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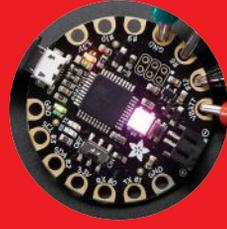
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HOW TO WIN THE
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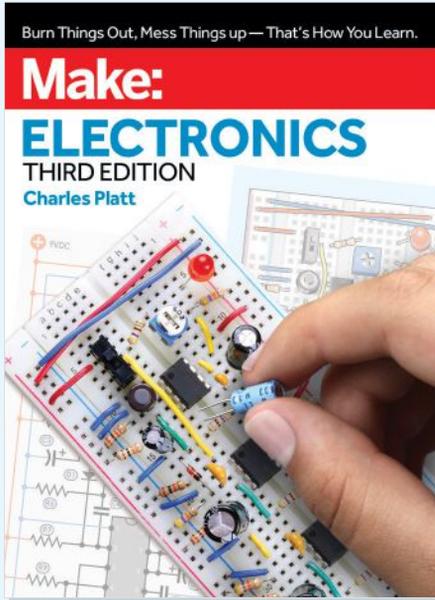
FIGHT FOR YOUR RIGHT TO FIX YOUR STUFF!

- **GPS-Guided Recovery Parachute**
- 12 Genius Shop Tips
- **3D-Printed Morphing Vise — Holds *Anything***
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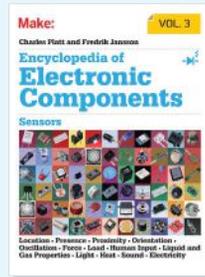
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Burn Things Out, Mess Things up — That's How You Learn.

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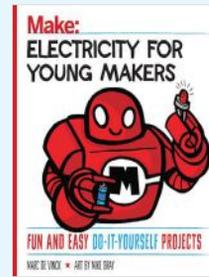THIRD EDITION
Charles Platt

MAKE: ELECTRONICS 3RD EDITION

Learning by Discovery is a system developed by Charles Platt to enable an experience that is fascinating, fun, and memorable. Our bestselling book, newly revised and expanded.

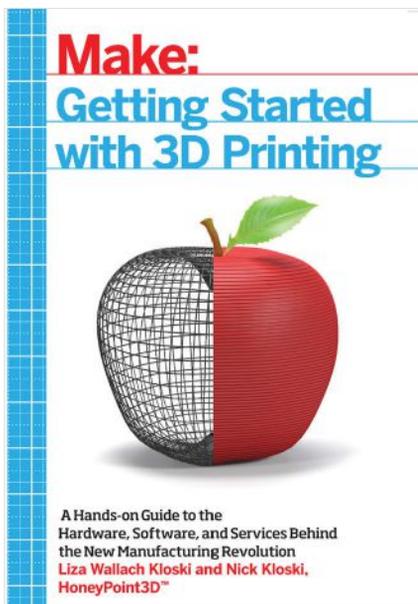#### ENCYCLOPEDIA OF ELECTRONIC COMPONENTS VOLUME 3
Loaded with key information on electronic sensors for your projects.

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Make: Getting Started with 3D Printing

A Hands-on Guide to the Hardware, Software, and Services Behind the New Manufacturing Revolution
Liza Wallach Kloski and Nick Kloski, HoneyPoint3D™

GETTING STARTED WITH 3D PRINTING

A practical, informative, and inspiring book that guides readers through the concepts of digital fabrication and empowers them to give their imagination a physical form.
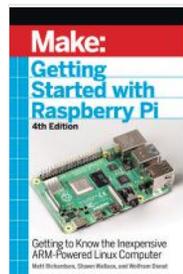
GETTING STARTED WITH RASPBERRY PI 4TH EDITION
An introduction to the inexpensive, ARM-powered Linux computer.

GETTING STARTED WITH MICRO:BIT
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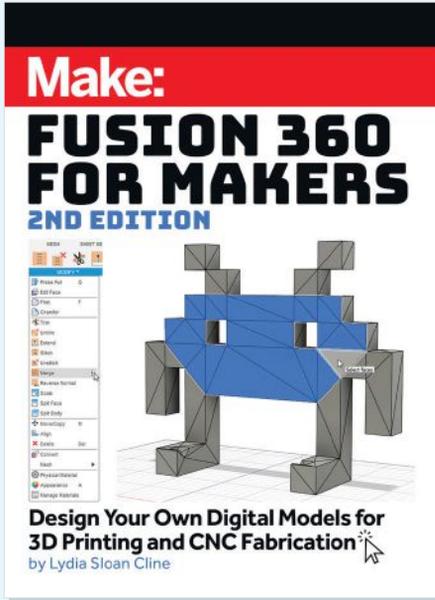
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quickly with the goal of creating models for 3D printing
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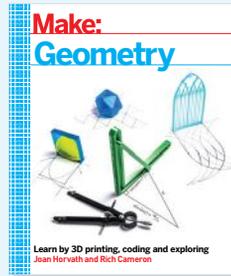
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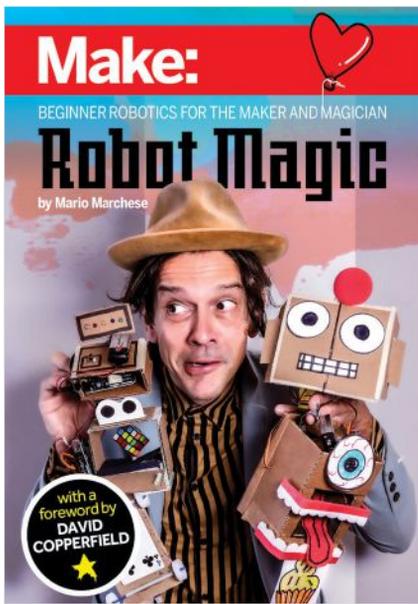
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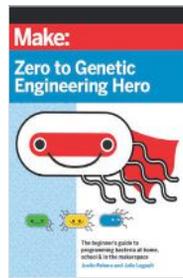
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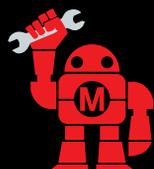
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Make: Community

Support for the publication of *Make:* magazine is made possible in part by the members of Make: Community. Join us at make.co.

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What's the best repair you've made?

Kyle Wiens
San Luis Obispo, CA (Inside iFixit)
I fixed an iPhone by replacing a surface mount 0Ω resistor half the size of a grain of rice with a piece of wire. Fired right up!

Téa Forest
Toronto, Ontario, Canada (DIY Fume Hood)
Hand sewing a piece of my cosplay costume back on that had fallen off, while still inside the convention.

Lee Wilkins
Canada, Earth (Wearable What's What)
If you need your CO2 laser repaired, call me any time!

Right Back 'Atcha

My wife has two chameleons, which need some amount of UVB to remain healthy. She found a UVI /UVB measurement device for $185... I told her I could make one much cheaper and just as good using Forrest Mims article, "DIY Sunburn Sensors" in *Make:* Vol. 65. I assembled the meter on Saturday and we tested it this evening and it worked great. Thanks again for allowing Mr. Mims to share his ideas in your publication.
–*Andy Lingenfelter, via email*

I was one of the earliest subscribers of *Make:*, for my son, Brad. I believe that he still gets it. I know for sure that it had a significant part to play in his growing up to be a very capable guy who believes that he can find a way to make just about anything ... and I believe that he is right! His son, Lucas, is featured in an early video of learning how to solder at age 6. We love *Make:*!
–*Pamela Olson, via email*

I really like your magazines and the random cool things that happen in them. Your magazines help keep me entertained and away from my phone. They also help me problem solve my own projects. Thank you for making the *Make:* magazine.
–*Landen Hoefs, via email*

Make: Amends

Benjamin Cabé

• In "Second Sense" (*Make:* Vol. 77, page 32), the input and output terminals shown on the wiring diagram on page 34 are backwards. We've included a corrected version below and online at makezine.com/projects/second-sense-build-an-ai-smart-nose. Thanks to readers Alan Pope and Paul Cryan for pointing out the mistake.
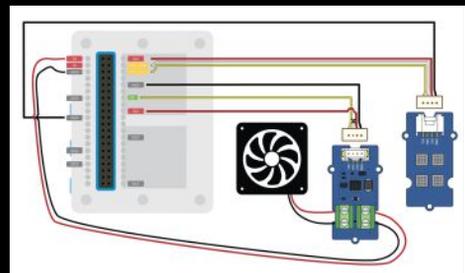
• In "A Chip is Born" (*Make: Guide to Boards*, Vol. 79), we meant to credit the RP2040 Stamp to Solder Party (solder.party). Our apologies!

Repair It Yourself

by Dale Dougherty, President of Make: Community

People have always repaired things. What's new is that there is such an abundance of information and expertise available online to help anyone do repair. The bulk of it is "unofficial," which is to say that people are sharing their repair stories with others, and that sharing is global.

Wayne Seltzer of U-Fix-It Clinic in Boulder, Colorado, describes a scenario from a recent virtual repair event: "A woman from Jakarta was helping a Belgian man fix his waffle iron, which was causing a short circuit when he operated it." The Belgian didn't think Americans making jokes about Belgian waffles were funny, however. The woman identified that the problem was a "ground fault." The waffle iron's heating element was tripping a ground fault interrupt and "the woman in Jakarta had experienced that problem before," says Seltzer.

What's remarkable is that people are taking the extra step to document how-to instructions for repair that someone else can use. One of those people is James Durand, who writes up repair endeavors on his website ashermade.com, including fixing an ice cream machine, a coffee grinder, and a particularly challenging controller on a broken mini lathe. He writes: "This repair tested the limits of my board troubleshooting and repair abilities. It was frustrating at times to find and fix issues only to reveal more issues, but I am glad I stuck with it as I now have a fully functional lathe."

Sites like iFixit.com also offer a library of useful repair how-to's, written by volunteer contributors. This is good news if you want to repair something yourself. The resources of this global community are a boon to anyone wanting help fixing something.

Trouble is, despite these resources, most people today don't bother to do repairs or even seek out people to do the repair for them. For many, the default is to throw things away and then buy a replacement. Lamps, appliances, vacuum cleaners, phones, and computers — all these find their way to the dump where they are crushed, shredded, and pulverized. The environmental impacts are obvious and unsustainable.

Manufacturers have also been making it harder for consumers to repair devices or find replacement parts. Nathan Proctor, director of U.S. PIRG's Campaign for the Right to Repair, says that many corporations seek "to monopolize repair and take control of it or they are ambivalent about repair by designing devices that cannot be repaired." Lobbyists for the consumer electronics industry have fought hard against right-to-repair legislation, often using a smokescreen of fear, claiming that they are protecting consumers by locking them out. There's a lot more manufacturers could do if they wanted to make a product last longer but first they need to accept that responsibility. They could be a lot more open about what's inside a device, how to replace parts that go bad and how to fix things that go wrong. Until they do, this global repair community will struggle to find workarounds.

At *Make:*, one of our earliest T-shirts had the slogan, in the words of Mr. Jalopy, "If you can't open it, you don't own it." We stand for a vision of an open and collaborative world in which people are empowered to modify, fix, and improve the things they use. Makers are not like every other consumer. We find real satisfaction in learning how to fix things and restore their value. Most importantly, we can show others that they can do this themselves, with the generous help of a global community. 🖉
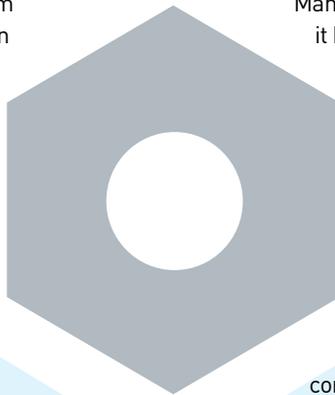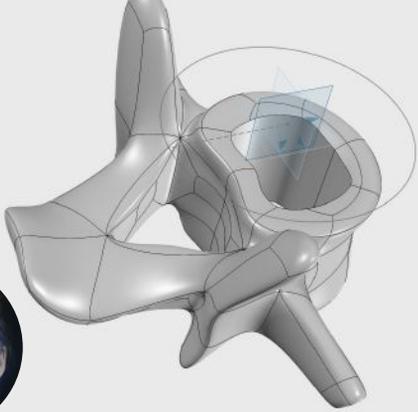
HIGH-TECH, NATURALLY

SolidWorks for Makers lets Kate Reed's biomimetic designs come to life

Kate Reed (biomimetic.io) is somewhat of a sorceress, weaving technology and nature together into stunning apparel-based creations. From wearable vertebrae to fungus-infused fanciness, she even works some modern computing into her spells.

Reed's pieces are outstanding displays both in the final result, and in their creation. "Once I understand the logic of how things grow in the natural world, I can translate that to computational space through CAD design tools like SOLIDWORKS, xShape, and xDesign."

Reed says that the inspiration for her work comes from the biological and technological world around us. Her vertebrae project, currently underway, exemplifies that: "Each vertebrae has a different electronic component — be it a heart rate sensor, or a speaker, or a gyroscope, and throughout the day the wearer can switch out vertebrae modules to make a hyper-customized wearable."

Anyone that's ever tried creating organic or biomimetic shapes by hand likely has a good idea of how quickly the task can become overwhelming. Reed has found the solution for her needs in her software. "As an artist, my dreams outgrew the physical capabilities of my body very quickly, so I turned to technology to help close the gap," she says. "I started working with CAD tools and my mindset shifted from designing products to designing processes, which completely changed my perspective."

"I found a balance in my practice between craft and computation that allows me to create out-of-this-world designs, which is all happening on the **3D**EXPERIENCEplatform."

3DEXPERIENCE SOLIDWORKS for Makers is now available for anyone doing personal, non-commercial projects. For just US $99/year or US $9.99/month you'll get the same intuitive cloud-connected CAD modeling tools that the professionals use, along with:

- Fully online design solutions you can access from any web browser — no download required

- An online community that lets you connect with worldwide makers from fab labs, makerspaces, and influencers, all ready to share their designs, ideas, and expertise

- Access to an expanded professional ecosystem to rapid prototype your parts, or receive engineering services via the **3D**EXPERIENCE Marketplace

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TREE TOPPERS

Ognyan Stefanov has been obsessed with airplanes and aviation since his childhood; his early dreams of becoming a pilot were shot down by a height limit, but he soon discovered a passion for photography and began pursuing a career as an aviation photographer in 2006. In time, he became a photographer for the Bulgarian Air Force, and later for the President of Bulgaria, but he continued his passion for airplanes through the hobby of scale modeling.

It was through this hobby that *Skyville* was born. At first, Stefanov began the display as a challenge, drawing on model train dioramas and his daughter's fairy tales in an effort to one-up his colleagues and to prove that traditional scale modeling wasn't *that* hard. However, he soon realized that he enjoyed working with wood and decided to expand his burgeoning fantasy world. Stefanov's model was constructed with a kind of freedom that really reflects the free-floating nature of *Skyville*. "I didn't make any drawings and everything came from my fantasy during the work on it," he says. "I had no limits and frames to follow. So, all the progress was a freedom of dreaming."

In an effort to make as much of the model as he could, Stefanov bought as few pre-made items as possible; only the greenery, mini-people, and tiny household items were prefabricated. Due to the time-consuming nature of his government job, however, he was only able to work on *Skyville* at night, oftentimes staying up until 3am after a busy day of work. As a result, it took him nearly two and a half years to finish the model, but the results more than speak for themselves.

When asked if he had any advice for those inspired by his creation or his other photographs, Stefanov replied, "Be different! Use your fantasy! Take the risk!" You can see examples of his aviation photographs at airphoto.bg and find more pictures of *Skyville* on at makezine.com/go/skyville.

—*Marshall Piros*

Ognyan Stefanov

KUMIKO-CASTER
MAKEWITHMILES.COM

Kumiko is an ancient Japanese technique of cutting strips of wood to puzzle together into patterns. Often these are held together using only friction or glue. The geometric patterns make sense for traditional aesthetic applications, but Portland, Oregon-based maker **Miles**, aka Make With Miles (youtube.com/makewithmiles), took things a bit further with his rendition. Melding the old technique with modern technology, Miles has created this beautiful Kumiko-infused guitar and amp combo.

Miles built the amplifier first, and then, inspired to compete in a woodworking contest, devised an instrument that would utilize the Kumiko style while retaining the rigidity and sound you'd expect from an electric guitar in 2021. Miles started by building a wooden guitar body from scratch, then hollowed out its front and painstakingly laid in Kumiko patterns with hand-cut wood pieces. Then, to bring it all together, he poured tinted epoxy into the gaps making the guitar solid again, and able to withstand a little on-stage abuse.

The final result is a real eye catcher. The guts are those of your basic Strat, but the visuals couldn't be more unique. You can watch the entire process (and learn some handy woodworking tips) at youtube.com/watch?v=U5r_PE2OznM.
                                                                    —Caleb Kraft

Make With Miles

TROPHY CHAMBER

For Christmas, **Mitch Couch** wanted to do something special for his friend Dustin, a doctor and youth-inspiring tinkerer who also happens to be a hardcore *Star Wars* enthusiast. Couch realized, what better way to commemorate his pal than to freeze him in Carbonite?

In order to keep the gift a secret, Couch casually asked to make a mold of Dustin's face during a small gathering a few months ahead of time. Dustin agreed, unknowingly providing the key piece to make a custom Carbonite replica. Couch, a central-California building inspector, then drew on his 16+ years of carpentry and contracting experience to assemble an MDF Carbonite-enclosure frame, based on accurate dimensions sourced from the internet. He next built control panel mockups, created molds, and cast resin pieces to use on the sides of the frame. Various hardware elements and embedded LEDs contribute an authentic look.

Finally, Couch mounted the plaster face and hands, and crafted the body out of expanding foam sculpted to appear to protrude slightly from the enclosure. A resin-soaked lab coat, glasses, and a stethoscope gave the finishing touches.

When delivered, Dustin, as may be expected, was in awe — you can see the build and reveal at youtu.be/d826PH-YB6A.

"My biggest surprise was how long it took to get it all put together," Couch says, in regards to the two-and-a-half-month-long timeframe. "So much sanding and detail, especially in making the control panels. Towards the end, I could see it coming together and it was encouraging."

