributions in the same league as those of Pythagoras, Archimedes, and Euclid. A polymath of sweeping scope, Heron wrote a lot of books on subjects ranging from classical mathematics and fluid dynamics to catapult construction.

The cranes Heron describes were simple affairs, but they were world changers. Dependable and efficient lifters, they made it possible to construct buildings taller than two stories without ramps. Heron's original



## MATERIALS

- » Rope, Manila hemp,  $\frac{3}{8}$ " diameter, 100'
- » Landscape timber, round, 8', 3" x 3" or 3" x 4"
- » Wood dowels:  $1\frac{1}{2}$ " or  $1\frac{1}{4}$ " diameter, 24" long (8),  $\frac{1}{2}$ " diameter, 12" (4)
- » Triple-pulley block and tackle with at least 60' feet of rope Look for a "rope hoist" at places like Harbor Freight, Tractor Supply, Amazon, or eBay.
- » Pine blocks, 2" x 2" x 1" (6)
- » Screw eye, large
- » Nails, 8d (18)

## TOOLS

- » Saw
- » Mallet or sledgehammer
- » Shovel
- » Hammer

manuscript, a tome called *Mechanics* or *The Elevator*, was lost. Luckily, Arabic translations survived, with the no-nonsense title *Heron's Book About the Lifting of Heavy Things*.

Another really big idea in Heron's book is the force-amplifying block and tackle, the compound pulley rig (credited to Archimedes in the 3rd century B.C.) that allows a person to lift heavy objects by trading displacement for force. As the diagram on page 139 shows, by using a single block and tackle (one pulley in the fixed block and one in the moving block) you can lift a weight of  $x$  pounds to a height of  $y$  feet by applying a force of only half of  $x$  ( $x/2$ ), if you're willing to pull on the rope for  $2y$  feet. That's a 2:1 mechanical advantage. This may be well known now, but in ancient Greece, it was an incredible insight.

Heron's ancient crane is a guyed derrick with a windlass, and it was the standard tool in building construction for a millennium and a half, until more complex cranes were developed in the Middle Ages.

That ancient, one-masted crane lives on today in an incarnation known as the *gin pole*. The gin pole is the aspirin of construction equipment; it's been around a long time and it

still works great. Used mostly for vertical lifts, it can hoist a load up to 50 feet. A good rigger and erector can also use it to swing loads from one place to another.

The gin pole is the simplest crane possible, consisting of a single upright spar with hoisting tackle at the top, plus a mechanical connection or two to direct the rope work. There's no heavy base or counterweight to deal with. Instead, a system of guy lines stabilizes it, and the spar's bottom is constrained by simply planting it in a shallow hole. This "poor man's crane" can handle a lot of weight. For example, a 6"-diameter, 20'-long wood pole rig can heft more than 2 tons.

But, and this is a big but, such enormous lifting capacity comes with inherent risks. Having spent time using a gin pole and other lifting equipment, I can tell you that lifting heavy objects is a dangerous business if done improperly. Inadequate staking, poorly tied knots, weak or undersized masts, or old, weak ropes can result in a broken rig and a bad situation. Rigging is an art, so start small and increase your loads slowly as you become more proficient. And *never* get underneath the load or the mast during a lift.

## 1. Dig a shallow hole.

Dig a hole to fit your timber pole, 8"–10" deep, a short distance from the load to be lifted. The distance from gin pole to load should be no more than one-third the length of the pole.

## 2. Prep the pole.

Attach the 6 cleats to the gin pole with 3 nails per cleat, as shown in **Figure A**. The cleats will keep the ropes from sliding down the pole, or slipping off the top. Attach the screw eye to the pole about 12" from the lower end.

## 3. Attach the hoist.

Lash the upper block and tackle hook to the top of the gin pole just above the lower cleat. Loop the rope through the hook 3 times and then use a secure knot such as a clove hitch or timber hitch to tie it off. This is the *fixed block* (**Figure B**).

## 4. Tie the guys.

Cut 4 guy lines about 20' long. Place the gin pole on its side and tie 4 clove hitch knots just above the upper cleat. Tie your knots so that when each guy line extends straight out, the rope is not bent or doubled back, as shown in **Figure C**.

## 5. Place the stakes.

Locate 4 of the 1½"×24" stakes 9' from the hole at compass points of 45°, 135°, 225°, and 315° from the line extending between the load and the hole (see diagram, opposite).



Pound in the stakes until about 8" remain exposed to view, at an angle about 25° from vertical, extending away from the pole.

Staking things is a skill in and of itself. Depending on the weight of the load to be lifted, great force will be pulling on those stakes. Use the "3-2-1" staking technique to increase the holding power of the rear guy lines at 135° and 225°. (The front guy lines don't hold much, if any, load.)

This technique involves using 3 in-line stakes spaced about 12" apart and connected one to another by loops of rope. Insert a ½" dowel in the middle of each rope loop and use it as a "Spanish windlass" to twist the loop until it's taut. This will spread the load across the 3 stakes. Then securely anchor the Spanish windlasses against the ground (**Figure D**).

## 6. Guy the pole.

Place the bottom of the gin pole in the hole. Angle your crane so that the hoist is directly over the load. Have a helper hold the pole while you extend the rear guy lines (the lines at 135° and 225°) to the stakes and tie them off with a clove hitch.

Extend the front guy lines to the stakes at 45° and 315°. When you actually start to lift, these lines will go slack, as all of the weight will be borne by the gin pole and 2 rear guys, but tie them off securely anyway, again with a clove hitch (**Figure E**).

## 7. Hoist!

Rig the triple block and tackle, and thread the load rope through the screw eye. Attach the load to the bottom pulley block; this is the *moving block*. Pull steadily on the load rope and the weight will slowly rise. Your ancient crane is giving you a 6:1 mechanical advantage. ■

William Gurstelle is a contributing editor of MAKE. The new and improved edition of his book *Backyard Ballistics* has just been released.



A little over a year ago, I had the opportunity to purchase an incredibly rare WSW audio console from the mid 1960s. This particular desk had formerly been in service on the road, so the whole thing was racked in heavy-duty subframes, boxed in custom cases. Each case had an I/O panel for power and audio signals such that the entire complement of modules could be snaked together and disassembled nightly.