Price-wise, the final tally came in around "just $650." "Most of the cost was in the resin, it took a lot to make."

"I only make or do projects for others, like friends or family, never for myself," Couch says. "I love giving out my projects as gifts. If I ever find a true diehard *Star Wars* fan out there I might surprise them with a project like this."

We think a lot of fellow enthusiasts may raise their hands for that. —*Mike Senese*

Mitch and Janessa Couch

Your World.
Their Experience.
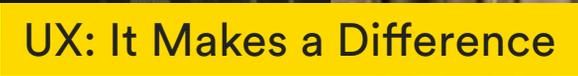
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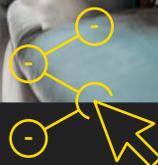
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FIGHTING BACK TO
MAINTAIN CONTROL
OF OUR TECHNOLOGY.

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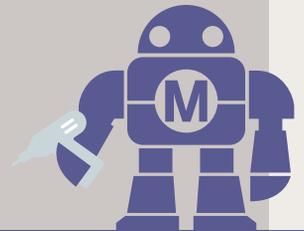
REPAIR WARS

CORY DOCTOROW (craphound.com) is a science fiction author, activist, and journalist.

THEY'VE STACKED THE DECKS AGAINST SERVICING YOUR OWN PURCHASES; THE COMMUNITY IS NOW RESISTING — AND WINNING **Written by Cory Doctorow**

In January 2019, Apple CEO Tim Cook published his annual shareholder letter, and with it, a dire warning to Apple investors: The iPhone market was cooling off, because Apple customers were hanging onto their phones for longer, getting off the annual upgrade treadmill and instead fixing their busted screens rather than using a dropped phone as an excuse for an upgrade.

This is what is meant by "saying the quiet part out loud." Cook's letter was the capstone on 2018, a year in which the company had defeated 20 state-level "right to repair" bills — bills that would have forced Apple and other companies, from John Deere to Wahl (of shaver fame) to facilitate repairs by independent service centers. These were bitter fights, in which repair activists — environmentalists, makers, digital rights advocates, and reps from fix-it shops — pleaded with lawmakers to do the right thing, while their corporate adversaries warned that independent repair would usher in an era of devices that leaked your data or even exploded in your face.

This anti-repair parade of horribles was short on evidence, but lawmakers bought it. That was good news for Apple and any other company that wanted to juice its profits. Attacking independent repair let manufacturers reap huge profits from repair jobs, freeze out rivals who made replacement parts, and, best of all, decide when a device was "beyond repair," so that customers would be forced to "upgrade" to a new one.

Why do we need right to repair laws in the first place? Why couldn't fix-it shops and third-party parts makers collaborate to fix our phones, laptops, shavers, Xboxes, cars, and tractors, with or without the help of the original manufacturers?

Well, they can ... sorta. For years, iFixit — the great heroes of the repair revolution — have produced independent, unofficial, unauthorized, free, open access repair manuals for all kinds of devices. They make these manuals without help from the manufacturers, by tearing down gadgets and figuring out from first principles how to fix

them. (See "Inside iFixit" on page 20.)

Likewise, there's a longstanding process of producing third-party parts for the stuff we use. Sometimes, these are standard parts that anyone can manufacture by reading the specifications, and other times they too are part of the guerrilla warfare between manufacturers and repairers, created through canny reverse-engineering.

MAKING REPAIR HARD

With independent repair guides and third-party manuals, the independent repair sector should have everything it needs to fix your stuff, or show you how to fix it for yourself. Manufacturers have gone to great technical lengths to prevent this — obfuscating the workings of their products, say, or designing them to require special tools just to open them — but in this battlefield, the challengers always have an advantage over defenders. A company that makes its devices completely unrepairable by third parties will almost certainly render those devices impossible for their own repair technicians to fix (and likely impossible for their own customers to use).

IN THIS BATTLEFIELD, THE CHALLENGERS ALWAYS HAVE AN ADVANTAGE OVER DEFENDERS.

So the war on repair has largely moved from the technical front to the legal front. Manufacturers use a suite of legal theories — often distorted beyond recognition or sense — to maintain their monopoly over repair. Take copyright law. In 1998, Bill Clinton signed the Digital Millennium Copyright Act (DMCA), and Section 1201 of the DMCA makes it a felony to provide tools or information that aid in bypassing an "access control" for a copyrighted work.

Originally, this was used to make it a crime

Dale Dougherty @dalepd · Nov 18, 2021
Do you have a good repair story to share? Have you brought a household device back to life by figuring out why it broke and fixing it? Did you track down a replacement part or make one on your own? I'm looking for fixit stories for the next issue of Make on #repair @make

💬 44   ⟲ 23   ♡ 66   ↑

Mike Carroll
@ScrappyMaker

Replying to @dalepd and @make

Mine is simple. As a kid our vacuum broke. My mom placed it next to the trash can outside. Curious and bored, I grabbed a screwdriver to take it apart. Once opened, I saw a belt slipped. When I showed my mom that I fixed the vacuum she stared in disbelief like I had a superpower.

to tell someone how to deregionalize their DVD player (so it could play discs from overseas) or jailbreak their Sega Dreamcast (so it could run homebrew games). Game console and DVD manufacturers argued that the embedded operating systems that enforced these restrictions were the "copyrighted works" mentioned in the DMCA, and that the digital locks that stopped you from altering these OSes were "access controls." Since altering the OS involved bypassing an access control, anything you did to the OS without the manufacturer's blessing violated DMCA 1201, and providing someone with tools or instructions to do so is a felony punishable by a 5-year prison sentence and a $500,000 fine for a first offense.

Today, this relic of the last century is the go-to tactic for blocking repair. John Deere are true pioneers here: They embed cheap microchips in their replacement parts. After the part is installed, it has to be "initialized" with an unlock code before the rest of the engine will accept it. This allows the company to insist that farmers who fix their own tractors pay a technician to come out and solemnize their repair by typing a password into their tractor's console, charging up to $200 for a useless "service call" — and as a side bonus, this cryptographic handshaking allows Deere tractors to detect and refuse third-party or refurbished parts, like an inkjet printer balking at printing with refilled ink cartridges.

This process is even more closely associated

with the automotive industry, where it's called "VIN-locking" — that is, locking parts to the engine's indelible Vehicle Identification Number. But while VIN-locking may have started in cars and tractors, it's spread into every gadget with a microchip, which is to say, every gadget.

This came to a head during the pandemic, thanks to Medtronic's use of VIN-locking to prevent repairs of its workhorse PB840 ventilator. Medtronic is the world's largest med-tech company, thanks to an unchecked program of buying and killing off competitors, something it is able to do thanks to the savings it realized by selling itself to an Irish company in history's largest-ever "reverse-merger." Flying an Irish flag of convenience virtually wipes out Medtronic's tax bill, leaving it with more cash to neutralize competitors.

Medical technicians working in hospitals have long been accustomed to doing their own repairs. When you've got a patient in the ER, you can't wait three days for a manufacturer's repair-tech to come out and swap out a part or fix a bad solder joint. Medtronic dressed up its VIN-locking tactics as a concern for patient safety, but really it was about extracting revenues from hospitals. If Medtronic really cared about patient safety, they'd prioritize technical support for on-site med-technicians, rather than creating a world full of busted ventilators in dusty closets, awaiting a visit from the official Medtronic technician.

COVERT RESPONSE

All this got a lot worse during the pandemic, of course. Overnight, the need for ventilators shot through the roof — just as lockdown meant that Medtronic technicians couldn't just hop on a plane and come to hospitals where the ventilators were breaking down.

Lucky for the world's sick and dying, a Polish technician went rogue. This anonymous tech was an ex-Medtronic repair guy, and he had held onto the software used to initialize VIN locks after new repairs. He reverse-engineered its cryptographic

signing routine and invented a microcontroller-based gadget that could initialize a field repair. He improvised housings for this out of small electronic devices, like alarm clocks and guitar pedals, and mailed them to hospitals all over the world. The technicians at these hospitals were able to cannibalize parts from multiple busted ventilators to make working ones.

LUCKY FOR THE WORLD'S SICK AND DYING, A POLISH TECHNICIAN WENT ROGUE.

VIN-locking is a globally attractive nuisance. The rogue Polish Medtronic tech has stayed anonymous because Poland is part of the EU, and the EU unwisely allowed the U.S. Trade Rep to pressure it into adopting its own version of DMCA 1201 in Article 6 of the 2001 EU Copyright Directive. Canada got its version in 2012, Mexico got one in 2020, and the rest of the world — Australia, Russia, Central America, the Andean nations — got their own somewhere in between.

The existence of a global mesh of laws that say that owners of devices can't alter or repair them without the manufacturer's okay is a powerful incentive to mischief, tending to a universal inkjet-printerization of everything. Apple has repeatedly announced new iPhones that use VIN-locking to prevent independent screen replacements, only to back down after public outcry. The most recent attempt was in November 2021.

SUPPLY-CHAIN STOPPAGES

DMCA 1201 isn't the only legal barrier to repair. Manufacturers use bogus patent claims to stop imports of third-party spare parts at the border, and they use trademark claims to stop refurbished parts from entering the country, saying that their own products become "counterfeits" the minute they're resold as a used

good. On top of that, manufacturers use terms-of-service and end-user license agreements to intimidate, bully and block independent repair, claiming that cybersecurity laws (like 1986's Computer Fraud and Abuse Act, which the Supreme Court finally narrowed in the summer of 2020 in its ruling on *Van Buren v. United States*) and weird contract-law theories about "tortious interference" make independent repair into a civil and/or criminal matter.

This is grossly unfair, of course, a recipe for a world drowning in e-waste as devices are scrapped rather than being repaired. But it's also economically catastrophic, because the independent repair sector is an engine of economic growth: According to the Repair Coalition, recycling a ton of e-waste creates 15 jobs, while repairing that same mountain of busted stuff creates 150 jobs — good, middle-class, local, small-business jobs that serve their communities (overall, independent repair accounts for a whopping 4% of U.S. GDP).

The war on repair is aimed squarely at killing off these jobs. When an industry manages to make independent repair difficult or impossible for five or 10 years, it guarantees that these small businesses will shut down. What local phone-repair place could survive for half a decade without being able to fix iPhones? Even if the independent repair sector — and the maker community — manage to find a way around the impediments thrown up by Big Tech monopolists, each anti-repair gambit reduces the pool of technicians who are able to set up shop.

Let's not lose sight of the stakes here: Independent repair is a proxy for the right to decide how your stuff serves you, and when it's time to retire it and move on to a new gadget. This is the right to technological self-determination — the right to decide not just what your stuff does, but who it does it *for* and who it does it *to*.

A SMALL VICTORY

As I write these words, Apple has just sued for peace in the war on repair. In November of 2021,

Charles Mire
@charlesmire

Did my first utility 3D print tonight. My kids broke the part that holds the wand on one of our vertical blinds. Found this STL, and 20 minutes later it's all fixed!
thingiverse.com/thing:2485265
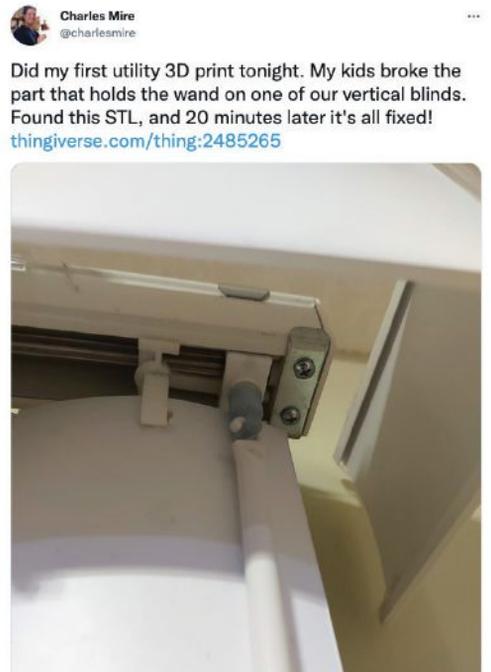
the company announced that it would start selling tools and parts to its customers so they could do their own repairs. The announcement is both seismic and worryingly vague: Apple is the vanguard of the war on repair, and there are plenty of ways it could implement its owner-repair program that would be effectively useless (say, by insisting that home repairs require swapping out whole assemblies rather than individual components, which could make replacing a screen nearly as expensive as buying a new phone). What's more, the mere existence of an owner-repair program could be mobilized as a pretext to kill future right-to-repair bills that safeguard independent repair by requiring that manufacturers make parts, manuals, and diagnostics available to competitors.

It's great that Apple has decided to permit its customers to fix their stuff, but ultimately, this shouldn't be Apple's call. You bought your iPhone, you own it. Who fixes it is your decision alone — and the same goes for tractors, ventilators, shavers, and every other gadget besides. ◉

INSIDE
IFIXIT

Written by Kyle Wiens

BUILDING A PATH TOWARD A REPAIRABLE WORLD, ONE TEARDOWN AT A TIME
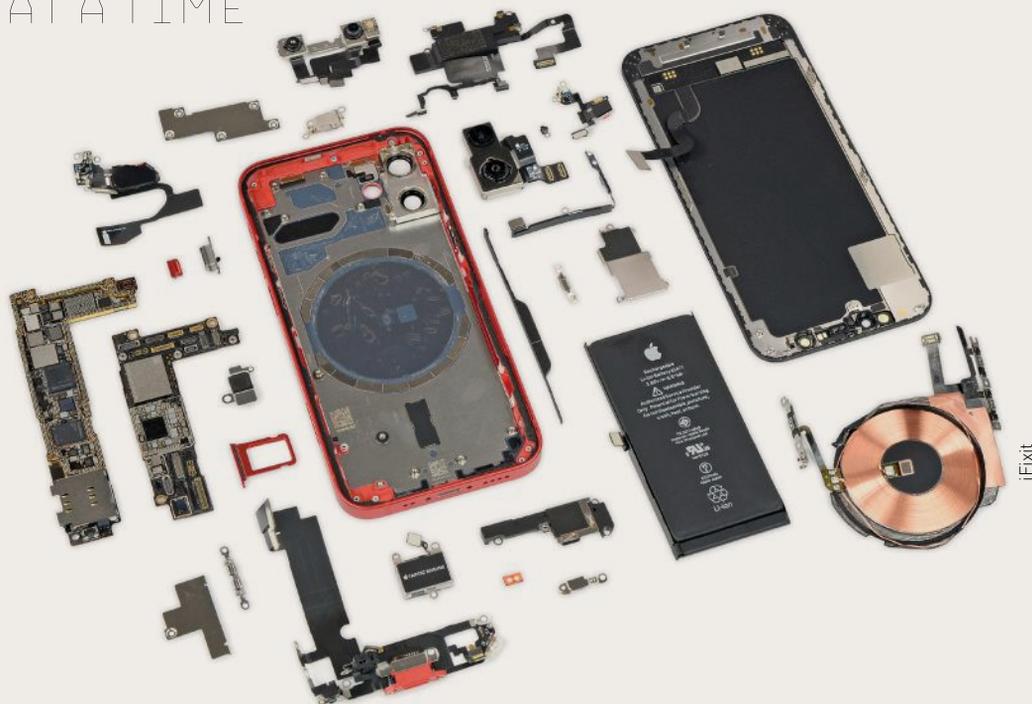
iFixit

I run iFixit, an online repair community dedicated to helping people fix their things. As manufacturers have rolled out mechanisms to artificially force people to replace their products more often, we've been fighting back. Through a conjunction of open source activism and political pressure, we're beginning to reset the damage done over the last few decades to consumer expectations and manufacturer behavior.

More and more policymakers are hearing the call to protect repair. Legislators in 27 U.S.

states introduced right-to-repair legislation last year. The bills passed the Senate in New York and Arkansas but did not make it over the finish line, setting the stage for a lively fight across the nation this year. The U.S. Federal Trade Commission performed the landmark investigation, "Nixing the Fix," detailing the problem and coming to the conclusion that "there is scant evidence to support manufacturers' justifications for repair restrictions." President Biden followed up with an executive order aiming to "make it easier and cheaper to repair items you own by limiting manufacturers from barring self- or third-party repairs of their products."

The fight has gone international. France has rolled out a repairability rating system, scoring products based on availability of spare parts and access to information. In Australia, car manufacturers must make parts, tools, and information available to independent repair shops. The Australian government is reviewing a report on electronics repair restrictions, with some legislation likely to follow. And a Canadian right-to-repair bill passed one chamber of their legislature unanimously in 2021. 2022 should be a banner year for right to repair legislation.

CHALLENGE ONE: PARTS

One of the biggest hurdles in securing our right to repair is making sure that spare parts are available for independent repair shops and DIY fixers. In 2012, Nikon cut off the parts supply to their retailers. Canon has taken similar measures, effectively ending local camera repair in the United States. Where once you could order parts directly from manufacturers, now we rely on a network of online retailers and eBay sellers often importing parts directly from Shenzhen.

It's not all doom and gloom, though: Motorola has started selling parts directly to consumers (disclosure: via iFixit), and startups Fairphone and Framework have built their business models partially on selling parts (see "Mod Squad," page 38). Most notably, Apple announced in November that they would start selling parts directly to customers, as well as making the software available to pair serialized parts to the device. After two decades of fighting repairers at every turn, it's hard to trust Apple, so we will be watching closely.

CHALLENGE TWO: EXCLUSIVITY

Many parts shouldn't have to come directly from the OEM — they're not actually making the components anyway. Modern manufacturing is more like integrating, where "manufacturers" buy parts from a variety of suppliers.

But there we run into another trap laid by manufacturer legal teams: exclusive contracts. The legal term for this is *exclusive dealing*: In exchange for a commitment to buy a large number of parts, suppliers give up their autonomy and agree not to sell to anyone else. Frequently, my parts purchasing team is told that they cannot buy parts without permission from the manufacturer. Another tactic that Apple is notorious for is asking manufacturers to make a slight change to a retail version of their product and then restricting it from sale. This has been a major thorn in the side of circuit board–level repairers like Louis Rossmann (youtube.com/rossmanngroup), who are forced to turn to donor boards rather than new parts supply chains.

CHALLENGE THREE: KNOW-HOW

I started iFixit because the service manual that I needed to fix my iBook had been removed from the internet by Apple's crack intellectual property legal team. They scour the web for unauthorized copies of this must-have repair documentation and threaten legal action of $150,000 per infringement and up to 3 years in prison if you don't censor the information. Apple's not alone. Toshiba's legal team went after Tim Hicks, a young Australian who hosts a tremendously useful website, Future Proof, that hosts hundreds of laptop service manuals. Without the resources to defend himself, Hicks removed the manuals. (iFixit has since crowdsourced open source manuals to replace them.)

Schematics, critical for board–level repairs, used to be available for everything from TVs to the Apple II. No longer. Nowadays, professional fixers rely on OpenBoardView (openboardview.org) and Chinese tools like ZXW (zxwtools.com/en), a $79 software tool that includes reverse-engineered schematics for hundreds of smartphones. But the market is limited to devices where the schematic has been fully decoded and published.

iFixit is well on our way to creating a free repair manual for everything, with over 75,000 how-to guides online and more being added all the time. And we may have help from the manufacturers to get this done. Apple announced that they will be publicly releasing the iPhone's service manual for the first time, and Framework is sharing schematics directly with repair shops.

Voluntary measures only go so far, however. Once right-to-repair laws pass, you should expect a baseline of public service information available for every electronic device.

CHALLENGE FOUR: TOOLS

I make a living selling specialized screwdrivers like Nintendo's GameBit and Apple's Pentalobe. There's even an oval screw used in high-end coffee machines. Violating my best interest, I'll say it: Knock it off, product designers. We have enough fasteners in the world already.

Look at manufacturer service manuals (and the tools hinted at in Apple's recent announcement) and you'll find a surfeit of specialty repair fixtures. These tools are more akin to the jigs used in manufacturing than the kind of tools you'd want in your toolbox. Heavy, bulky, and often designed for a single device's form factor, these specialized tools are expensive and wasteful. They're the result of a combination of fine tolerances and a desire for reproducible perfection, but they leave repairs out of the realm of the typical maker.

What we need instead are general-purpose tools that address a wide range of product designs. Repairs do not need to achieve the same tolerances as factory manufacturing.

REPAIR TWEETS:

> **Jackie Tan**
> @stmsmakerlab
>
> Replying to @dalepd @dorifriedman and @make
>
> My father in law's dishwasher stopped working. My husband researched and suspected a loose solder joint. Yup, fixed it. For many, it would have been a new dishwasher.

CHALLENGE FIVE: DESIGN

The iPod pioneered a design trend that we've seen spread, first to other media players, then to the iPhone, then to every single other phone in the world. The Maker's Bill of Rights (opposite page) reads like a point-by-point counter to the iPod. "Cases shall be easy to open" — the iPod's case snaps together, and opening it is rather akin to shucking an oyster. "Screws better than glues" — we've had to engineer a whole suite of specialty tools to remove adhesive, from suction cups to heat application tools.

What was rare is now the norm. When it debuted, we gave Microsoft's Surface Laptop our first ever zero out of 10 repair score. The battery was welded inside the case, and replacing it was not possible without destroying the laptop. Fortunately, Microsoft has seen the error of their ways. They redesigned the Surface Laptop (it now earns a five!) without compromising their industrial design, and agreed to a shareholder proposal to "Expand the availability of certain parts and repair documentation beyond Microsoft's Authorized Service Provider network."

Ever since the iPod, we've been operating without a baseline of support from product manufacturers. No parts, no information, and tinkerer-hostile designs. That is starting to change. As companies grudgingly start sharing and participating in the repair economy, it's going to be up to all of us to guide them. ◈

KYLE WIENS is the CEO of iFixit, the popular online repair community. He has dedicated his life to defeating the second law of thermodynamics, a battle fought in the courtroom as often as in the workshop.

THE MAKER'S BILL OF RIGHTS

- Meaningful and specific parts lists shall be included.
- Cases shall be easy to open. ■ Batteries shall be replaceable. ■ Special tools are allowed only for darn good reasons. ■ Profiting by selling expensive special tools is wrong, and not making special tools available is even worse. ■ Torx is OK; tamperproof is rarely OK.
- Components, not entire subassemblies, shall be replaceable. ■ Consumables, like fuses and filters, shall be easy to access. ■ Circuit boards shall be commented.
- Power from USB is good; power from proprietary power adapters is bad. ■ Standard connectors shall have pinouts defined. ■ If it snaps shut, it shall snap open. ■ Screws better than glues. ■ Docs and drivers shall have permalinks and shall reside for all perpetuity at archive.org. ■ Ease of repair shall be a design ideal, not an afterthought. ■ Metric or standard, not both.
- Schematics shall be included.

Make:

Drafted by Mister Jalopy, with assistance from Phillip Torrone and Simon Hill.

Written by Nathan Proctor

THE PROFESSIONAL REPAIRER TRAP

WE ARE ALL GENIUSES, DON'T LET THE CORPORATIONS TELL YOU OTHERWISE.

For years, my organization, U.S. PIRG (Public Interest Research Group), has been campaigning with iFixit, Repair.org, and a plucky team of repair shops, makers, and hackers to pass laws that guarantee access to what people need to fix modern gizmos, specifically the parts, tools, and service information. We've had "right to repair" bills in 40 of 50 states over the last 6 years, and put considerable pressure on manufacturers to stop blocking access to repair.

As they've ceded more and more ground to the marching right-to-repair campaigns, manufacturers have attempted to create a new fallback position. Instead of letting just anyone fix products, manufacturers would set some kind of standard for who gets to read the manual, or have access to spare parts or special tools. This was a concession the European Union put in place for appliance repair rules which have been rolling out across the continent after passing through the EU Parliament. Only "professional repairers" can access necessary parts and service information.

The idea that I would need some kind of business license to fix a door gasket on a washing machine, or replace the control board on a dishwasher, is bizarre. But industry rigorously pushed to restrict access to only an undefined class of "professionals," and is trying to make a similar push around rules here in the United States. Take Microsoft for example: When debuting a new, more repairable Surface laptop in 2019, Microsoft Chief Product Officer Panos Panay showed the ease of removing the keyboard on stage, by simply snapping it open — a huge design improvement over an earlier model. But Panay then declared that repair is intended for "commercial customers." "I have a disclaimer: Don't try that," Panay said during the demonstration. Reporters later confirmed that the tools needed would be restricted to "authorized repair technicians."

Not only does such a limitation give manufacturers an opportunity to maintain control over repair access (which allows the same monopolistic restrictions to continue in a new form), it also concedes to a worldview which I intend to undermine if not destroy. To me, it's the essential idea behind why we become makers.

WE ARE ALL GENIUSES

After I posted the news about Apple's repair-friendly Self Service Program, one Twitter user responded: *#Righttorepair is certainly a good idea, but a manual, online video or some tools don't qualify someone to fix an iPhone or even a toaster. There is a reason people get trained. Once the first person attempts to repair a device and gets a* [sic] *electrical shock this will be over.*

U.S. PIRG is a collection of state-based

advocacy groups, and as such, I've been working to pass right to repair in dozens of states. I hear arguments like the above all the time, mostly from opposition lobbyists or the lawmakers who've been influenced by those lobbyists. The core of the argument is that people can't be trusted to make their own decisions. We need a special class of people — the "Geniuses," as Apple calls their sales representatives — to make choices for us, otherwise we will just ruin everything. To me, this is not only false, but violates the core premise of democracy. People are resourceful. They aren't reckless and stupid. They can make their own decisions. They manage all manner of risk in their lives without disaster. There is no reason to believe we can't figure out when to fix something or when to hire someone else. We fix cars after all!

Not only are we capable, but society benefits when more people are adding their creativity to the mix. We fix problems that manufacturers neglect because they have different incentives. They aim to maximize value to shareholders, and don't prioritize the kind of innovations that make

THERE IS NO REASON TO BELIEVE WE CAN'T FIGURE OUT WHEN TO FIX SOMETHING OR WHEN TO HIRE SOMEONE ELSE.

life better for people. To me, this is why the right to repair is so important. It's not just a rebellion against planned obsolescence, but it's a rebuttal against the worldview that sets us up as passive consumers, consumers who aren't smart or capable enough to contribute.

Two years ago, Apple made the smallest opening in their repair model to include additional repair shops as "certified," undoubtedly with the hope that this might satisfy right-to-repair advocates. It did not. Now, while other manufacturers are still trying to convince us

Lori Kothe
@Kocreate

Replying to @dalepd and @make

My 14-year-old son and I fixed our old Bosch dryer when it died. Still can't believe we ordered the correct replacement part online (before we knew what was wrong), took it apart, replaced the belt, put it back together, and it worked! YouTube videos saved us.

NATHAN PROCTOR is the Senior Director of Right to Repair campaigns with U.S. Public Interest Research Group (PIRG), a consumer and public health advocacy group. He is a 16-year veteran of advocacy campaigns, and lives in Arlington, Massachusetts.

to limit reforms to "professionals," Apple has included DIY repairs. It's a huge milestone.

As more and more manufacturers show that repair access is reasonable and doable, it should become clear to lawmakers that there are no more excuses. We'll continue our work in Congress and state legislatures across the country to convince decision-makers: It's time to give every American the right to repair, so everyone can fix all their products or take them to the repair shop of their choice. That's the way it should be. ✪

THE FIX IS IN

NEED A REPAIR? THE FIXIT CLINIC WILL GUIDE YOU TO GET THINGS WORKING AGAIN.

Written by Peter Mui

PETER MUI is the founder of Fixit Clinic (fixitclinic.org), which conveys critical thinking and troubleshooting skills through both in-person community repair events around the U.S. and globally online. Over 600 Fixit Clinic events have been hosted through libraries, colleges and universities, and science and research institutions. He is based in Berkeley, California.

I often describe Fixit Clinic as "a hobby that's gotten way out of control." We held the first Fixit Clinic in 2009 as a modest experiment to make basic tools and specialty tools available so attendees could disassemble, troubleshoot and — hopefully — repair common consumer items: to take apart appliances and electronics, mend fabric and textile items like clothing and luggage, fix furniture; to work on and work with any and all sorts of durable goods.

Now through our Global Fixers Server and Intergalactic Zoom Fixit Clinics, we have

expanded and transformed Fixit Clinic into a global phenomenon with participants and repairers from around the world working together to fix things. We're able to support underserved and remote areas that don't have the resources or population density to support holding local community repair events. We can also consider large things that would be too unwieldy to bring to an in-person event.

COMMON FAULTS

The Fixit Clinic has a historical repair success rate of about 70%, and that's mostly without access to repair manuals, engineering diagrams, schematics, or diagnostic tools. Based on our experience of seeing tens of thousands of items, here are some of the top issues we encounter on a regular basis:

NO POWER: The item's often not working because it's just not getting power, whether from batteries or through the power cord.

• **Battery-powered devices:** Confirm that replacement batteries are indeed good, and that the battery contacts are free of corrosion. If batteries have leaked inside the battery compartment (i.e. you see a white powder of potassium carbonate) you can usually get the device working again by cleaning out the battery compartment and using an eraser, a piece of steel wool, and/or some 91% isopropyl alcohol to make the contacts shiny again.

• **Wall-powered devices:** Appliances frequently plugged and unplugged often stop working because people tend to yank hard on their cords, stressing the point where it is molded together with the plug. Where the cord goes into the appliance is the other common stress point. Wiggling or applying pressure at those points can often confirm that's the problem. If you can get the item to work intermittently this way, simply change out the plug or whole cord.
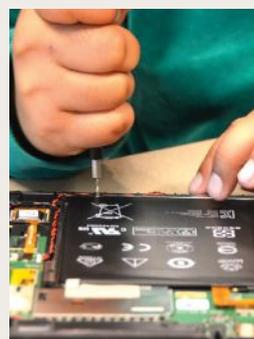
Also, before tearing a device apart, ensure your source of AC power is good and switched on, including any outlet strips used.

BAD PORTS: Power connections, USB ports, HDMI ports, etc. can collect dust, dirt, and debris that can impair their function. Careful inspection and cleaning with 91% isopropyl alcohol and an old toothbrush can often restore function. Apple's MagSafe connectors are magnetic and can attract all sorts of little pieces of metallic debris so take extra care to remove any small metal shards or flakes.

• **When cleaning doesn't work:** There's often physical damage to the port, or the port has separated from the circuit board. If you're lucky the port can be replaced or resoldered. We see many items where failure of the port could've been avoided by reinforcing the area around the port better. As a design and manufacturing rule of thumb we believe all ports — anywhere a user might connect two things together — should be heavily reinforced. Ideally, ports should also be designed to be modular so that replacement of the port alone is possible.

IF YOU SPILL LIQUID ON YOUR LAPTOP, PHONE, OR OTHER ELECTRONICS:

Immediately power it off and turn it upside down; try to get as much liquid to drain out as quickly as possible, ideally from the same direction it came in (i.e. keep the liquid from spreading). Time is of the essence here so don't dilly-dally.

Then disassemble it as much as possible/ practical to get air circulation inside, encouraging any remaining liquid to evaporate as quickly as possible. If you open it, observe where the liquid is or was, scrub those areas gently with a toothbrush and that handy 91% isopropyl alcohol. Depending on the level of liquid intrusion, leave it open for up to several days before attempting

Fixit Clinic

to power it on again. Be patient. If you've led a good clean life, your item might power on again successfully with no lingering issues.

As a general rule, liquid and electronics don't mix. Even if your device claims to be waterproof, don't tempt fate unnecessarily; keep it far away from liquid hazards. And note that the idea of putting your water-damaged item in a bag of rice has been debunked: ifixit.com/News/30047/rice-is-for-dinner-not-repair.

VACUUM CLEANERS: The root cause of weak suction in a vacuum cleaner is almost always a rigid or semi-rigid item wedged in a hose that accumulates fluff around it until it clogs the hose. Run a plumbing snake through all the hoses to find and free up the clog: you will invariably find that a foreign object like a pen, coin, cigarette lighter, or cat toy is lodged in the hose; you need to get that out too or the clog will re-occur (see fixitclinic.blogspot.com/2021/02/vacuum-clogs-carefully-check-for-root.html).

ITEMS THAT HEAT: I refer to all these items as "resistive element heating devices" because they all have an electrically resistive element inside that produces heat: electric kettles, space heaters, rice cookers, coffee makers, griddles, waffle makers, hair dryers, etc. These often stop working because their *thermal fuse* fails. It's a one-use component designed to stop electricity going to the heating elements or the whole device if a predetermined temperature is reached. Once you can locate the thermal fuse it's easy to test and replace. Our how-to: youtu.be/XE-XlDP1wHs.

Appliance motors, such as those in blenders, food processors, fans, and coffee grinders, also have lower-temperature thermal fuses designed to fail if the motor is overstressed and gets too warm. (So don't try to make nut butter with your coffee grinder.)

Fixit Clinic sees so many items with bad thermal fuses we're suspicious that the quality control in their manufacturing may just be poor. There was a well-documented capacitor plague

between 1999 and 2007 (see en.wikipedia.org/ wiki/Capacitor_plague); what if we are living through a comparable thermal fuse plague?

Another common problem with resistive element heating devices is when the activation switch won't stay down, or stays down and won't release. This often happens with hot water kettles and rice cookers. In this case there's a contact inside that is slightly misaligned and has been arcing electrically for a long time, sparking internally and creating carbon build-up on the switch. Cleaning off the carbon build-up with sandpaper or an emery board solves the problem.

INCESSANT PAPER JAMS OR MISFEEDS WITH YOUR PRINTER? There might be a small piece of torn paper wedged deep inside, or a foreign object like a paper clip or wayward staple. Vacuum the printer carefully, then clean the entire paper path and rollers with rags and cotton swabs moistened with 91% isopropyl alcohol.

SEIZED SEWING MACHINE: It's OK to use WD-40 to free up a gummed-up sewing machine but note that WD-40 is primarily a cleaner and is not the ideal long-term lubricant. Once the sewing machine is working smoothly again, lubricate immediately and frequently thereafter with sewing machine oil.

CRACKED PHONE SCREEN: Avoid getting nasty glass shards in your fingers and moisture and dirt in the cracks by applying clear packing tape over the full, broken screen.

We've found there is weak correlation between purchase price and ultimate long-term quality and durability. Don't rely too much on paying extra for what you assume is a higher-quality product because you think it comes from a "reputable" brand. Whether the blender is from a discount drug store or a high-end kitchen shop, they share many of the same failure modes and may have even been manufactured in the same factory.

Fixit Clinic

CHALLENGE: DESIGNING FOR SUSTAINABILITY

THE CHOICE IS OURS. OUR FUTURE MAY DEPEND ON IT.

Fixing is the on-ramp to making. Every maker I know started as a fixer; they were somehow dissatisfied with what was pre-existing, what was available to them to fulfill a need, and were compelled to embark on a journey to create the thing they truly wanted instead.

Repairing and maintaining our broken electronics and appliances, repairing and maintaining our furniture and fabrics, repairing and maintaining our industrial equipment and infrastructure, repairing and maintaining our built environment overall — it's all a proxy for how we are interacting with our world today and what it means to repair and maintain the planet, the precious and singular ecosystem that sustains us. In our current consumptive behavior mode we're extracting and exhausting resources to make far too many items that are of poor quality and poor utility that are not serving us as well as they might ("consumer trifles"). It bodes poorly for the future of the planet if we don't figure out how to quickly get to a sustainable, closed-loop system for our consumption.

Right now that's being framed as deprivation: that we'll get less of what we say we want and less of what we think we want, and that we'll pay more for it; that we'll have to submit to individual and shared sacrifice if we're going to get through numerous environmental and economic crises.

But what if it doesn't have to be so dire? What if there's a more positive, more hopeful alternative future? What if we've succumbed to the marketing hype and are thus distracted the true value of the items that we choose to bring into our lives, and the way they affect our quality of life? What if our future relationship with durable goods includes more digital fabrication, more on-demand manufacturing, and more local manufacturing?

What if, as an alternative to our durable goods coming to us from remote, overseas factories through a global supply chain, instead most things that we consume are designed, built, serviced, and maintained, in a local service area using locally available tools, materials, processes, and services?