The center of my studio at the time was a modern line mixer by Tonelux. It's small, sounds amazing, and

is modularly scalable. Best of all, the end user designs their own system from that myriad of options to cover what their individual needs dictate.

The unifying aspect of these two vastly different consoles is the modularity of each. Both use edge-simple connectors to apply power as well as get audio in and out. Additionally, WSW included unbalanced direct outs on each channel, so we only needed to add balancing transformers in order to easily interface the vintage channels with any gear already in

# AUDIO CONSOLE FUSION

WRITTEN BY  
BRIAN BENDER

Past and future come together in this state-of-the-art audio console.

the studio. This provided a way to easily conjoin the two halves with nearly infinite flexibility through the intelligent use of the patchbay.

The frame you see pictured is a custom-designed and hand-built masterpiece by François Chambard of UM Project. Given that we didn't have an original frame from the WSW, François had the freedom to start from a blank slate. He reused some of the subframes from the original WSW cases. The center is sized for a 30" Apple display, as well as a touch-

sensitive control surface. Metering is handled by several original WSW meters as well as a pair of highly accurate modern Dorrrough 40-Cs (loudness meters). The belly is brass, sides are in ash, and the meter bridge and armrest are both rolled steel finished in ceramic enamel. The enamel is Sharpie-proof, and that might be the best part. ▣

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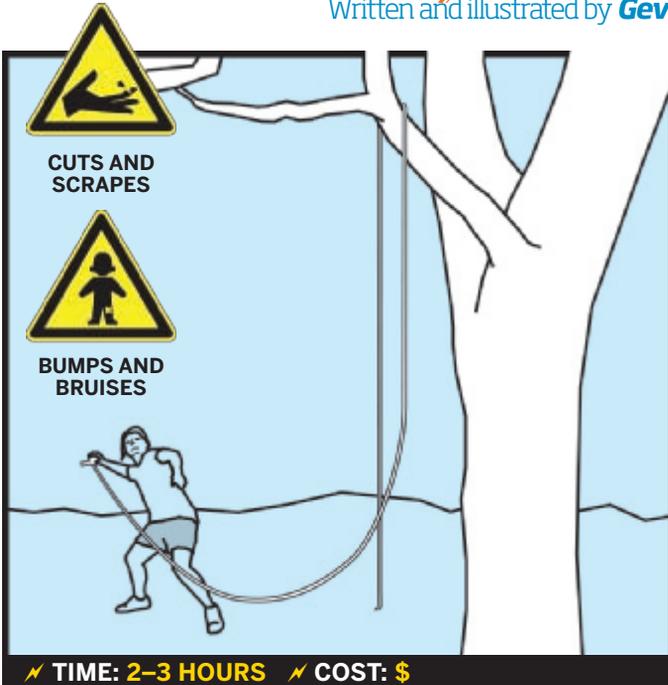
Brian Bender is a producer and engineer based in Brooklyn, N.Y.



FALL

# DANGER Make a Rope Swing

Written and illustrated by **Gever Tulley** with **Julie Spiegler**



**YOU WILL NEED:** Strong rope » Sturdy tree branch » Adult supervision

**WARNING** A healthy-looking branch can be rotten inside. Before you risk life and limb, inspect your hang-point carefully. Pull on it with a rope (while on solid ground). Have an adult confirm your choice.

## SUPPLEMENTARY DATA

A person on a swing is what physicists call a *pendulum*. The rate at which a pendulum swings is determined by the length of the rope from the attachment point to the swinging mass (that's you). When we "pump" to make a swing go higher, we're really changing the length of the pendulum. We lay back (lengthening the pendulum) as the swing goes down, and sit up (shortening it) as it goes up. It's the fast bit at the end of the arc that makes us go a little higher. This exchange of energy is called Conservation of Angular Momentum.

## GOING FURTHER

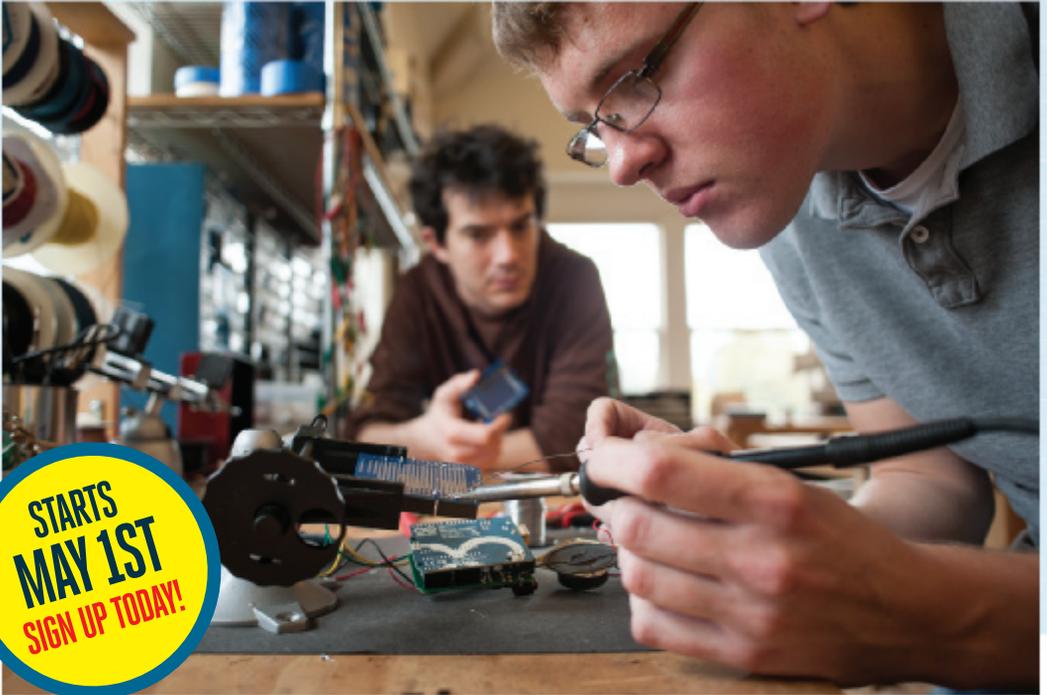
You can just hang on to the rope to swing, but your desire to swing may outlast your ability to hold the rope. Tie a stopper knot to make it easier to hold, or tie something on the end to sit on, like a board or a tire. If you're in a park, don't leave your swing tied to the tree. Untie knots and throw the rope back over the branch so you can pull it down.