Here's an example of how that might work: you order a toaster unique to your requirements; when you click "Purchase," digital files propagate to local micro-factories that manufacture constituent parts of your toaster. Those parts are assembled and delivered to you (or you assemble them yourself). If, at some point a part of the toaster fails, you resend the digital file that describes that part to a microfactory to have the new part manufactured (adding in improvements from ongoing re-assessment of the part's durability). When it arrives you snap it into place and keep making toast.

What if not only our consumer durable goods, but our commercial and industrial goods and the rest of the built environment was conceived this way? What if local farm equipment was optimized to local growing conditions? And it doesn't have to be high-tech: what if local farm straw was used to make locally consumed brooms? How would that impact local skilled and semi-skilled labor and fortify resilience?

HOW DO WE FIX THIS?

In concert with holding Fixit Clinics through colleges and universities we're promoting the idea of a higher-education design challenge that leverages both user-centric design and design for manufacturing to ask: Can we create open-source, digitally documented designs for many popular common household appliances and electronic devices? Starting from current mass-manufacturing designs, how much of the item can we source locally at the moment? How can we nudge the design over time so that more and more of it can be sourced locally?
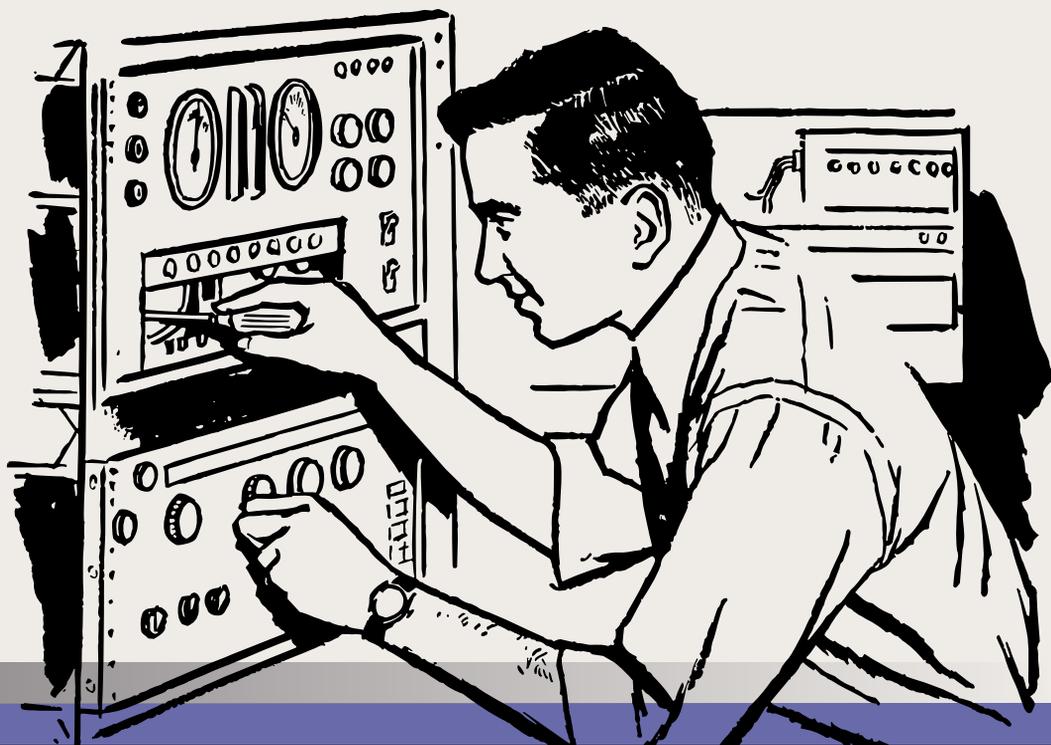
It's a hopeful vision for a future we want to craft along with you, one broken toaster at a time. ◉

OMEGA APPLIANCE REPAIR

Written by Wayne A. Seltzer

I STARTED MY OWN REPAIR BUSINESS IN EIGHTH GRADE. NOW, IN MY RETIREMENT, I'M PART OF THE GLOBAL FIX-IT MOVEMENT.

Adobe Stock–RetroClipArt

Fixing broken things was just a normal part of my family life.

I was born in New York City and was raised in New Jersey in a home with lots of tools, a garage, a basement workshop, and a backyard. My father was a Depression-era baby who grew up with a sense of frugality. He had lived through some pretty tough times as his parents were refugees from Eastern Europe. He was an electronics engineer trained in the U.S. Army Signal Corps in World War II. With his work, my parents were able to move from a small apartment in the Bronx to a house in Queens and later to a new home in the NJ suburbs.

In this burst of postwar suburban growth, people acquired lots of things that would eventually break. My father wouldn't throw broken stuff away — we fixed everything, sometimes with the help of my Uncle Arnold, a mechanical engineer who designed hydraulic control systems for the U.S. Navy (he had a machine shop in his basement!). We enjoyed solving these repair puzzles and were all known in the neighborhood and family as the people who have the tools and knowledge to fix anything.

My dad was a pioneer in consumer electronics. He worked for Emerson Radio & Television, where he designed and tested "Hi-Fi" radios, "stereos," and later, color televisions (we were the first on the block to have one). In the 1960s my dad gave me an Emerson portable AM radio with six transistors! Our home workshop was filled with his audio experiments in his quest for perfect sound.

Dad taught me to solder at a young age so I could help him build his audio projects. He often needed another pair of hands and liked my small fingers and sharp eyes for detailed work. We built all kinds of crazy stuff. Some things caught fire. Some things didn't work. We had a lot of fun.

FINDING A CALLING

Maybe based on my inherited sense of frugality, I noticed that people would throw useful things out on trash night. I'd see a vacuum cleaner, lamp, kitchen appliance, or maybe an entire dishwasher. And I said to myself, "... there must be useful parts in there."

I SAID TO MYSELF, "... THERE MUST BE USEFUL PARTS IN THERE."

When I was in middle school, when people had their trash cans out, I would often ride around on my bike and harvest parts from their discards. With tools in my bike basket, I would quietly collect useful parts like power cords, switches, valves, and motors. The summer between seventh and eighth grade the local newspaper in central New Jersey advertised: "Hey, kids. Free summer work ads. Send us a classified. We'll print it for free." So I put in "Omega Appliance Repair. No job too big or small," along with my phone number. (I suppose I was thinking about the movie *Omega Man* which was playing in theatres at the time.)

My friend, Gary, who was into graphic arts, printed up some business cards in the school's shop for me. I realized years later that we spelled appliance wrong; just one "P," but maybe that was my trademark. Much to my surprise, I got a lot of phone calls with people asking, "Hey, can you fix this toaster, blender, dishwasher ...?"

I would ride over on my bike to pick up small repair items, or customers would bring things to our house. If I had the part that I harvested from the garbage, I wouldn't charge people for it, only for my time. I'd tell them: "People threw it away; it had no value to them, so it's yours now."

PHONE: 679-▮▮▮▮   PHONE: 679-▮▮▮▮

Wayne Seltzer

Old Bridge, N.J.

SMALL
APLIANCES
REPAIRED

**QUALITY SERVICE/LOW PRICES

Me at one of the first Boulder U-Fix-It Clinic events, demonstrating how to use a multimeter to troubleshoot a broken floor lamp.
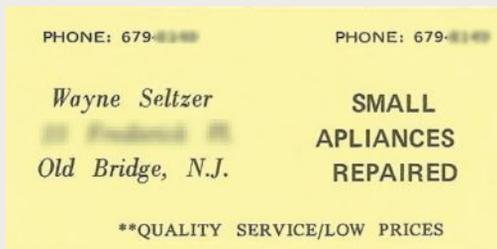
Marty Crigler, Eco-Cycle, Wayne Seltzer

In high school, I had a well-paying job at a small electronics shop, fixing TVs, stereos, car radios, etc. I was one of a few kids who took shop classes as well as the advanced math and science track. I was fortunate to get admitted to MIT on a scholarship, majoring in electrical engineering and computer science. I quickly found a cool job working for MIT's "Dormitory Telephone System," repairing telephones and switching equipment. During my time there, I was thrilled to be accepted into the MIT co-op program with Bell Labs where I worked summers through graduate school, designing digital telephone systems and other networking and communication projects.

After college, I moved to Boulder, Colorado and

was part of the growth of technology companies At Sun Microsystems, I led the "Auto Service Request" project which automated the diagnosis and repair of high-availability servers, no doubt driven by my obsession for fixing stuff efficiently.

Several years ago, my friends Peter Mui and Steve Berl challenged me to create a volunteer repair clinic in Boulder, following the model of the successful Fixit Clinic in Berkeley (see "The Fix Is In" on page 26). Partnering with Boulder's community recycling non-profit, I started the Boulder U-Fix-It Clinic. My engineering friends and co-workers at Sun became enthusiastic volunteer repair coaches at our series of free clinics. We received a grant to purchase tools and

supplies, and were thankful to be the recipients of some great toolkits from iFixit. We're now part of a growing global community of fixers; it's been a lot of fun to meet people who share their passion for diagnosis and repair to save the planet by fixing our broken stuff. During Covid, we've had an ongoing series of Zoom repair clinics with volunteers around the world. And, of course, we're looking forward to resuming our in-person events.

Now I have more time to share my passion for making and repairing. I retired a few years ago to become the interim director of the "Blow Things Up" makerspace at the University of Colorado's ATLAS Institute, where I am now "technologist-in-residence." I'm also a part-time electronics/computer science/robotics instructor at the CU Science Discovery summer camp and after school program. A few years ago, at a Denver Maker Faire, I met Qing Hua who encouraged me to teach Arduino classes through her Build-A-Robot program. It's been great teaching middle-school kids who are the same age as I was during my "Omega Apliance Repair" days.

STILL BROKEN...

I suppose what I was doing in the 1970's was not a whole lot different than the repair movement that's going on now. Can we keep things out of the landfill? Can we make use of the stuff that's worn out or just broken? Unfortunately, we haven't really solved the problem. Products are increasingly complex and harder to repair. And, even worse, manufacturers design products to be not repairable. I'm glad to be part of the international #rightorepair movement that seeks to require manufacturers to make replacement parts, tools, software and documentation available to enable consumers to fix the products they own. ◍

During the first part of Covid, I joined Make4Covid (make4covid.co/blog); volunteers across Colorado used their 3D printers to make parts for thousands of face shield masks.
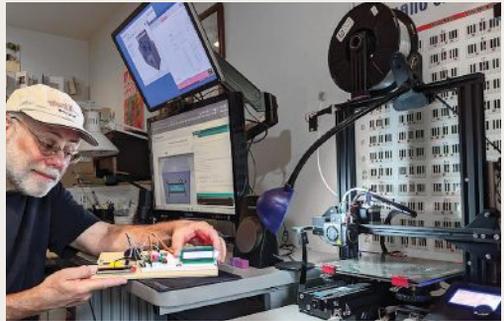
I was featured in an *MIT Technology Review* article "Hands on: How four alumni have built making into their lives."
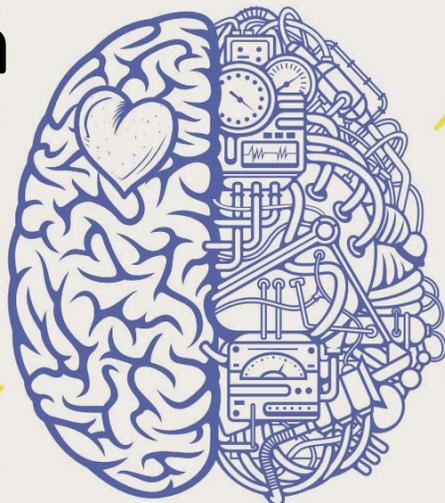

My father Alex Seltzer, an electronics technician and a pioneer in the early days of consumer electronics design and production.

WAYNE SELTZER is the founder of the Boulder U-Fix-It Clinic in Colorado: boulderufixitclinic.org

CULTIVATING A REPAIR MINDSET

USE THIS EDUCATIONAL REPAIR TOOLKIT TO GUIDE YOUNG LEARNERS TO RESOURCEFULNESS AND STUDENT AGENCY

Written by Brooke Toczylowski and Aaron Vanderwerff

As educators we see the opportunity to support young people to cultivate their repair mindset at home, in after-school experiences, and in the classroom. Since 2019 **Agency** *by* **Design Oakland** and **Maker Ed** have partnered with **The Culture of Repair Project** to ignite an interest in repair within maker-centered learning and the broader educational landscape. Our group has explored this topic and how it might be engaged in K-12 education. The resulting publication, *Cultivating a Repair Mindset Toolkit*, both shares our research and invites engagement in the richness of repair. Download the full toolkit (designed by Bri James) for free at makezine.com/go/makeredrepair. Here are some ways educators can use it with their learners.

Curious about repair? Print out the "Repair Zine" (Page 18 of the Toolkit). Fold the zine into a poncho book and then use your home to do the listed activities like a repair hunt (to find objects that need repair) or to sketch and write the names of tools you have on hand.

Explore design, engineering, and invention: "Repair Exploration" (Page 19 of the Toolkit) cultivates learners' curiosity about how objects and systems work. Look closely at a single object in need of repair while weaving in the design process: after "Noticing" and "Exploring," "Reflecting" leads to defining and ideating solutions.

Supporting language development: When exploring an object, invite learners to diagram and label the parts with their own language (this also provides an assessment for you), then move learners into researching the accurate names of components and materials to learn new vocabulary.

Empathy: The Common Core Standards ask learners to consider multiple perspectives and look at one scenario from multiple vantage points. Use the "Parts Perspectives Me" tool (Page 22 of the Toolkit) to support learners to develop perspective taking as a habit.

Creating space for open exploration? Create a repair station by setting up a stack of "Repair Journals" (Page 23 of the Toolkit) near a set of objects in need of fixing (collect these from the school or program and/or have students bring them in from home), tools, and documentation materials (chart paper, markers, pencils, rulers, etc.). Students could also opt into repairing objects for the larger community. Encourage learners to think about different outcomes for repair — are they hoping to bring it back to its original function or do they want to change its function? Do they want to make it more beautiful, more efficient, more environmentally friendly, or other?

Establishing a community repair stance: After you have engaged in repair with your learners, write your own repair stance together. Ask: "What is important about repair?" "How do you think repair can impact our world?" "How can we think about repair as part of our community?" Use our "Repair Stance" (Figure **A**; Page 6 of the Toolkit), as well as iFixit's Repair Manifesto as inspiration.

In the Toolkit, we focus on the repair of physical objects because kids love to get hands-on. But repairing objects sets off a chain reaction that is part of restoring the many systems to which each object is associated, meaning objects and systems are interconnected. Learning to repair a coat zipper is an invitation to consider the labor that sewed it in the first place, the processing of the metals, and the right to access the information needed to fix it. The process of repair cultivates curiosity, systems thinking, problem solving, and many of the 21st century skills that schools focus on.

Repairing objects is a gateway to student agency. Our national public education system still centers on the standardized methods of the industrial revolution. We want to see a system that produces graduates who are ready and excited to tackle the world's most pressing problems. We think the Toolkit will help. ◉

OUR REPAIR STANCE

There is a worldwide movement to Repair and we honor their expertise and beliefs. We notice, as educators and activists, that we have additional ideas to contribute, in our own words.

We believe that because everyone is a maker everyone is also a repairer.

We value the complexity of repair and the potential it holds to both understand and shift power, culture, and ways of knowing and being.

We recognize that we need to learn and teach a new ethos of materials, manufacture and consumerism because of its impact upon the lives of our students and our planet.

We value repair and understand that access to tools, raw materials, a workspace and time are real life constraints and often contribute to why repair does not happen when it could have.

We value the community effort that supports a disposition of repair.

We believe that to make, mend and repair is non-gendered.

We strive to continue to learn how to hold community values that recognize and attempt to break from the norms of consumerism and instead prioritizing care and/or interactions with the living world.

We support the right to repair movement, and advocate for design that values hacking and fixing as well as product guides, instructional videos, and replacement parts.

A

Designed by Bri James

BROOKE TOCZYLOWSKI is Co-Director of Agency by Design Oakland, which works with ecosystems of educators to shift schools from places of compliance to curiosity. She is also a practicing visual artist.

AARON VANDERWERFF is Director of Learning at Maker Ed, which supports educators to shift their practice to be more liberatory through making. He lives in Oakland, CA with his family.

Framework laptop
Expansion cards
Bezel
Memory
Battery
Touchpad
Bottom cover
Heatsink and fan
Storage
Blank keyboard
Framework screwdriver
Clear keyboard
Input cover
Mainboard

MOD SQUAD

FRAMEWORK'S MODULAR LAPTOP AIMS TO FIX AN INDUSTRY BUILT ON OBSOLESCENCE

Written by Nirav Patel

Every year, the new devices launched by big brands have gotten faster, thinner, and shinier, but also more locked down and less accessible to repairs and upgrades. Across a decade working in consumer electronics at Apple, Oculus, and Facebook, I felt an increasing sense of unease about the direction the industry was going in. Some of the most advanced outputs of human civilization were built in ways that meant they would end up as expensive paperweights after a few years, or worse, part of the growing global e-waste crisis. This sounds like an impossibly large mission, but I started Framework (frame.work) to fix the consumer electronics industry.

FIXABLE BY DESIGN

Our first product is the **Framework Laptop**. We decided that repairability and upgradability couldn't come as a tradeoff. We needed to build a notebook that was as thin, light, and powerful as what consumers would otherwise buy, and then within those constraints, make it as modular as possible. Additionally, we felt it was important to trust and respect the end user by providing you with repair manuals, documentation, open and transparent communication, and the physical tools to enable you to do anything you would like to with the product. On the last point, we actually include a screwdriver in the box with every laptop to drive home the idea that the product is open for

repair and upgrade.

We've aimed to make every repair possible for someone who had never been inside a computer before by providing clear labelling and scannable QR codes for instructions. We've also focused on simplifying repairs and upgrades for the most common scenarios like battery replacement and memory and storage upgrades. We've kept things convenient and user friendly by avoiding glue and tape, minimizing the number of unique fasteners, and even including a few spare screws in the case for when one inevitably disappears into the void during a repair.