## Trust life and limb to something you made.

- 1. Find a tree.** Look for a branch as big around as your waist, with lots of green leaves at the end, and no big rocks or roots directly below. Can you reach it if your rope gets stuck?
- 2. Find suitable rope.** Get rope that can hold at least twice your weight, according to the "test weight" on the package. You need it to be long enough to go up to your branch and back down, plus extra for knots and loops.
- 3. Hang your rope.** Hold one end and throw the other over the branch. If it's too high, tie a rock to string and toss that over first; then use the string to pull the rope over.
- 4. Check the position.** If your rope is too far from the tree, the branch may bend or break; too close and you may bump into the trunk when you're swinging.
- 5. Make fast, and swing!** Repeat steps 3 and 4 so the rope wraps around the branch. This keeps it from slipping or sawing through the branch while you're swinging.

Excerpted from *Fifty Dangerous Things (You Should Let Your Children Do)* by Gever Tulley with Julie Spiegler ([fiftydangerousthings.com](http://fiftydangerousthings.com)). Gever is co-founder of Brightworks, a K-8 school in San Francisco ([sfbrightworks.org](http://sfbrightworks.org)).

# Training Camp for Makers!



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### FIRST COURSES:

**Introduction to Arduino**  
**Introduction to Raspberry Pi**

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# Make:

[makezine.com/trainingcamp](http://makezine.com/trainingcamp)

# GAMI-BOT

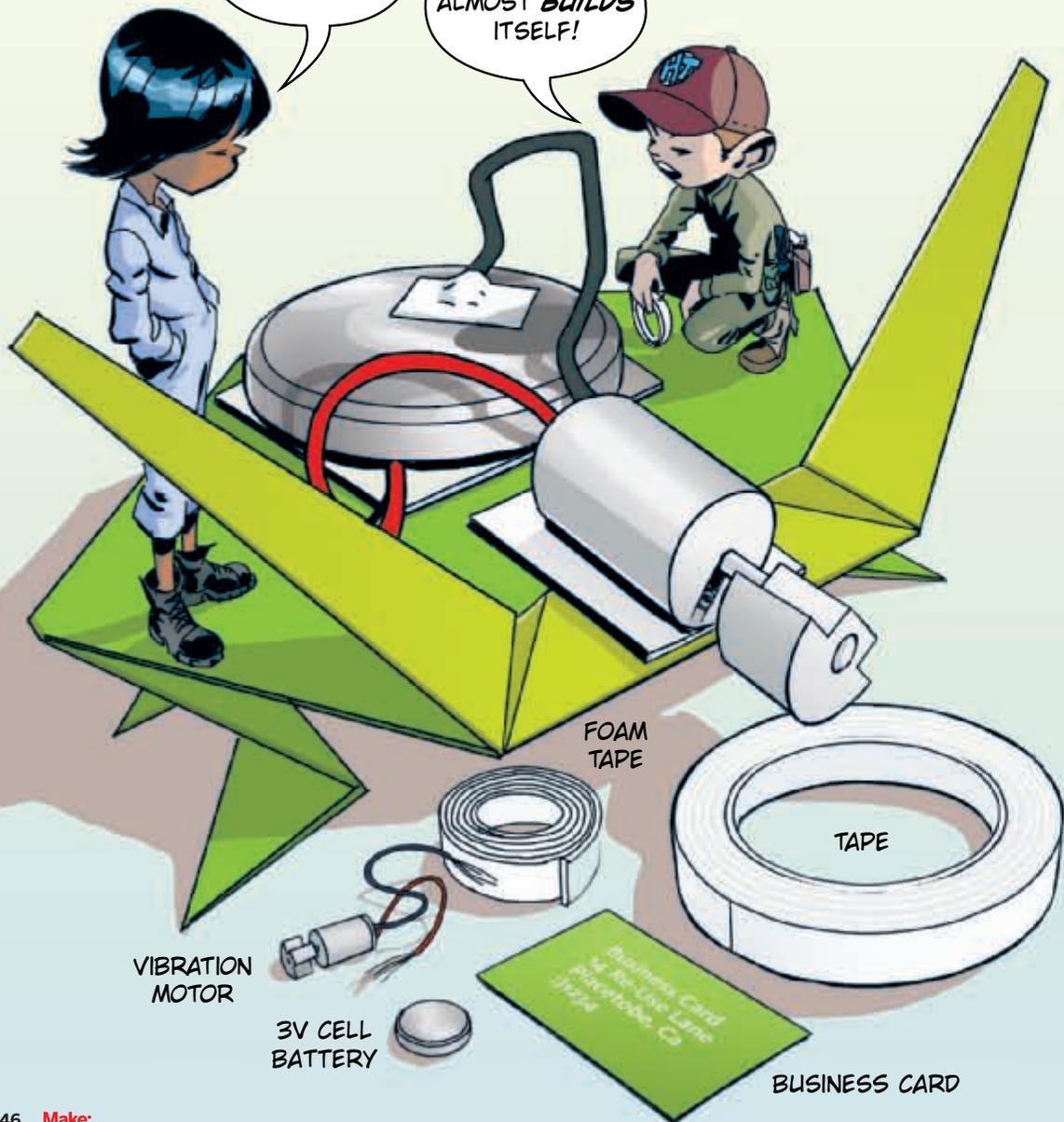
**ROBOTS** ARE SMART MACHINES CAPABLE OF AUTONOMOUSLY PRODUCING COMPLEX MOTION TO PERFORM COORDINATED TASKS LIKE RUNNING.

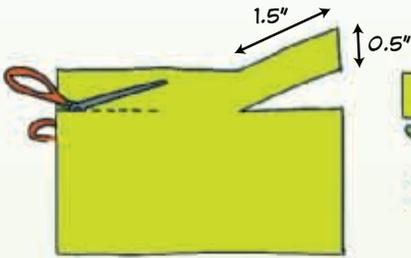
THEY ARE USUALLY ELECTROMECHANICAL IN NATURE AND ARE GUIDED BY INTELLIGENCE EMBEDDED IN MECHANISMS, ELECTRONIC CIRCUITS, OR COMPUTER PROGRAMMING ...

BUT NOT ALWAYS!

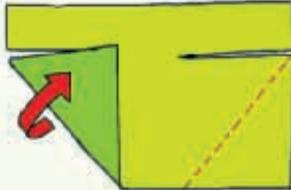
IT'S THAT **EASY** TO MAKE A **ROBOT**?

YEP, IT ALMOST **BUILDS** ITSELF!

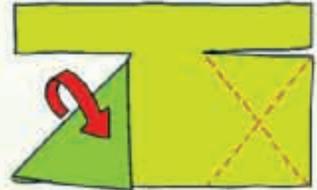




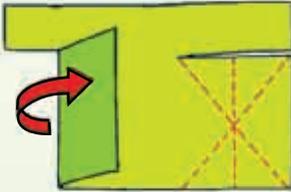
**1** CUT 2 STRIPS 1.5" IN FROM EACH SIDE, 0.5" DOWN.



**2** VALLEY-FOLD CORNERS UP TO MEET CUT LINES, CREATING A VALLEY CREASE.



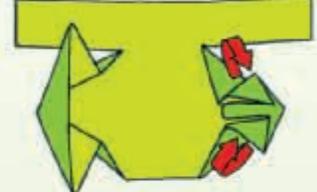
**3** VALLEY-FOLD TOP CORNER DOWN, CREATING A DIAGONAL.



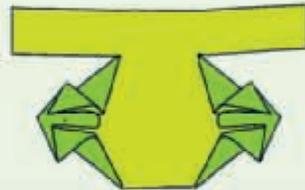
**4** FOLD IN HALF ALONG THE CREASE. REPEAT STEPS 2-4 ON THE OTHER SIDE.



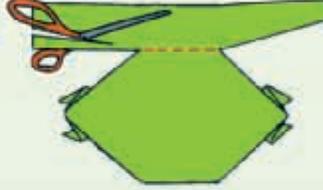
**5** CREATE A COLLAPSIBLE FOLD BY PINCHING THE CENTER CREASE IN.



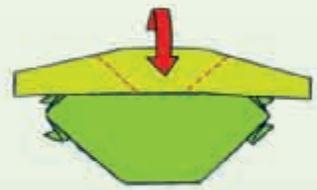
**6** FOLD CORNER POINTS UPWARDS TO MAKE YOUR LEGS.



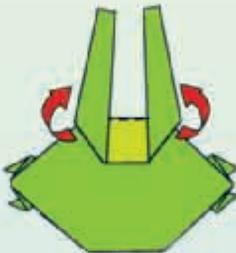
**7** REPEAT ON THE OTHER SIDE.



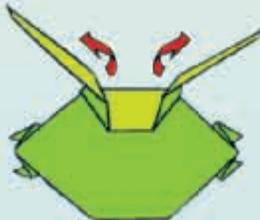
**8** SHAPE YOUR ANTENNAS BY CUTTING DIAGONAL LINES.



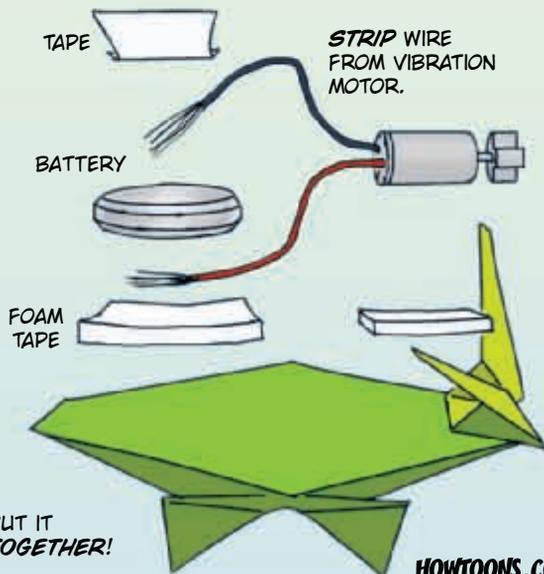
**9** VALLEY-FOLD ANTENNA UP ALONG THE CUT LINES.



**10** VALLEY-FOLD ANTENNAS UP.



**11** MOUNTAIN-FOLD ANTENNAS DOWN.



**12** PUT IT TOGETHER!

HOWTOONS.COM

# TOOLBOX

## Bosch 1575A Foam Rubber Cutter \$314 [boschtools.com](http://boschtools.com)

» I used to work for a puppet maker, and I've cut a lot of foam with less-than-ideal tools. Band saws are fast but immobile, and wrestling large sheets through complex patterns can be tough. Utility knives are light-weight and nimble but tend to flex, and can't cut very deep. Scissors are a tragic choice. I just accepted these hardships as part of the process.

Then, a couple years ago in England, I watched a Cambridge Market foam vendor whip through a huge sheet of foam rubber using a handheld electric reciprocating cutter. He told me it was a specialty tool with a steep price, but he wouldn't do business without it.

No, it isn't cheap, and accessories – blades, guides, feet – are sold separately, but it's a great investment if you cut a lot of foam and want to do it well. Guides and blades are available in four lengths up to 12". Fitted for 3" depth, the 1575A zips through puppet foam as well as carpet. First on my spring project list? A new Jeep interior with removable fitted dog bed.

–Gregory Hayes



# ToughBuilt Compact Bolt Cutters

**\$25-\$144** [toughbuilt.com](http://toughbuilt.com)

My inner juvenile delinquent loves bolt cutters. Imagine all the padlocks and chains they can defeat! ToughBuilt's patented folding cutters, in sizes from 14" to 42", slip into a toolbox or, say, a backpack for making mischief. The folding action is slick, and the handles are extra wide so you can really lay some force on them without pulverizing your palms.

Tested in the MAKE Labs, the 18" pair cut through a ¼-20 steel bolt like a piece of cheese, without a sound. Compound leverage is a beautiful thing. A 5/16" lag bolt made only a feeble pop as its head was lopped off. So we escalated to ¾" hardened steel rod and the massive 36" cutters. A small crowd gathered. My lovely assistant Dan Spangler clamped the stock vertically in a vise. I donned goggles, braced one handle against my chest, and heaved on the other like an oarsman. Grrrrrrr — bang! A bullet of ¾" steel dinged the ceiling tiles, and there was much rejoicing.