We also drew upon the modularity that exists already in the PC space wherever we could. We used standards like SO-DIMM memory and M.2 storage to let customers bring their own off-the-shelf modules where we could. We took advantage of USB-C for our Expansion Card system that lets every port on the system be user-selectable. Because this is a popular standard, it also made it easy for us to release open source reference designs and documentations (github. com/FrameworkComputer/ExpansionCards) to enable community creation of new cards using home 3D printers and hobby PCB fab services.

We're seeing some incredible designs in development already, from UART bridges to dual USB-C hubs to snack drawers (!!!). In addition to hobbyists being able to satisfy their own needs, we're looking forward to opening a marketplace to enable people to be able to share modules they develop with each other.

A FIXABLE PHONE

While Framework is bringing a modular mindset to the world of laptop design, another company touts the easy repairability of their device. **Fairphone**, an Android 11-running smartphone with a Qualcomm Snapdragon processor, has recently released their 4th gen phone. It offers an easy-to-open design with screwed-in components, specifically for helping the end user keep their phone in use for longer than the 2-year consumer average. To back up their stance, they're promising upgradable components for five years, with a warranty to match. Their phones are the only to ever receive a 10/10 on iFixit's repairability rankings. Let's hope the trend continues. —*Mike Senese*


Framework, Fairphone

FIRST OF MANY

Another great thing about the PC space is that there is a large base of existing users who inherently understand why repair and upgrade is useful. Our mission and product resonate with that audience immediately, but we're happy to see the early interest beyond that group as well. People worldwide are increasingly aware of the impacts of e-waste and the perils of locked down, glued together, and ultimately disposable devices. We're excited to continue to do our part in fixing this, one product at a time. ◈

NIRAV PATEL is the founder and CEO of Framework, where he is focused on fixing the consumer electronics industry. Before that, he was part of the founding team of Oculus and led the hardware team there.

REPAIR
ROUNDUP

A
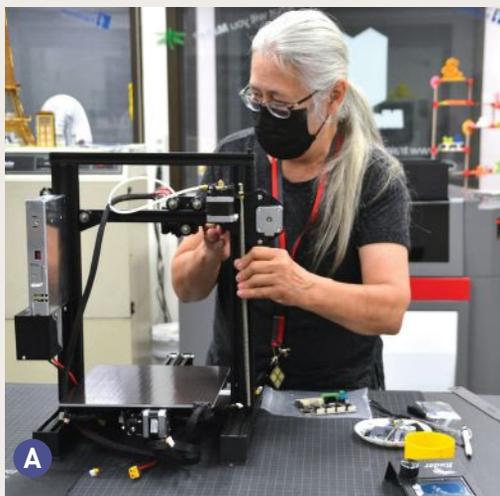
TRASH INTO TREASURE, AMAZON EDITION

Make: President Dale Dougherty recently hosted **Debra Daun** *(Figure* A *) on the Make:Cast podcast (*makezine.com/2021/07/19/fixing-broken-machines-from-the-amazon-return-bin*). Daun is the director of the Maker Lab at Joliet Junior College. She likes to find broken machines in online auctions, government auctions, and Amazon returns and fix them and then put them to good use. Some of her tidbits:*

I often start searching using keywords like "liquidators," "salvage," "returns," "pallets," "Amazon," and combinations of these words. There are also government auctions at sites such as govdeals.com.

Online auctions and Amazon returns are "Buyer Beware" venues, but I hunt for what others pass up, namely "broken" 3D printers that I use to improve my repair skills. My ideal target is a pile of parts (dismantled, not broken) in a shabby box that's not its own. The more beat-up looking it is, the better I like it. Less bidding competition too!

Listings are often inaccurate. I have seen parts of power recliners and popcorn machines listed as "3D Printers." I study the photos and description, then do Google research and hopefully preview the item in person. I always assume that I'm buying for parts, no matter how good the listing looks.

Don't forget to research replacement part cost and availability too! My research helps decide which auctions to bid on and where to set my bid limit. It's easy to get carried away and overspend in the last few heated moments of an auction.

I don't buy with the intent to resell, but it can be an option. You can't get a consistent profit margin this way. However, if you do your research and take a chance, it's possible to get great machines at crazy good prices. I have yet to buy one that I couldn't fix.

DIY BIKE REPAIR STATION

Bike repair stations are a trend we're happy to see spreading through municipalities — there's probably no repair gateway as universal as learning to fix your bike, after all. These publicly accessible setups include a stand to mount your bike, along with a pump and all the standard

wrenches and tools attached via cable, to keep them from walking away. Why not build your own to add convenience for anyone pedaling through your part of town? One portable version: instructables.com/Portable-Bicycle-Repair-Station. Or, Rich Dana describes his more sophisticated solar-powered version at homefixated.com/diy-solar-bike-station.

And while you're at it, consider signing Bikes Together's petition to end the manufacturing of low-quality, built-to-fail bikes: makezine.com/go/nocrappybikespetition.

EXPLORING E-WASTE RECYCLING

Just what happens to those electronic devices that you drop off at the local e-waste recycling center? *Business Insider*'s recent video (youtube.com/watch?v=S2lmPla1iWE) gives a tour of the recycling facility in La Vergne, Tennessee, showing how it processes over 6 million pounds of old computers, printers, phones, and more. Sims Lifecycle Services Global President Ingrid Sinclair states in the video that their primary objective is to "reuse, repurpose, re-engineer. If we can't reuse it, the very last resort is recycling."

REPAIR CAFES

Along with the Fixit Clinics, a global network of physical meeting points for community-based repair endeavors exists. Called Repair Cafes, they were started in 2009 in Amsterdam by Martine Postma. Now, over a decade later, over 2,200 of these venues exist around the world. You can start one in your community too. Find all the locations here: repaircafe.org/en/visit

FIXING FURNITURE WITH CHEAP TOOLS

There's a lot you can do to keep your home furnishings looking good and feeling sturdy, and you don't always need fancy tools to do the job. Here's one take to inspire you: youtube.com/watch?v=zC5PPeGuq9o. Got other repair tips? email us! editor@makezine.com. ✪

Debra Daun, allcycling.com.au.jpg, Sims Lifecycle Services

Wearables What's What

It's 15 years since LilyPad — learn what's new and make your first iron-on circuit!

Written and photographed by Lee Wilkins

LEE WILKINS is an artist, cyborg, technologist, and author of our new "Squishy Tech" column in *Make:* looking at technology and the body and how they intertwine. Follow them on Twitter @leeborg_

Since the first LilyPad Arduino that Leah Buechley made in 2007, wearable electronics boards have evolved so much. Fifteen years on, most wearables boards are now made in the LilyPad style — round with large contacts around the edges, with lots of surface area to solder, clip, or sew onto. This style of board has no corners, and generally has a very slim profile so it doesn't get caught on clothing.

These days, there are a variety of new products — an entire ecosystem — that make wearables much more manageable, whether you're just learning or setting out to produce advanced products. And today we've also got online access to purchasing large quantities of specialty products, often not originally intended for wearables at all!

This guide is an overview of products and materials you might find useful on your wearables journey in 2022. Learn a bit about the latest gear, and then we'll build an iron-on wearable circuit!
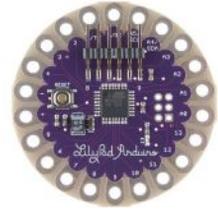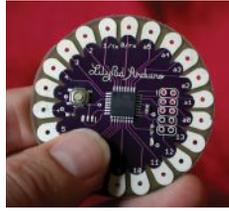
MICROCONTROLLER BOARDS
FLORA
The Adafruit Flora is my go-to board for beginners in wearables. It's got a thin, round profile lots of accessible pins, and is completely Arduino compatible. Because of the large contact pads around the edge, I even use the Flora for non-wearable projects because it can be soldered to easily, or clipped onto with multiple test leads. The Flora has both a USB plug and a JST socket for your LiPo or CR2032 battery attachments and runs on an ATmega32u4 chipset. There are multiple indicator lights for power and testing, even an onboard NeoPixel. The ICSP connectors are broken out for any advanced users if you want to dig deep. The Flora isn't the cheapest option, but it will definitely do what you need!
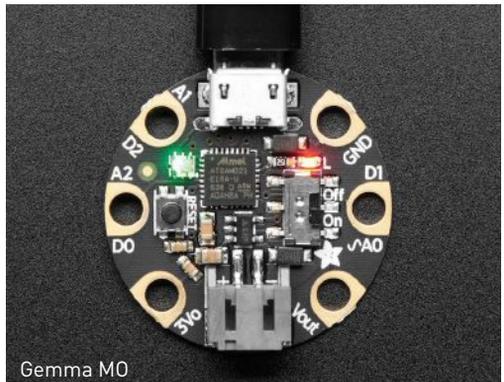
GEMMA M0
The Gemma is a smaller, more compact version of the Flora. While I had some gripes with the old version being sometimes difficult for beginners, the new Gemma M0 uses an ATSAMD21E18 chipset instead of the ATtiny85, making it a whole lot more friendly and powerful. Unlike its predecessor, it can communicate with the Serial

The original LilyPad Arduino (left) designed by Leah Buechley for e-textiles and wearable electronics in 2007, based on the ATmega168V microcontroller. Today there are several models, including a basic ATmega32U4 (right) and USB versions.
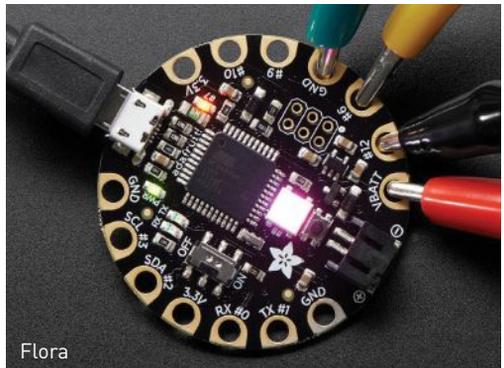
Flora

Gemma M0

Monitor with no issues. This small board can also be programmed through the Arduino IDE, or it can be a great introduction to CircuitPython. The Gemma is a bit small, so attaching lots of jumpers or making complex circuits with it can be tricky. I'd recommend the Gemma M0 if you're looking to finalize a project that you've already prototyped. If you previously tried a Gemma and had trouble uploading or getting reliable results, it's time to try the M0.
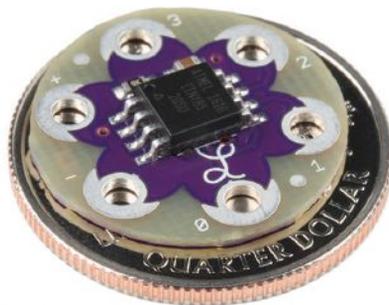
LILYTWINKLE

The LilyTwinkle from SparkFun Electronics is the smallest and cheapest wearables board currently on the market. It's a minimal ATtiny85 board that comes with pre-programmed patterns on each of its pins. You can take it right out of the box and add it directly to your project! However, what makes the LilyTwinkle special for me is that you can also reprogram the board for your own uses using an AVR programmer and an ISP pogo pin adapter — then you have a super-tiny wearables board for your advanced projects! This makes the board good for both beginners and more advanced users. The contact pads on the LilyTwinkle are a bit smaller and don't go right to the edge of the board, so they're better suited to sewing than to alligator clips or soldering. This board also doesn't have a JST or USB connector, so you'll need to either sew, solder, or clip a power supply to the board.

A few honorable mentions here are Adafruit's **Circuit Playground** series and the BBC **micro:bit**. Both are great boards for beginners and are loaded with features of their own, but are in my opinion, simply overshadowed by the Flora and the Gemma for most wearables projects.

### MATERIALS
CONDUCTIVE THREADS

For me, one of the biggest pains about wearables was always the conductive thread, but I'm happy to share that is no longer the case! It used to get tangled and be difficult to use, which was tricky both for skilled sewers who were already frustrated with the electronics, and for people new to sewing who struggled with the material itself. I'm very pleased with all the new conductive thread options that have appeared in the last few

LilyTwinkle
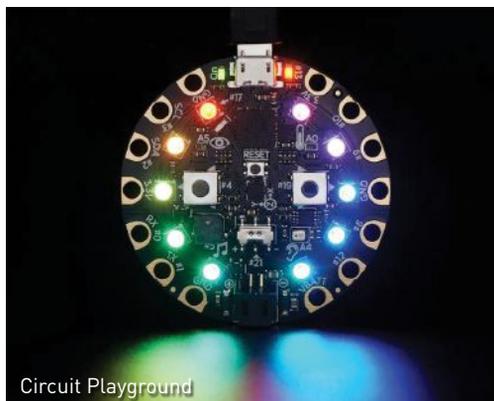
Circuit Playground
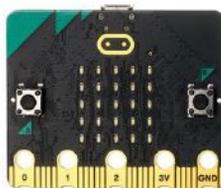
micro:bit v2

years. I'll go over the broad categories of thread currently available. Each supplier might have variations, but knowing the broad strokes can help you identify a thread that will be helpful in your project.

Stainless steel thread was an early, tried-and-true conductive thread. It has pretty low resistance, and comes in 2- or 4-ply types. The 4-ply is much more conductive, but it's a bit harder to work with and might get tangled easily. You won't get this thread in a sewing machine without trouble, but it will never oxidize like some other threads. There are many brands, and they all vary somewhat. Stainless steel thread can also be difficult to thread a needle with, so if you use it I recommend getting a needle threader.

Silver- and nickel-coated threads can offer a more workable solution. These can often go inside sewing machine bobbins, and feel much like regular thread. I've even used silver-plated thread in a digital embroidery machine. Depending on the thread, there are different bases, often nylon, which have super-thin nanoparticle coatings. Some of these coatings can wear off or oxidize over time, and all have very different resistances, so make sure to check the specs and test the materials too.

38AWG copper magnet wire is my personal favorite. You can get this at many hobby shops or hardware stores. It's a very fine-gauge copper wire coated with a clear enamel, which makes it head and shoulders above all other conductive threads for usability. Unlike the others, you can let your traces touch and they won't create a short circuit, because of the enamel. You'll have to use a flame or sandpaper to remove the enamel at your connections. Some gauges can even go into the sewing machine bobbin. Copper is extremely conductive, so you can use this to cover long distances with multiple traces. It's really a game changer for wearables.

Conductive yarns, which are thicker than threads, are available too. **Habu**'s silk-coated steel yarn is beautiful and easy to work with. As far as I know, it's the only colorful conductive yarn. **SewlY** also has some beautiful insulated conductive thread that comes pre-loaded on metal bobbins. It's a bit thicker than other threads but it looks fabulous and is easy to work with.

There are a wide variety of **steel core** or **golden** yarns and threads that are not specifically advertised as "conductive" that also work really well.

FABRICS
Wovens — A longtime beginner-friendly favorite is **iron-on conductive fabric**. This fabric is usually made of copper-nickel plated polyester, and it's woven so it doesn't stretch and is easy to place. It can even be cut with a laser or vinyl cutter so you can create beautiful designs and iron them on without worrying about being handy with appliqué.

There are also copper-nickel plated polyester strips of **conductive tape** that are great for paper circuits, and come in varying widths. Unlike the

iron-on fabrics which are pretty robust, I've found that the adhesive on the tapes isn't great for surfaces that move a lot, but they are so easy to apply and super fun for learners. Some iron-on or adhesive fabrics aren't conductive on both sides due to the glue, so it's best to double check before you buy.

My favorite non-adhesive woven fabric is the pure **copper polyester taffeta** from Less EMF. It's got a gorgeous color, doesn't tarnish, and is extremely conductive. While it's easily the priciest, it really stands out as a centerpiece of any work.

> **TIP:** You can use *fusing* if you want to iron on a non-adhesive fabric.

Knits — There are a number of stretchy, knit conductive fabrics available in the last few years. They're a bit harder to work with, and sometimes their resistance is different along the horizontal and vertical axes. This is due to the structure of the fabric itself which sometimes has a stretchy fiber as well as a conductive fiber in an interlocking pattern. While knit conductive textiles feel a bit more natural, they can be difficult for beginners because the edges tend to curl, and the stretch makes them harder to sew down. My favorite though, is the **jersey knit fabric** that has spandex and silver fibers — it feels like a T-shirt!

Nonwovens — Nonwoven fabrics can have interesting properties unlike knits or wovens because of their construction. **Velostat** is commonly used for pressure sensors, as it changes resistance when it is squished. I would argue that Velostat, aka Linqstat, is not really a fabric but a plastic sheeting, so sometimes it's also a bit challenging to work with. Lucikly **Eeonyx** makes a few interesting piezoresistive fabrics that can be used both for heating and for force-sensitive resistors.

While some of these materials can be pretty pricey, if you find yourself using a lot of them I recommend searching for an industrial-sized bobbin on Alibaba.com. (I have one and I don't think I'll ever run out of silver-plated nylon thread.) They'll cost you a few hundred dollars,

depending on the thread or fabric, but it's well worth it in the end. A great source for all of this is the **Less EMF** shop at lessemf.com, and of course **Kobakant** has a stellar list of international suppliers for fabrics, yarns, threads, and more, at kobakant.at/DIY.

I should also mention that **silicone wire** is a great alternative to conductive thread. It's incredibly soft and flexible, but of course it can't be integrated into garments quite the same way.

SNAPS AND CLASPS
Snaps and clasps are the unsung heroes of wearable electronics. When you're working with materials that are, by design, squishy and flexible, it's hard to get good connections without compromising wearability. Snaps and buttons are already a part of the mainstream design of clothing, so people won't think twice about them being all over your wearable device.

Sewable snaps have small holes along their edges which are perfect for attaching conductive thread to make a connection. Snaps can also be soldered to the pads of your wearables board, so that it can easily be removed for washing.

Clasps and buttons can also be used as switches to turn your device on and off. While snaps do the task perfectly well, there are a variety of clasps that provide a more interesting interaction to close a circuit, like bag clasps and belt buckles. Some have protective coatings on them, so always test before you commit to adding traditional sewing elements to your circuit.