—Keith Hammond



# HexBright Flex

**\$129** [hexbright.com](http://hexbright.com)

A crowdfunding project from BattleBots veteran Christian Carlberg, the HexBright is an open source, programmable flashlight equipped with a top-of-the-line Cree XM-L U2 LED. Out of the box, there are three brightness settings — 50, 150, and 500 lumens — and the maximum setting is astoundingly bright. The USB-rechargeable lithium-ion battery is good for 30 hours of run time at 50 lumens, and there's a strobe mode that blinks at the middle brightness level. The rugged



aluminum construction conceals an onboard Arduino-compatible microprocessor. Community-sourced programs from the project's GitHub repository include different brightness settings, Morse code, and — my personal favorite — a program

that uses the built-in accelerometer to vary the brightness of the flashlight by the angle at which it's held. Compact, tough, and highly hackable, this may be the ultimate maker flashlight.

—Jake Spurlock

## Skinth OG Multi-Tool Sheath

\$35 [skinthsolutions.com](http://skinthsolutions.com)



I remember a time when all I needed to carry in my pockets was a set of three house keys and maybe a piece of candy. Now, they bulge with house, car, and office keys, my cellphone, wallet, a tube of lip balm, a flash drive, a small flashlight, and my pen. And I want to carry more, but can't.

That's where the Skinth comes in. These slim, unobtrusive tool and gadget sheaths are custom-built to your needs from heavy-duty Cordura nylon. Flap closure? No problem. Side pockets? Sure. Belt clip? They can do that, too.

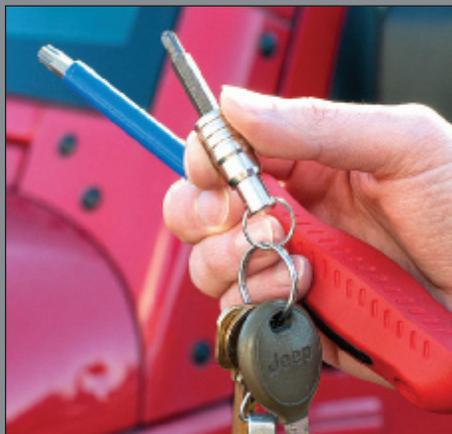
The Skinth OG, shown here, is a nice size to start with and has room for medium-sized EDC (everyday carry) tool kits. If you don't need as many options, their Spartan and Shield models are simpler and lower-priced.

Skinths are thoughtfully designed, very well made, and extremely durable. Don't have a belt? They make pocket organizers as well.

—Stuart Deutsch

## Engineer, Inc. DR-61 Bit Pit

\$10 [iheartengineering.com](http://iheartengineering.com)



This locking storage socket is handy for keeping an odd hex bit on hand wherever you go. The Bit Pit is small, light, and solidly built. It's only about as thick as my key fob, and slightly shorter, so it doesn't add much bulk to my keys. Ball detents grab tight to any grooved or indented bit. Use it to keep up with your Torx, pentalobe, security head, or whatever other weird bit you might need.

—Sam Freeman

## UDIRC U816 RC Quadcopter

\$60 [weksirc.com](http://weksirc.com)

You get a lot for your money here: a USB charger, two batteries, the quad itself, a manual, stickers, and a fairly capable 2.4 GHz transmitter. With the press of a button, the copter can automatically perform loops and rolls, or switch between one of two flying modes: subdued and stable, or quick and responsive. I was pleasantly surprised by the durability; crashes and falls barely show, and though the foam shell finally cracked after days of abuse, it took all of 5 minutes to repair with a couple drops of glue. The batteries charge in an hour and give roughly 10 minutes of flight time.

—Eric Weinoffer

# Steadicam Smoothee

\$169 [tiffen.com](http://tiffen.com)

This slick rig gives a semblance of that dolly-smooth movie tracking shot effect without the multi-thousand-dollar price tag. It consists of a handle with a camera mount (iPhone or GoPro) freely floating on a ball joint, with a pendant weight, hanging below, to keep things smooth and level.

The action is smoothest and offers the prettiest videos when the mount is allowed to float free. There is a tendency to drift along the X-axis. The manufacturer suggests holding onto the floating part of the rig with your thumb, to stabilize the swing, but this takes a bit of practice. Once you've got the hang of it, the Smoothee can give very satisfying results.

—John Baichtal





# Dr. Klick's Kit Dental Tools

\$35 [duluthtrading.com](http://duluthtrading.com)

Frankly, dentistry gives me the creeps. So my fascination with dental tools may be of the morbid variety. Nonetheless, when I saw this set of consumer-priced dental picks and tools from Duluth Trading, they began to whisper to me. I had to have them. The tweezers are perfect for arranging tiny electronic components for product photography, and the picks help clean stray glue, dust, and other schmutz from projects before shooting. They are super sharp, so you need to be careful about scratching softer materials, including yourself.

—GH



# Bosch RH228VC Rotary Hammer

\$255 [boschtools.com](http://boschtools.com)

I've been a stonemason for 18 years, and I know the value of a good rotary hammer drill. I tested this one, first, by drilling into a piece of stone with a  $\frac{3}{4}$ " masonry bit, and immediately liked the variable speed trigger control and high top drilling speed. I was also pleased to find a hammer hook that makes it easy to hang the drill up on something for storage or in the middle of a task. But far and away the most important feature, for me, is the counter-balance vibration control, which claims to reduce shaking up to 30%. I often drill for more than three hours in a day, and this feature can mean the difference between walking away from the job with aching wrists, or not.

—Jason Carter



## Dremel 8220

\$99-\$140 [dremel.com](http://dremel.com)

Though I've only used it a short time, the 8220 seems to offer all of the advantages of my old corded Dremel tool without its one major drawback: the bulky, dangling power cord.

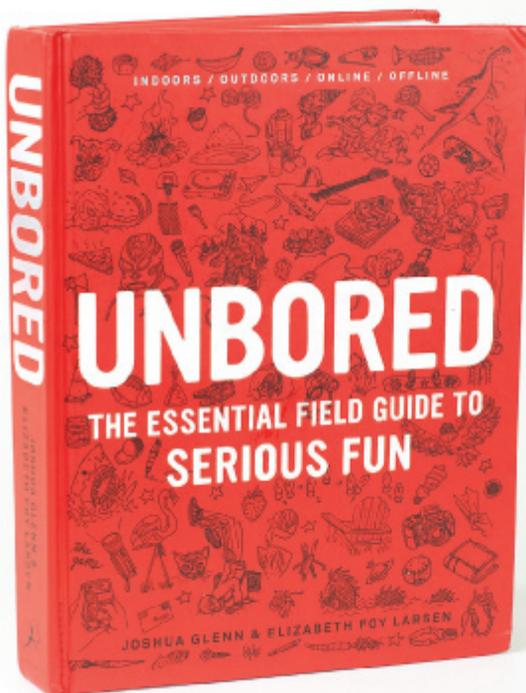
First of all, not being tethered to an outlet is great, especially for the close, precise work where rotary tools really shine. You can get around, behind, and under your work without worrying about tangling a cord. The tradeoff, of course, is down time while the battery recharges, which takes about an hour. A charge indicator on the handle shows how much juice you have left.

Another improvement is that the power switch and speed controls have been separated, so you can set the rpm exactly where you want it before turning on the tool. Even better, the speeds are now clearly marked (5-30K rpm) so you never have to guess.

—JB



# BOOKS



## Unbored: The Essential Field Guide to Serious Fun

by Joshua Glenn and Elizabeth Foy Larsen

\$25 Bloomsbury

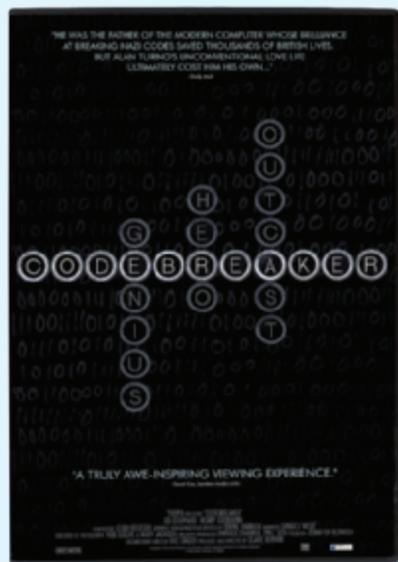
"I'm bored." Anyone who spends time around kids has heard that before. But it's hard to make that complaint with a copy of *Unbored* in the house. The book is loaded with projects, games, experiments, and just plain fun that will get kids and adults off the couch. There's a pleasingly subversive undercurrent to the book that rejects convenience and consumer product abundance and the boredom it can breed. The great sense of curiosity and exploration within the pages of *Unbored* is the antidote.

—Stett Holbrook

## Codebreaker (2012)

Directed by Clare Beavan, TODpix / Turing Films

This drama-documentary examines the life of Alan Turing, one of the most influential minds of the 20th century. Not only a brilliant WWII cryptographer, Turing's groundbreaking thinking set the stage for the modern digital world. Unfortunately, as a gay man living in repressed postwar Britain, he endured years of official persecution, and (most likely) committed suicide at 41. This film throws back the curtain on Turing's life: there are dramatized segments, interviews with people who knew him, and glimpses of primary source materials. We see letters, drawings, and equations in his hand; his psychiatrist's daughter delightfully recalls how he taught her to win at solitaire. The film both humanizes Turing's genius and underscores the tragedy of his early death. What would he have done next? (TODpix allows viewers to crowdfund screenings. Bring one to your local theater!) —Arwen O'Reilly Griffith



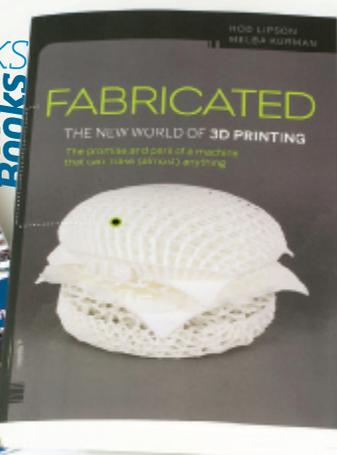


## Watch it Made in the U.S.A.

by Karen Axelrod and Bruce Brumberg  
**\$22 Avalon Travel Publishing**

This book was written by a husband and wife who set out to “kick the tires of the American economy” by traveling around the country taking factory tours. Turning through its pages gives a fascinating glimpse, not only of the wide range of products that are made here, but of the everyday lives of the workers that produce them. At National Braille Press in Boston, blind proofreaders listen to a digital text-to-speech reader, and the room “chatters with the sound of Braille typewriters.” In Colorado, world-class athletes work out at the U.S. Olympic Training Center. At Shidoni Foundry in New Mexico, watch a dramatic pouring of hundreds of pounds of molten bronze. Intriguing stuff.

—Laura Cochrane



## Fabricated: The New World of 3D Printing

by Hod Lipson and Melba Kurman  
**\$28 Wiley**

Robotist Hod Lipson and technology writer Melba Kurman bring great experience and intelligence to introducing the thirty-year history of 3D printing to general audiences. Topics like “the ten principles of 3D printing” and “the language of shapes” synthesize years of teaching, writing, and speaking on these subjects and are full of persuasive arguments. But many of the strengths and pleasures of the book derive from speculation about 3D printing in the near, middle, and distant futures. Lipson is director of Cornell’s Creative Machines Lab and co-founder of Fab@Home, and his extensive experience of this field tempers the wide-eyed optimism of some of his predictions. If anyone is capable of bringing about the future described in *Fabricated*, it’s probably him.

—Matt Griffin



## Getting Started with MakerBot

by Bre Pettis, Anna Kaziunas France, and Jay Shergill  
**\$16 O'Reilly Media / MAKE**

Lots of useful information here, especially for new MakerBot owners with little 3D printing experience. About half the book focuses on using MakerBot’s Replicator 2, and the rest covers topics that all printer owners will find useful, like the basics of 3D CAD and 3D scanning. Free software like Tinkercad and 123D Catch are covered comprehensively, among a few others, as is the intimidating process of preparing a scan for printing — perfect if you’d like to print out busts of yourself or friends. In short: if you recently purchased a MakerBot, or plan to in the near future, and would like to get as much out of it as you possibly can, this is the book for you.

—EW

# New Maker Tech



## BARCH DESIGNS Raspberry PiHolder

**\$75** [piholder.com](http://piholder.com)

This beautiful case is CNC-milled out of a solid chunk of aerospace grade 6061-T6 billet aluminum. It has substantial heft and strength. The milling removes just enough material to let the Pi fit inside, access all the ports, run a ribbon cable to the GPIO header, and swap out SD cards.