A
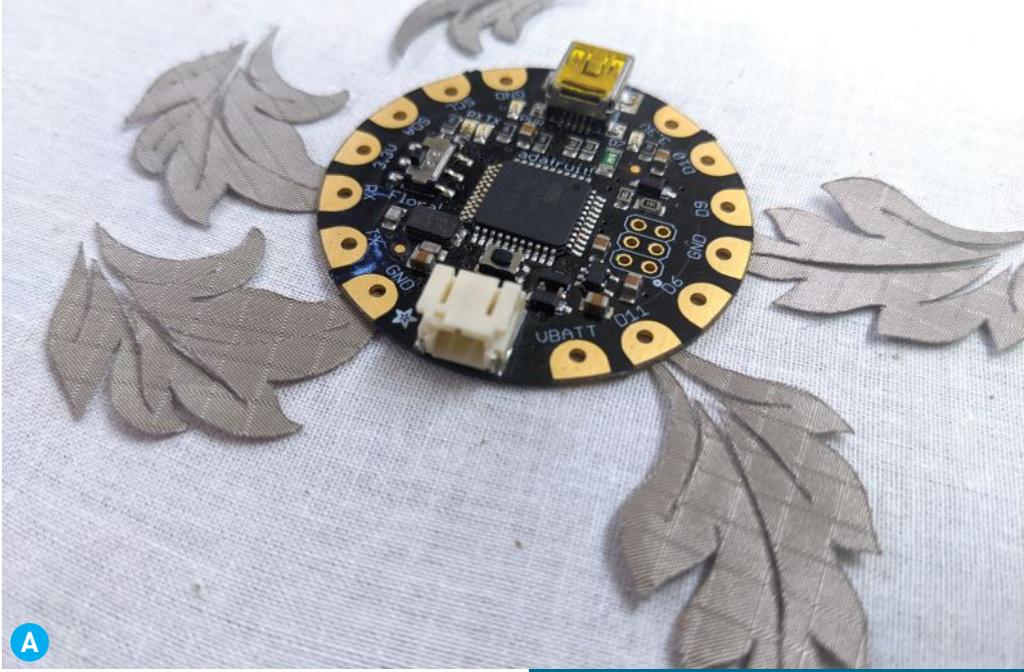
MAKE AN IRON-ON TEXTILE CIRCUIT

In this tutorial, I'll show you how to build your first wearable circuit using iron-on conductive fabric (Figure A). This project will take you through cutting, ironing, sewing, and programming as your introduction to wearable electronics. The technique I will show you is how to attach LilyPad-style electronics to traditional through-hole components — in this case LEDs — which is something you'll do a lot if you build soft electronics!

The benefit of using the iron-on fabric to make traces in this example is that you can get a much cleaner appearance, and experiment with the shape of your circuit. When you're done with this project you'll have a circuit that can live on a textile and blink any pattern you'd like — and the skills to try new circuits of your own.

1. PREPARE THE DESIGN AND CUT IT OUT

Start by making your design in your favorite vector graphics program. I use Adobe Illustrator. It's useful to draw a circle the same size as your Flora board so you can tell how big your connection pads have to be. We'll be making the circuit traces using conductive fabric. I find it easiest to use squares to make simple patterns, but these floral designs can make beautiful work as well; their tips will serve as connection pads to the Flora. In Figure B, the red circle is the board
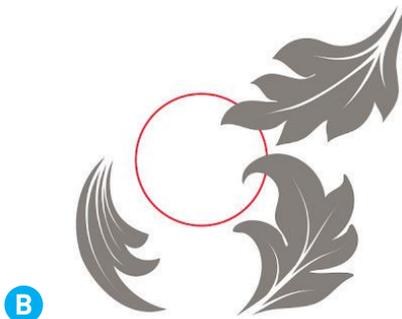
B

outline and the gray shapes are the outlines of the conductive fabric. I'm going to cut mine out on a Cricut cutter.

You'll need to plan how your circuit will work before you commit to a design. Here we're using pins D10 and GND on the Flora to make a simple LED circuit. You'll also want to leave enough room around each connection where you'll sew down a component, around 5mm–10mm. The battery holder will go on the left, and the LEDs will be sewn on the bottom.

I cut the design out of copper-nickel plated woven fabric with iron-on adhesive backing (Figure **C**).

2. IRON ON AND SEW DOWN
The next step is to iron your design onto the final fabric. Make sure to keep an eye on the spacing between the pads so your design doesn't get distorted. You can use transfer paper if you want to make sure to keep the dimensions, or just be very careful as you place each piece. If your design is complex, feel free to pin it down.

Place the board on top of the design to make sure it all lines up. You can play around with the pieces until you find something you think will work. I cut out a few extra floral bits to see how it would look (Figure **D**).

Then iron it down (Figure **E**). I set my iron to a very low "silk" setting as it doesn't need to be that hot to melt the glue on the iron-on fabric.
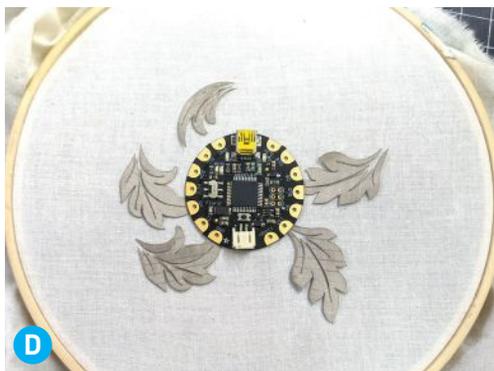
3. MAKE SEWABLE LEDS
Use a pair of needlenose pliers to twist each lead of the LED to make a tiny circle (Figure **F**). This makes your normal LEDs into sewable LEDs!
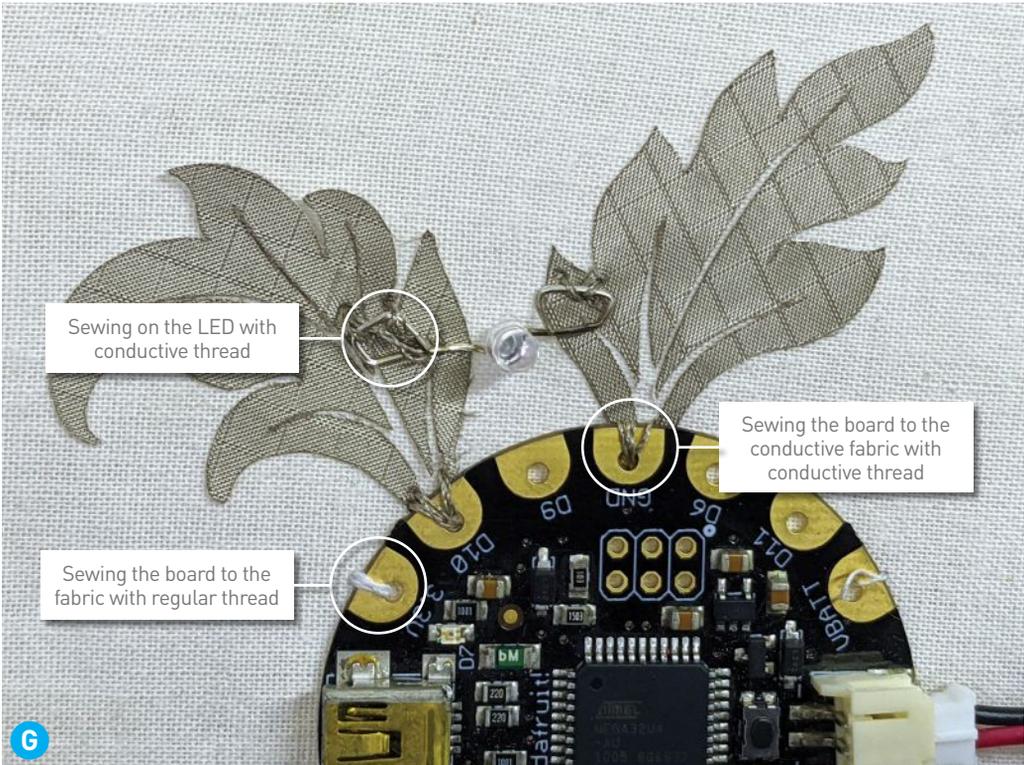
Make sure you have correctly identified the negative (–) and positive (+) leads of your LED. You can identify the positive because it is the longer of the two; this will be connected to pin D10. The negative lead connects to ground (GND). Keep an eye on these while you're making your circuit.

4. SEW YOUR CIRCUIT
First I like to sew down my microcontroller with normal thread in at least two places, or four if I'm worried about it falling off. For this you can use the holes in any unused connection pads.

Now start sewing down your circuit with

Sewing on the LED with conductive thread

Sewing the board to the conductive fabric with conductive thread

Sewing the board to the fabric with regular thread

G

conductive thread. Use conductive thread to bridge each connection between the board's pad and the conductive fabric, and between the component (the LED) and the conductive fabric. This thread is both structural and functional, and it's important to keep that in mind.

When sewing down a component, make sure the thread is pulled tightly and the stitch goes from the back of the fabric, through the component hole in the front, around the component, and back through the conductive fabric. Do 2 or 3 stitches and pull them tightly. Tie it off with a simple knot as close to the back of the fabric as you can, and trim the excess thread after the knot. Pulling the stitches tight is important because as your fabric moves, you don't want to risk the connection breaking.

You're done! Check out Figure **G** if you need help figuring out the circuit placement.

5. CODE AND TEST

If you've never programmed a microcontroller board before, check out some Flora tutorials on Adafruit's website for a more in-depth look.

Here is some very basic code we'll use:

```
void setup() {
pinMode(10, OUTPUT);
}

void loop() {
  for (int fadeValue = 0 ; fadeValue <=
255; fadeValue += 5) {
    analogWrite(ledPin, fadeValue);
    delay(30);
  }

  for (int fadeValue = 255 ; fadeValue
>= 0; fadeValue -= 5) {
    analogWrite(ledPin, fadeValue);
    delay(30);
  }
}
```

Before hitting Upload, you'll need to make sure the right board is selected. In your Arduino IDE, go to Tools → Boards → Board Manager and add the Adafruit board set. Then you'll be able to select Adafruit Flora from the board's dropdown menu before clicking Upload. Your sewable LED should be blinking!
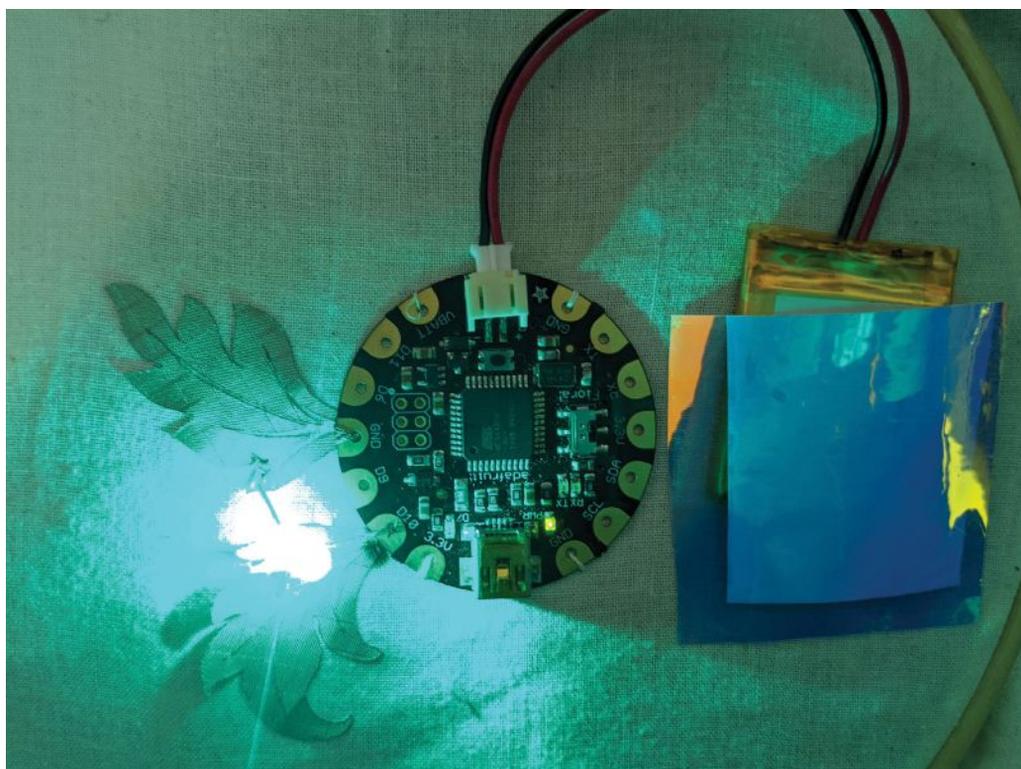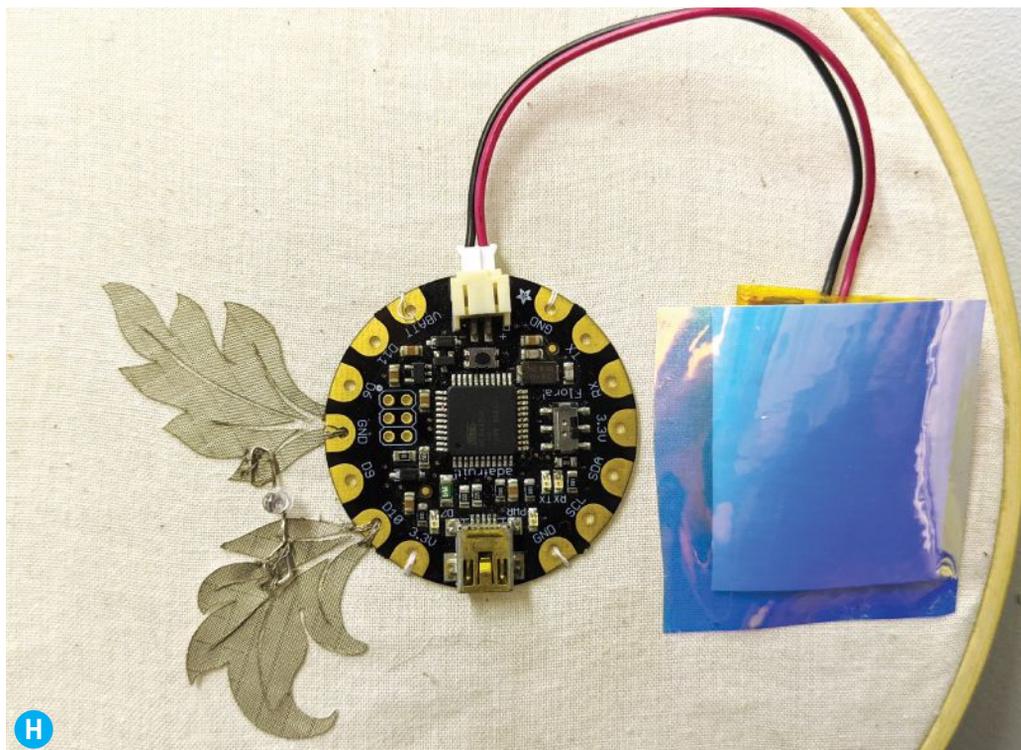
6. FINISH UP!

I added a vinyl side pocket to hold the battery (Figure **H**) and cut off all the excess conductive and nonconductive threads on the back.

TROUBLESHOOTING

If your LED doesn't blink, try checking your code and making sure the traces are fully connected. Remember you need to flip the switch on the Flora to turn it on. You can also trim the tails of the thread on the back of the board to be sure they're not creating a short circuit.

TAKING IT FURTHER

Putting together a soft circuit often requires using a variety of techniques: sewing, programming, and basic knowledge of circuitry. One of my favorite things about wearables is that there aren't always established methods for doing things "correctly," so you'll get to experiment and see what works best. Don't hesitate to get creative, use multiple materials, or try new things. You can use all kinds of materials like belt buckles and jewelry that are already on your body and can be good additions to any circuit.

Additionally, there are a whole bunch of wearable **breakout boards** and **sensors** that usually come in a "LilyPad" style that you can add to your circuit to make it sense, move, or respond to the world. **SparkFun** and **Adafruit** are top vendors.


Loomia has newly launched a series of fabulous components that use a completely different system. Rather than the hard circuit boards we've seen before, Loomia uses a soft circuit board technique with small contact points on the edges. Their button switches, FSR pressure sensors, and heaters are completely squishable and can be either soldered to or clipped to. This is a whole new dimension to DIY wearable technology.

I also love to think of the body as a whole new possibility for interactions. You can make circuits that open and close with a snap of your finger or a clap of your hands. By using soft materials to make circuits, you can build things that feel like an extension of yourself! ◑

ADDITIONAL BREAKOUT BOARDS AND SENSORS

LILYPAD: Vibe Board, Button Board, Accelerometer, and Sewable LEDs
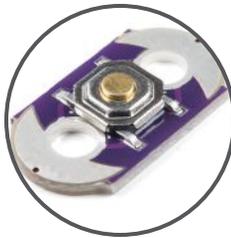
FLORA: Bluetooth LE Module, RGB Smart NeoPixel, LED Sequin, and Ultimate GPS Module
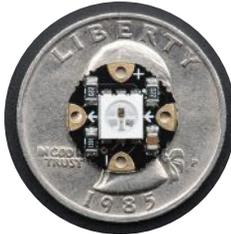
DIY Fume Hood

This build sucks — toxic fumes away from your workshop! Written by Téa Forest

TÉA FOREST is a cosplay costume designer based in Toronto, Ontario. Her work blends traditional sewing techniques with digital fabrication tools.

One of the largest obstacles I faced when first starting to cosplay was what to do with all the toxic fumes created by a lot of products I needed to use, such as contact cement and spray paint. The easiest thing to do is work outside but that's not possible in all situations, especially during the winter.

This fume hood allows me to work year-round without the fear of breathing in toxic chemicals. It's a straightforward build that anyone can do, and with a few adaptations it can also be used for laser cutting fumes, 3D printing fumes, and other noxious or obnoxious emissions.

1. ASSEMBLE THE BOX

You can cut the plywood sheets yourself, or get them cut (when you're buying them) by most hardware stores for a small fee. Show them the cut diagram (Figure (A)) and they should be able to cut it for you. They'll probably tell you they can't be that precise but that's okay for our needs. Since the fan will be pulling air into the box, having some small gaps in places is OK since all leaks will be inward, not out into the room. (You may notice that my box has the bottom sticking out a little bit, because I didn't account for the thickness of the plywood — but that's fixed in the final measurements.)