Now, when my daughter wants to do Scratch programming on the living room TV, we just grab this sturdy little computer, plug it in, and go. If it gets accidentally trod upon, no big deal: this case can take it.

OK, sure: it costs twice as much as the Raspberry Pi itself, but if you're using your Pi in a public installation, or something similar, this is a classy, beautiful, and durable way to encase it.

—John Edgar Park

## 1. Brainwave 1.0 RepRap Controller

**\$100** [metrix.net](http://metrix.net)

Made in the Pacific Northwest and representing the latest approach to open hardware printers, this single-board solution unites Metrix Create:Space's community manufacturing effort with a trim selection of features.

This board supports Cartesian and delta-style single extruder printers at minimal cost, with an eye toward flexibility and ease of repairability and patching. From designer Matthew Wilson: "I've wanted to design my own 3D printer electronics for some time. It wasn't until I found myself building machines where 50% of the cost was in the electronics that I really threw myself into it." —MG

## 2. Arduino Micro

**\$25** [adafruit.com](http://adafruit.com)

Do you love all the power of the ATmega32u4, but not all the bulk? Then the Arduino Micro is for you. About the size of a stick of gum, it boasts most of the features found on the Arduino Leonardo, in a smaller package.

The board features 32k of flash memory and 2.5k of RAM, onboard micro USB, 20 digital I/O pins, 7 PWM channels, and 12 analog input channels. It even has a 6-pin ISP header for all you advanced users. Although it lacks shield compatibility, it can be plugged directly into a breadboard which makes it extremely useful when prototyping.

—Marc de Vinck

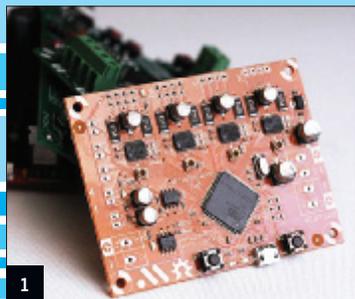
## 3. Gemma Miniature Wearable Electronics Platform

**\$15** [adafruit.com](http://adafruit.com)

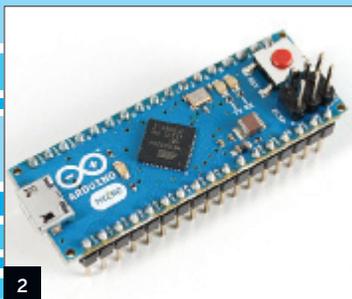
Not an Arduino per se, but this little gem is sure to interest anyone playing around with Arduino and wearable technology. The Gemma from Adafruit Industries is a tiny wearable microcontroller powered by the ATTiny85.

It measures in at only 1" in diameter, yet it still has three available I/O pins, onboard 3.3V regulated power, and an LED. One of the pins can be used as an analog input, and two are capable of PWM. What makes it really easy and fun to use is the fact that it can be programmed via its onboard micro USB port and the Arduino IDE.

—MV



1



2



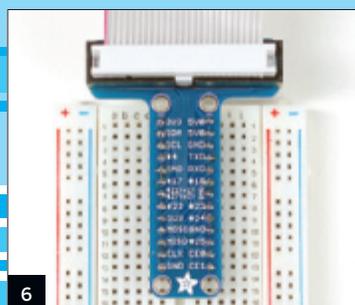
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4



5



6

## 4. Raspberry Pi to Arduino Shield Connection Bridge

[\\$52 cooking-hacks.com](#)

Wouldn't it be nice if you could use all those Arduino shields you've collected over the years with your Raspberry Pi? Well now you can, with the Raspberry Pi to Arduino Shield Connection Bridge from Cooking Hacks. All you have to do is install the free arduPi library, and you'll be on your way to programming your Raspberry Pi and the vast array of Arduino-compatible shields. The shield even includes an XBee socket for additional wireless communication possibilities with your Pi. —MV

## 5. AlaMode for Raspberry Pi

[\\$50 makershed.com](#)

While it's possible to connect an Arduino via USB to the Raspberry Pi, there's also WyoLum's AlaMode, a Raspberry Pi snap-on board that's Arduino-compatible. You can program it with the Arduino IDE and even use it with the Arduino shields you already have (though you may need an external power source). Not only that, but the AlaMode also adds a real time clock chip for keeping track of the date and time and a MicroSD card slot for data logging while your Pi is powered down.

—Matt Richardson

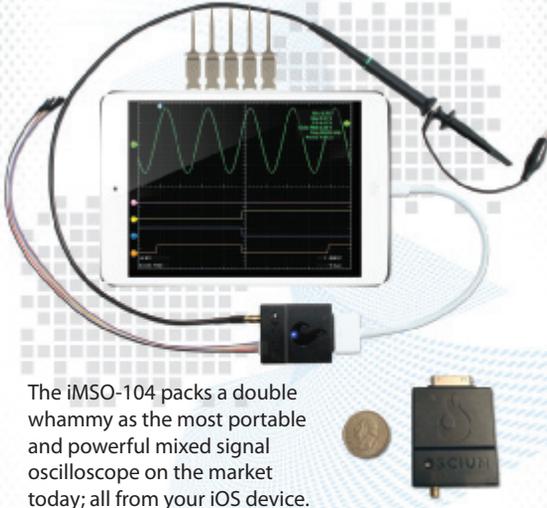
## 6. Adafruit Pi T-Cobbler

[\\$8 adafruit.com](#)

Working with the Raspberry Pi's unlabeled GPIO pins can be a bit frustrating, especially when developing a project that uses a lot of those pins. Luckily, we now have Adafruit's Pi T-Cobbler to solve the problem. This clever solder-it-yourself kit uses a ribbon cable (remember those?) to connect the Raspberry Pi's GPIO pins to your breadboard via a small PCB with clearly labeled pin numbers. —MR

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Compatible with Arduino Uno, Leonardo, Mega, and Due