Start by attaching one of the side pieces to the back panel. Using the #8×1½" screws, screw through the side, into the edge of the back panel. Putting the bottom into place can help you line everything up (Figure (B) on the following page). Some tape or a helping hand might be necessary to hold things together while you get started. We did 5 screws per side.

TIME REQUIRED:
A Weekend

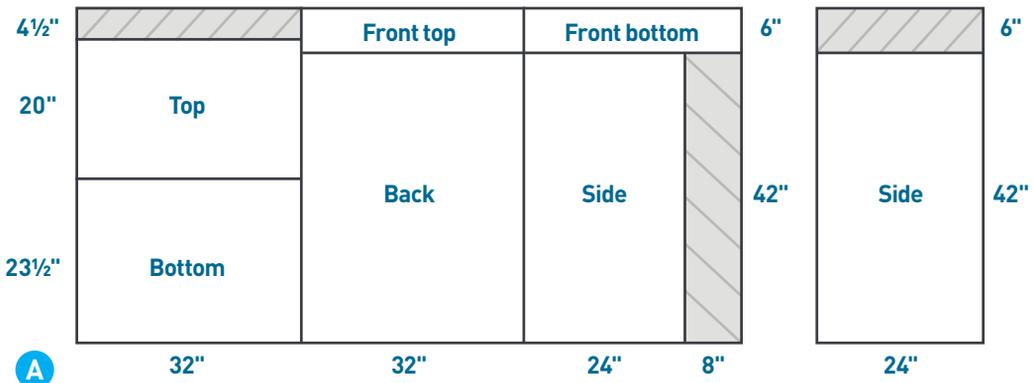**DIFFICULTY:** Easy

COST: $500–$700

MATERIALS

- » **Furnace filters, 16×20×1 (2)** from any hardware store
- » **Carbon filter, 8"** We ordered an 8", 720 CFM air filtration kit from Vivosun (vivosun.com) that includes the carbon filter, inline fan, dryer vent hose, and 2 duct clamps.
- » **Inline fan, 8"**
- » **Dryer vent hose, 8"**
- » **Duct clamp, 8"**
- » **Roll of aluminum foil tape**
- » **Duct reducer, 8" to 6"**
- » **Straight duct boot, 6"**
- » **Plywood sheets, ½" thick: 4'×8' (1) and 2'×4' (1)**
- » **Quarter-round moldings, 5/8", 8' long (4)**
- » **Wood screws: #8×1½" and #5×1"**
- » **Felt furniture pad strips (2–3 packs)**
- » **Acrylic sheet, 30"×32"**
- » **Painter's tape** to hold things in place while you screw
- » **A window that can open**
- » **Straps** to secure the filter to the top of the box. Our kit came with 2 straps but you could also use some metal strapping with ½" screws.

TOOLS

- » **Compact hacksaw**
- » **Jigsaw (optional)**
- » **Drill/driver with bits** including a ½" drill bit
- » **Screwdriver**
- » **Pencil** for marking
- » **Measuring tape**
- » **Plastic cutting tool (optional)** if acrylic sheet is too wide

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4½"				6"		6"
20"	Top	Front top	Front bottom			
		Back	Side	42"	Side	42"
23½"	Bottom					
(A)	32"	32"	24"	8"	24"	

Next, attach the bottom by driving screws through the side you just screwed on and through the back piece, into the edges of the bottom piece. You can prop the whole thing up on some extra pieces of wood or anything else you have lying around to be able to get a good angle on it (Figure **C**). Now that there's a good solid corner it is much easier to attach the other side to the back and bottom.

The last part to attach for now is the top. Lay the whole thing on its back and wedge the top piece between the 2 sides, pushed flush against the back piece (Figure **D**). You might have to loosen the screws on either of the side pieces first, if it was cut a little big. Screw into place.

2. SECURE THE FAN AND FILTER

With the box still lying on its back, test-fit the fan. It should be up at the top of the box with the fan on whichever side you want the air duct to exit (Figure **E**). Mark where to make a hole on the side using a pencil.

To get started cutting this big circle, first drill some holes using the ½" drill bit. If you're using a jigsaw, 4 holes around the perimeter of the circle should be fine. If you're using the hacksaw you'll have to make the holes much closer together since the hacksaw can't cut curves (Figure **F**). Cut out the circle by connecting the holes.

Using the ½" drill bit again, drill one more hole close to the big circle you just cut out, to feed the fan's power cord out of. Saw a gap between the two holes large enough to fit the cord through (Figure **G**).

Put the fan and filter into place, making sure the arrows on the fan are pointing the airflow outside of the box. In order to get the filter in straight, you may need to start the fan and filter on an angle (Figure **H**) and turn it into place. You could also loosen or remove one of the sides if you're still having difficulty.

Now it's time to mount the filter to the roof of the box. The air filtration kit we bought came with a couple straps, so all that was needed was to drill a couple holes in the roof of the box using a ½" drill bit and I was able to loop the straps

B

C

D

E

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through (Figure **I**). The filter is not very heavy so this is enough to keep it up. If yours didn't come with straps, you can use some metal strapping with ½" screws to secure it to the roof.

Once you're sure everything is working you can use some of the aluminum tape to make the connection between the fan and filter more secure, but it's OK to leave it for now.

3. ATTACH THE FRONT

The front is made up of two pieces, so that this project be can be cut from as little plywood as possible. We'll start by attaching the top front and then move to the bottom front. For this step you'll either need someone to come hold things while you screw, or you'll need a lot of tape to hold things in place.

Position the top front piece under the edge of the top piece and screw down into it through the top, using more of the 1½" screws (Figure **J**). Then, making sure you won't hit the screws coming down from the top, screw into it through the sides too. To make sure you'll hit it, first measure and mark where to drill.

The bottom front piece is secured the same way through the sides (Figure **K**).

4. MAKE THE SLOT FOR FURNACE FILTERS

There are 13 pieces we need to cut from the quarter round molding. Here's a diagram with the approximate lengths but I'd recommend measuring the space where you need to put them on your own fume hood to get more accurate

(1) 23⅜"	(1) 23⅜"	(2) 30¾"	(3) 12½"

(1) 23⅜"	(1) 23⅜"	(2) 30¾"	(3) 12½"

(4) 32"	(5) 27¾"	(5) 27¾"

L

(6) 27¼"	(6) 27¼"

measurements (Figure **L**). Cut them using the compact hacksaw.

The easiest place to start is to line up a piece (1) just inside the bottom edge of the box front, with its other end pressed against the back panel (Figure **M**). This molding has two flat faces; you'll want one against the side and the other facing toward the bottom of the box. Screw it on, using the 1" screws. I found it was easiest to first drill a hole then use a screwdriver to manually screw the quarter round into place. Do it again on the other side. Then take a piece (2) and line it up on the back between the two pieces (1) you just attached, and screw it on (Figure **N**).

Repeat with the other pieces (1) and (2) to create a 1" gap below the box front (big enough for your furnace filter to slot into), except this time one of the flat faces on the moldings should point up instead of down (Figure **O**).

There's one more piece needed to complete the filter slot and that's the piece that goes across to hold up the front of the filters, piece (4). Position this piece in line with the other 3 you just attached, 1" below the box front. Screw in, starting from the outside of the side panel, the same way you attached the front pieces (Figure **P**).

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Two furnace filters will slot into this space, side by side, so they're easy to change out whenever required.

5. MAKE A CHANNEL FOR THE ACRYLIC PANEL

The rest of the quarter round pieces are used to guide the acrylic front window or *sash*, as it slides up and down. Apply the felt furniture pad strips along one face of each quarter round, and along the side edges of the box front. These will prevent the acrylic sheet from scraping when it's moved up and down. Put any extra strips along the bottom edge of the box front to help with scraping there as well.

Line up piece (6) with the front face of the fume hood, with its felt facing outward and one end resting on the box bottom, and screw it into place (Figure **Q**). Find something that is about the same thickness as your acrylic sheet to use as a spacer. I used a couple paint stirring sticks. Sandwich them between the already attached piece (6) and piece (5). With the spacer between them, screw piece (5) into place with its felt facing inward (Figure **R**).

Repeat a similar process on the top with piece

(3), using the spacers again but this time lining the end up with the box top.

Do it all again on the other side.

The acrylic sheet should now be able to slot into the channel between the quarter round guides, and slide up and down with ease (Figure Ⓢ). If it doesn't fit, now is the time to trim it down using the plastic cutting tool.

6. VENT IT OUTSIDE

Even though the air is being filtered it still must be vented outdoors to be totally safe (Figure Ⓣ). Using a duct clamp, secure the 8" dryer vent hose to the part of the fan sticking out the side. I found using metal tape alone wasn't strong enough to hold it in place. Use the duct clamp, then you can tape around it for extra security.

Cut the vent hose so it's long enough to reach your window with a little extra wiggle room. Tape the 8"-to-6" reducer to the 6" duct boot using more aluminum tape. The rectangular shape of the boot makes it easier to vent out a window. Once attached, put the reducer on the end of the vent hose, securing it with tape once again.

All that's left to do is open a window and stick the duct boot in it. Fill any extra space with a piece of wood or cardboard. Depending on the weather where you live, you might want to take it out whenever it's not in use to close the window.

FUMES-B-GONE!

Turn the fan on and you're ready to go! Using one of the wood off-cuts, you can prop up the acrylic sash to make room for your hands to fit inside while you're painting or spraying. If your fan is quite powerful you may need to raise the sash a bit further to let in enough air.

When spray painting, I tape a washable fiberglass furnace filter to the bottom of the other filters to catch the larger particles (Figure Ⓤ).

Remember to leave the fan on while anything is drying inside as well, since it could still be giving off fumes.

EASY UPGRADES

Now that all the basics are done you can upgrade your fume hood by mounting a light inside or adding a power strip somewhere handy.

A fancy paint job would look nice, or even just

Ⓢ

Ⓣ

Ⓤ

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some stickers. For mine I opted to laser-cut some foam to make it look like Kirby was sucking all the air up (Figure V).

Lining the bottom of the box with kraft paper can be a big help with cleaning as well.

LASER CUTTER FUME EXTRACTOR

This build can be easily upgraded to serve as a fume extraction and filtration system for laser cutting. The key is to add more particle filtration for cutting wood, more carbon filtration for cutting acrylic, and potassium permanganate pellets to filter formaldehyde like in MDF and other engineered-wood products.

This fume hood box design is perfect for adding more filters at the top; just stack up what you need! Go for 4"-thick, pleated filters with a coarse filter first, on the bottom, and then a finer filter on top. You can add more carbon filters at the top if you make ductwork to connect them together.

At the Steamlabs makerspace in downtown Toronto, we made a system to filter the exhaust from our 120W laser cutter (Figure W). The filter box has coarse Camfil 30/30 D9 25×20×4 filters first, then fine Camfil Opti-Pac OPMV14 24×20×4 filters next. For filtering acrylic, MDF,

and other fumes, the system next goes through two pollution control barrels in parallel. These are from General Carbon and each is filled with 86 lbs of silicate compound impregnated with potassium permanganate (GC HS600) and 108 lbs of granular activated carbon (GC 4x8S). ◷

Freaky Fractal Feedback

How I built the world's coolest video feedback machines

Written and photographed by Dave Blair

DAVE BLAIR is a videographer, video producer and editor, photographer, and artist based in South Florida. He studied biology at UC Santa Cruz and video production and photography at Ohio University, and has incorporated his love of art with science and technology ever since.

TIME REQUIRED: A Weekend

DIFFICULTY: Intermediate

COST: $800–$1,000

MATERIALS

» **Digital SLR camera**
» **Panasonic 9" LCD field monitors, BT-LH900 (2)** Other HD models such as BT-LH80W, 7.9", or BT-LH1760WP, 17", can work with more modification.
» **Teleprompter glass, 50/50 light transmission** aka beam splitter glass
» **HDMI to SDI converter** Blackmagic Design Micro Converter HDMI to SDI 3G, $60
» **Power transformers (2)** for your field monitors
» **Adapter cables, 2.1mm coax female to 4-pin XLR (2)** to power the monitors
» **Wire or 12-pin cable** to extend control cables from the monitors
» **HDMI cable, 6' (1) and BNC cables, 6' (2)**
» **Wooden dowel** several feet long
» **PVC pipe** to fit closely around dowel
» **Tripod screw, ¼-20** with washer
» **2×4 lumber and/or T-slot aluminum**
» **Aluminum angle, ¾"** for lower monitor rails
» **Kitchen drawer tracks** for upper monitor rails
» **Scrap wood**
» **Machine screws with wing nuts and washers (3)**
» **Fishing weights and string**
» **Grease, heavy**
» **Extra monitor, HDMI splitter, cable (optional)**
» **Wood screws, glues, etc.**

TOOLS

» **Basic woodworking hand tools**
» **Wire cutters/strippers**
» **Soldering iron and solder**
» **Screwdrivers**

A

My first prototype of the video feedback contraption in 2003.

In college at UC Santa Cruz in the late 1980s I started pointing a camcorder at my little Sony TV screen, creating video feedback — TVs within TVs within TVs, receding into the distance like an infinity mirror. As I zoomed the camera, all the tiny TV screens came forward, piling on top of each other. This is where things get interesting and emergent behavior occurs: Instead of seeing a bunch of screens you get colorful patterns and rotating shapes and general freakiness!

That little TV had the all-important hue / contrast / brightness / saturation knobs. Making good video feedback is a balancing act between the image getting too bright or too dark, the screen going all white or all black, going all blue or all red, etc. The knobs allow you to fine-tune the feedback and to keep it in the delicate middlespace where interesting things happen.

Around 2000 I decided to experiment with video feedback again, but I wanted more control over the image. I knew that the rotation of the camera and its distance to the screen are important, and that small changes in either make a big difference in the feedback that's made. Instead of hand-holding the camera or putting it on a tripod like I did at school, I wanted a way to slowly and smoothly change its position and rotation.

I used a wooden dowel with a box on one end to hold a little Sony Mavica camera (with standard definition video output). On the other end was a thin piece of wood, like a yoke, for twisting the dowel. The dowel passed through a PVC tube and was heavily greased to smooth out the movement. Now the camera could move toward and away from the screen, and 360 degrees around its axis. This was a simple contraption, suspended from the low ceiling where I lived (Figure **A**), but it produced some pretty cool results. Instead of wildly spinning colors like you might see in a 1970s Jimi Hendrix video, I was making tightly controlled, almost mandala-like patterns. But the knobs were at one end on the TV, and I was on the other end at the yoke. I could change the camera position and I could rotate the knobs, but I couldn't do both at the same time.

QUEST FOR HD

Starting around 2010 I had the idea to do video feedback in HD, but it just wasn't feasible since

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affordable HD TVs don't have those necessary analog knobs. Except for very expensive high-end monitors used in color grading, the controls for hue / contrast / brightness / saturation are usually all on-screen. Not only is it difficult to change these quickly, but when you do change them an indicator pops up, ruining the feedback.

When everyone began video conferencing in 2020, I hooked up my DSLR (with HD video out) as a webcam. At one point I aimed the camera at the monitor, and this got me thinking about HD feedback again. I went on an internet search for HD monitors that do have analog knobs.

What I found was a game-changer: Panasonic BT-LH900 9" HD LCD field monitors. These little monitors are designed to be used at video production facilities or out in the field during video shoots. They probably cost a few thousand dollars new, but these were several years old and only cost a couple hundred dollars each on the aftermarket. And they had the knobs!

I figured I would desolder the potentiometers from the monitors, lengthen the wires, and bring them to the front of the contraption so I could move the camera and turn the knobs at the same time. But when they arrived, it turned out these monitors have a separate control panel with the knobs in it. This made it much easier to bring

the knobs to the front. I just needed to find a cable with the right number of wires and splice in the connector that plugged into the back of the monitor (Figures **B** and **C**). Perfect!

TELEPROMPTER GLASS
For this project I didn't want to just make video feedback, I wanted to make actual *fractals* — infinitely complex geometric patterns that are "self-similar" at any scale, like the famous Mandelbrot set. I looked online and found a simple solution (sweetandfizzy.com/fractals/diagrams.html) using a sheet of reflective glass at a 45-degree angle between two monitors. The camera looks at the upper monitor, but its output goes to the lower monitor too. It's the mirror-image reflection of the lower monitor mixed in with the same image on the upper monitor that creates the fractals.

At first I tried a plain sheet of glass, but that didn't work at all. I then tried using some tinting on the glass, but that cut out too much light. What ended up working great was teleprompter glass (Figure **D**), sometimes called *beam-splitter glass*. Teleprompter glass allows a certain amount of light to pass through, and a certain amount to be reflected (often 60%/40%). I'm using 50/50 glass: 50% light transmission, 50% light reflection.

FIELD GUIDE TO FIELD MONITORS

There are a few tricky things about these little field monitors. They only take SDI input to a BNC connector — but the output of DSLR cameras is HDMI. Blackmagic Design makes the perfect thing for this: an HDMI to SDI converter for $60, with one HDMI input and two SDI outputs (one for each monitor, like I said, perfect!). I found that my Nikon D810 worked with this setup, but my Canon XC10 did not. That's because these monitors need to see an *interlaced* signal, not a *progressive* one.

If you have trouble getting your camera to work with these monitors, you might need the more expensive Blackmagic Design Mini Converter UpDownCross HD — this little box converts from any video format to any other (and also adds a nice bit of delay, which can be interesting). Set DIP switches 1, 5, and 6 to "On" to create a 59.94 1080i output (I set the camera's output to a frame rate of 59.94 for the smoothest image).

The monitors have menus that you should get to know. You might need to switch the input to Auto, or to turn off the on-screen display of information (you don't want a little bar indicator coming up every time you adjust the knobs). Also, one of the knobs shares function between Peaking (a focus aid) and Phase (same as Hue). You'll need to change this menu setting if it's set to Peaking. There are a lot of other parameters you can play with, like sharpness.

Another tricky thing is that these monitors are usually powered either by a large, expensive, Anton/Bauer type battery, or by power from a camera through an XLR connector. I bought the power transformers my monitors needed (12V 2A), and found 2.1mm coax female to 4-pin XLR female cables from B&H Photo. This works great.