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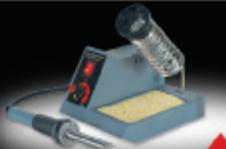
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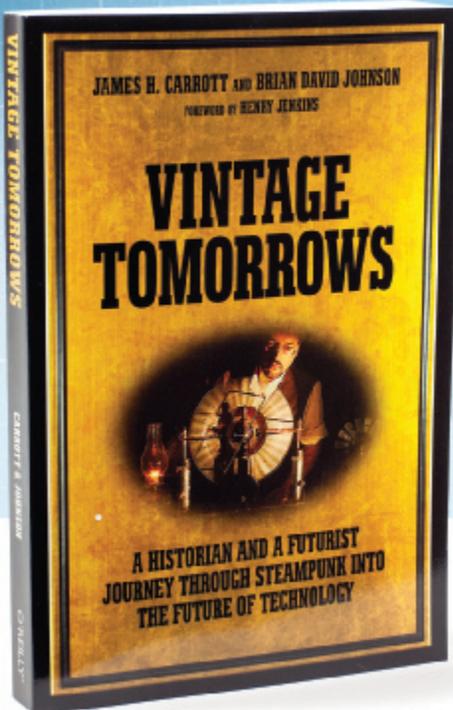


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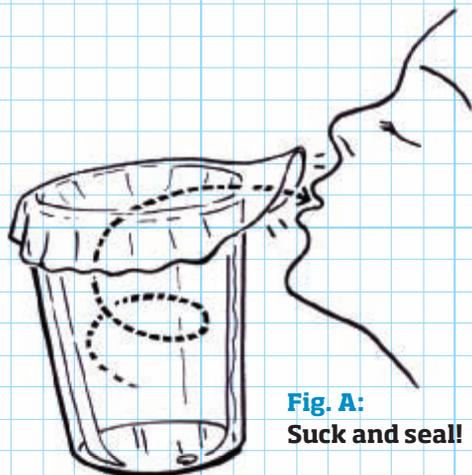
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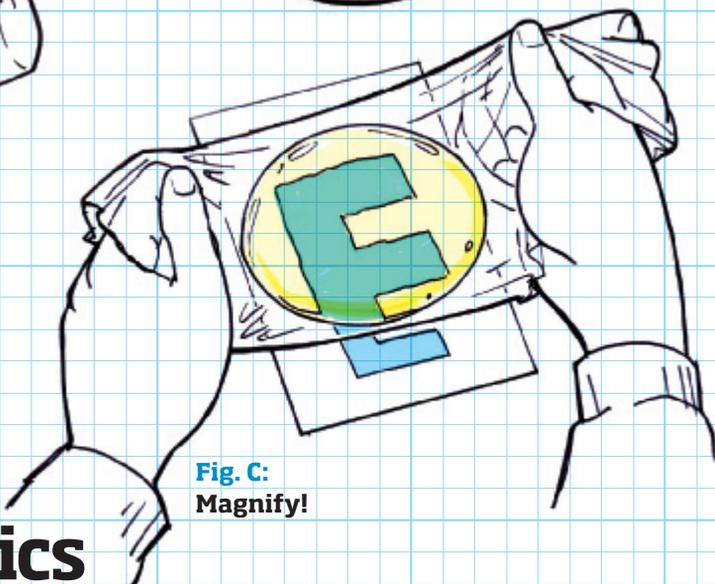
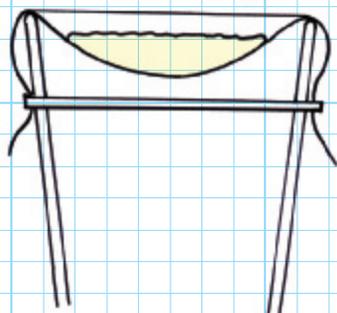
# TOY INVENTOR'S NOTEBOOK



**Fig. A:**  
Suck and seal!



**Fig. B:**  
Cast gelatin!



**Fig. C:**  
Magnify!

## Edible Optics

Gelatin is used in lots of things like food, candy, and pharmaceutical and paintball capsules, but it also has interesting optical properties. Before plastics, it was used to make colorful filters for theatrical lighting and photography (called “gels”).

A fun way to play with gelatin optics is to cast lenses. Mix the gelatin in a very concentrated form, about 1Tbsp powdered gelatin in  $\frac{1}{8}$  cup of water, and leave to set in the bottom of a rounded bowl or dish. (A concave watch glass makes a perfect lens mold!) You can also make a convex lens mold by stretching plastic wrap over the mouth of a glass and then sucking out the air before quickly sealing the wrap (**Figure A**). The stretched film will make a wrinkle-free concave shape. Add a rub-

ber band around the rim to keep it sealed airtight. Pour the gelatin mix on top and let set in the fridge (**Figure B**). When set, remove the wrap to use the lens (**Figure C**). Unflavored gelatin makes clear lenses, but you can use flavored gelatin to play with colored filters, too.

How powerful is your lens? That depends on the shape and the material:  $1/\text{focal length} = (n - 1) (1/\text{lens radius})$ . With a refractive index of around  $n = 1.38$ , gelatin is less refractive than glass ( $n = 1.51$ ) and only slightly more than water ( $n = 1.33$ ). I'll leave it to you to combine two gelatin lenses to create a “jello-scope.” When you're done looking, eat your edible optics! ❑

➤ For photos, go to [makezine.com/34](http://makezine.com/34).



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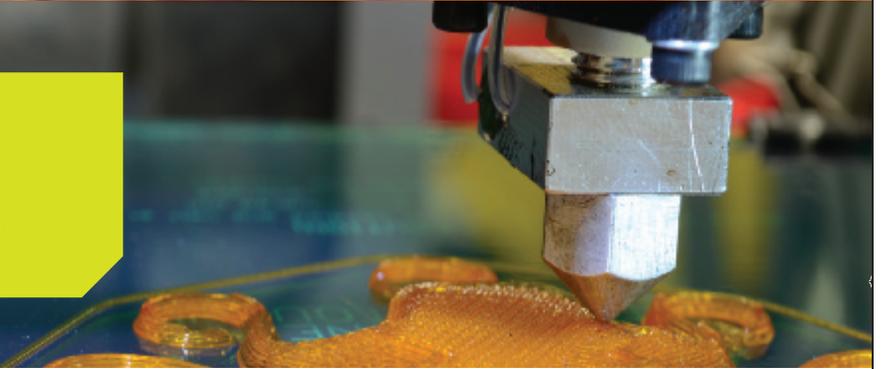
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