If you can't find these specific monitors, there are a few other Panasonic options like the Panasonic BT-LH80W 7.9", but they don't have the knobs in a separate module, so you'll have to carefully detach each of the potentiometers from the circuit board and lengthen the wires, then mount them in their own box.

BUILDING THE RIG

For the camera structure I used wooden sawhorses and mounted the PVC tube on a piece of wood on top of them (Figure **E**).

I built an L-shaped camera holder (Figure **F**) to mount the DSLR, using a standard tripod screw and washer. Make sure you can change your camera's battery and get to its controls without having to remove it from the mount. If the camera is hanging over to one side because of this, you can use a weight on the other side to balance things out.

It's important for the center of the lens to be aligned as perfectly as possible with the center of the dowel, so there's no wobble when the camera is turned. I made a mounting plate on the dowel with oversized holes, and made matching holes in the back of the L-shaped camera holder. Then I used large washers, long screws, and wing nuts to attach the camera holder to the mounting plate (Figure **G**). These large holes allow for the camera to be slid around a bit and repositioned

before securing it tightly.

It takes some experimenting to get the camera in the perfect position. A trick I discovered is to look at the lens in the refection of the teleprompter glass (make sure the glass is completely vertical), and rotate the camera. Pick a point in the reflection as reference, and you'll be able to see if the lens is moving up and down or right and left as you rotate the camera. Adjust the position of the camera mount on the plate accordingly. Once it's perfect, lock the wing nuts down tight (Figure **H**).

I use heavy green marine grease on the dowel to allow for really smooth movements of the dowel through the tube (you'll need to regrease occasionally). I also decided not to use a piece of wood as a yoke this time, but to just grab the end of the dowel instead. This seems to work best. Make sure everything is level so when the camera is moved back and forth through the tube it's not going up and down.

For the monitor structure I originally used wood, but later switched to T-slot aluminum. In both cases, I created a lower monitor platform where a monitor can slide back and forth on aluminum rails, and an upper monitor holder at a right angle to that where the monitor can slide up and down on tracks (the kind usually used for kitchen drawer slides). On the wooden structure everything is either screwed together or two-part epoxied. Instead of relying on precise measurements, I used the monitors when assembling this, kind of building around them, to ensure everything fit together properly.

I used 2×4s, but you might want to use something smaller. I first created two big L-shaped pieces by screwing two pieces of wood together at right angles. At the bottom part of these L-shapes I added another 2×4 across (this is what the structure rests on).

Next I glued on the outer drawer slide pieces and the lower rails (Figure **I**). Getting the right width for these lower rails is important (Figure **J**) — too wide and the lower monitor won't fit between them correctly, too narrow and it will fall down between them. I then glued the inner part of the drawer slides to the sides of the monitor.

When everything dried, I slid the upper monitor into the structure as you would slide a drawer into

place. I placed the second monitor to make sure the lower rails were the right distance apart, then took measurements so I could add the extra wood pieces to secure everything together.

For the upper monitor I used counterweights on string, much like a sash window uses. I did the same for the sheet of glass, so it can be moved and placed at any angle between the two monitors (Figure **K**), although 45 degrees is usually where you'll want it. I glued a couple of small pieces of wood extending out from the glass to attach these strings to. Finally, I used mounting tape to affix the two monitor control panels at the front of the device.

At first I was just looking over the top of the device at the upper monitor, but later I added a separate viewing monitor closer to me, resting on a piece of wood I added across one of the sawhorses. I recommend doing this, since it allows you to see what you're doing in much greater detail. The easiest way to wire this is to use an HDMI splitter on the HDMI coming off the camera before it goes to the HDMI to SDI converter box.
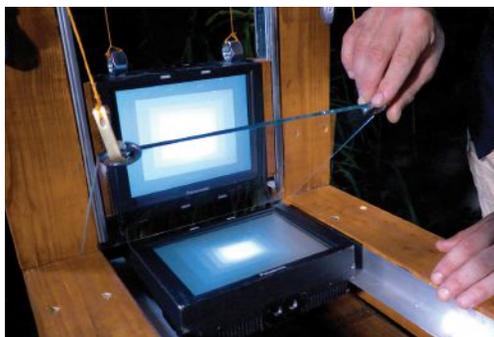
MAKING FRACTALS

To create fractals, there are a lot of things to play with. I find I don't mess around with the lower monitor's knobs as much as the upper monitor's (I ride the brightness on the upper monitor a lot).

Your DSLR will have different settings you can change. Increase the sharpness to create more stable images (but increasing it too much creates very line-y feedback). Play with the camera's contrast and saturation. Take the camera out of auto iris and auto white balance — if it's in auto iris the exposure will pulsate, and if it's in auto white balance the color will pulsate. You can play with different ISO and f-stop combinations, focal lengths, and auto versus manual focus.

Changing the position of the upper and lower monitor in relation to one another will make different fractals. Rotating the lower monitor 90 or 180 degrees will create different fractals too (for 90° you'll need to place something under the monitor to support it, since it will be off the rails).

Rotating the dowel smoothly and subtly can create very organic-looking feedback — things like sea creatures, plants swaying in the wind, etc. You can also create classic fractals, like the Sierpiński triangle.

It's best to operate this in a dark room, although a bit of ambient light is OK. You'll find very small movements of the knobs work best, and it might be difficult at first to create anything that looks good. Don't give up — it took me many, many hours to start getting interesting results. Of course, hit Record on the camera when you do!

GOING FURTHER

Since creating my original Video Feedback Kinetic Sculpture I've greatly increased the complexity of the device, adding more cameras and monitors so that two complete feedback rigs can now also feed back to each other (Figures **L** and **M** on the previous pages). For details, see the extended version of this article at makezine.com/go/video-feedback-machine.

Next, I'd like to re-create all this in 4K. The intricacy of the fractals would be amazing! But just like HD wasn't feasible in 2010, 4K monitors with the necessary knobs are not affordable now. Maybe in 2030 — but I'm hoping before then! I've started a GoFundMe to help make this a reality. ⦿

Check out thelightherder.com for feedback videos, more explanation, and a link to my complete build notes.
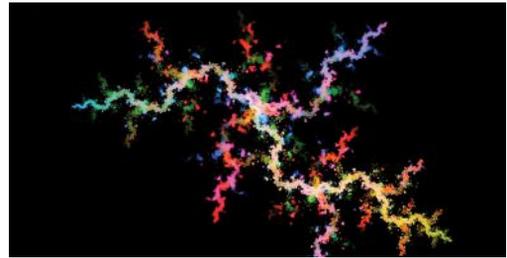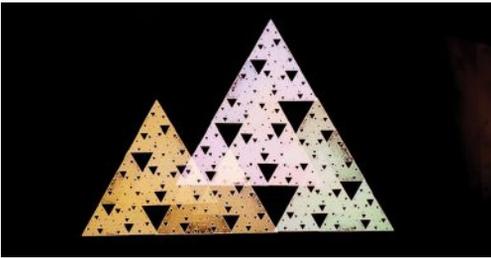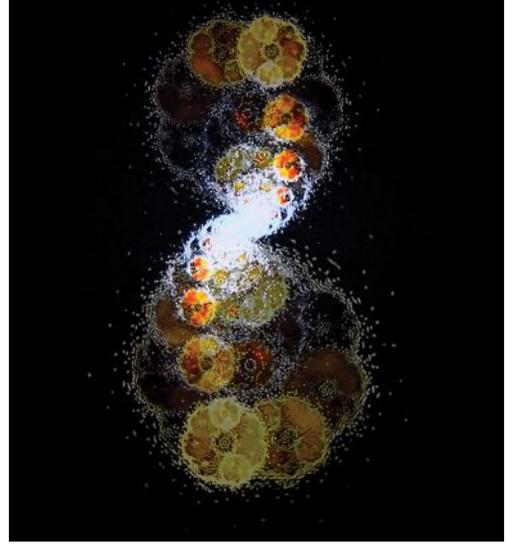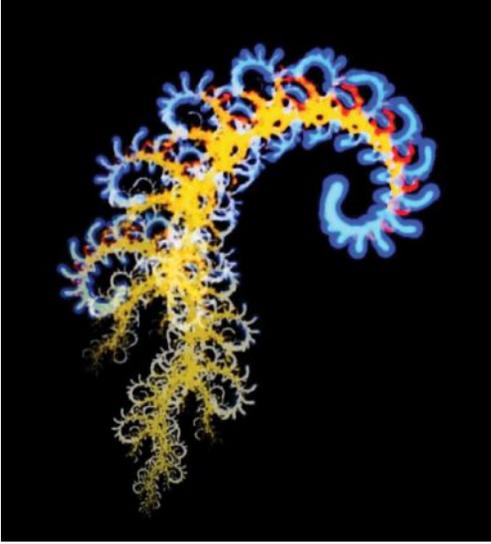
"Much like a musical instrument, the operator at the helm of this device plays it, but instead of making sounds, makes entire worlds, spirals within spirals, loops within loops, galaxies, classical fractal imagery and primordial organisms, leaves, trees, and insects. It really is the God machine." —*Dave Blair*
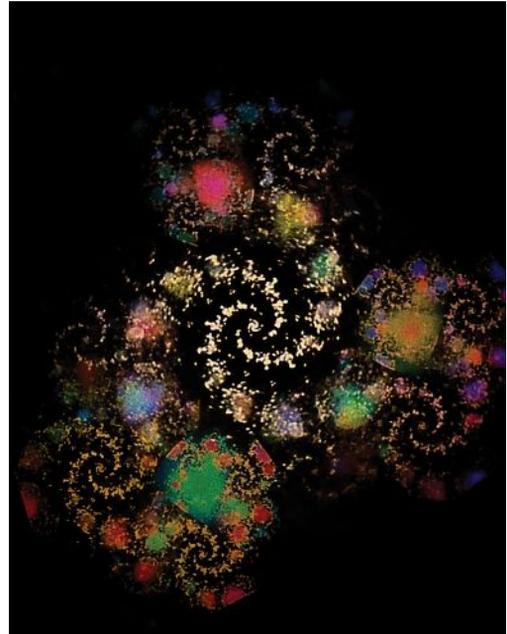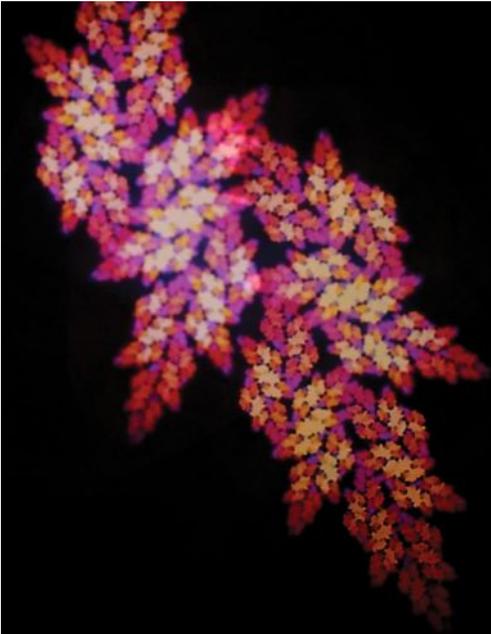
Building an Open Wave-Receiver

Experiment with no-power, low-budget crystal and foxhole radios using found materials and your local environment

Written and photographed by Shortwave Collective
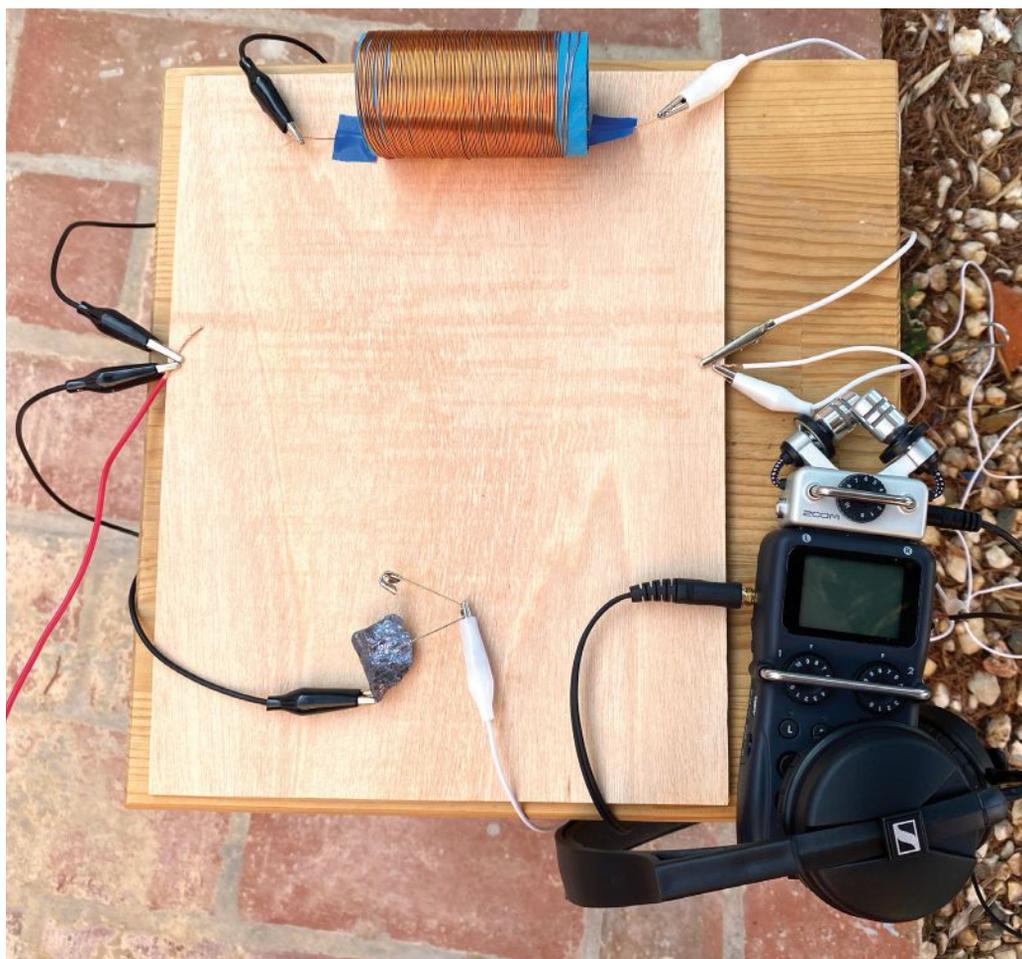
SHORTWAVE COLLECTIVE is an international, feminist artist group, established following a workshop at Soundcamp in May 2020. We meet regularly to consider feminist concerns within amateur radio and experiment with the radio spectrum as artistic material.

Shortwave Collective is a 10-member feminist art group founded in 2020. Collectively, we've been exploring the process of radio circuit assembly, considering the radio spectrum as an artistic material, and building self-powered radio receivers. Through an artist residency at Buinho Creative Hub in Portugal, we also spent a week of in-person and remote collaboration developing radio wave receivers and experimenting with designs with others in an open workshop.

Here are some of the lessons we've learned — and how to build your own radio wave receiver.

A FEMINIST APPROACH TO BUILDING RADIO

We support inclusive and participatory STEM education that transcends gendered stereotypes. We learn by collaboratively doing, with a goal of exploring creative possibilities. We believe in demystifying technologies and connecting with others by making and doing.

With our experimental radio projects we are interested in listening, in a broader sense. We measure success in ways other than by signal strength or tuning frequencies for the clearest sound. Instead, we are interested in all the sounds detected — data signals, talk radio, and *sferics* (radio bursts emitted by lightning) alike. We are fascinated by the idea that radio waves surround us, and being able to detect them and translate them into audio signals to listen to illuminates something about our environment.

What interests us about the radio wave receiver projects is their accessibility. It's a great way to learn about the physics of radio through practical experimentation.

SIMPLE RADIO CIRCUITS AND OPEN WAVE-RECEIVERS

Probably the most famous example of simple radio design in action is the *foxhole radio*. These were made from materials that were accessible to soldiers in the trenches (foxholes) during World War II. Though designs varied, they typically used a razor blade, pencil, and safety pin for parts. The official military vacuum-tube radios used during the war could be traced to reveal broadcast or reception locations, but foxhole radios operate without a power supply, and could not be

TIME REQUIRED:
1–2 Hours + More for Tuning

DIFFICULTY: Easy/Intermediate

COST: $15

MATERIALS
- » **Board** cardboard, foam, wood, or found object
- » **Alligator clip jumper wires (5)** aka crocodile clips; or use basic insulated wire (e.g. hookup wire) and 10 bulldog clips
- » **Cardboard tube** such as an empty toilet paper roll; or try an alternative hollow cylinder or glass bottle
- » **Magnet wire, enameled copper, 22–28 gauge (10 meters)** for the coil
- » **Pencil stub, 2" or less**
- » **Safety pin, medium sized**
- » **Razor blade or galena crystal** for the radio wave detector. Also try experimenting with a metal tent peg, iron pyrite (fool's gold), silicon, a germanium diode, or other metal objects. **LEAD WARNING:** Galena is a mineral that contains lead, and its dust is toxic if inhaled or ingested. However, the mineral can be handled safely if there is no lead dust present. Always wash your hands after handling galena. You can wear gloves and/or a dust mask to be extra safe.
- » **Metal tent peg** for a ground rod
- » **Wire, any type and length** to connect to ground. Longer allows you more flexibility.
- » **Speaker wire (30 meters)** or as long as possible; for the antenna
- » **Mini audio plug, ⅛", with wire leads**
- » **Speakers, battery powered** or audio recorder with strong preamp and headphones

TOOLS
- » **Electrical tape**
- » **Wire strippers**
- » **Wire cutters**
- » **Pliers**
- » **Candle or gas stove**
- » **Disposable gloves and a dust mask** if working with lead crystal

Members of Shortwave Collective testing their DIY radio wave receivers.

detected. Thus, soldiers used them as a way to safely keep up with the world from their posts.

Crystal sets are another form of early radio circuitry — a popular DIY project in the 1920s and even today — that relies on a mineral crystal (usually galena) as a radio wave detector.

We began our experiments by examining popular designs for radio receivers, such as crystal sets and foxhole radios. There is a basic recipe to build simple radio circuits, and we found many how-to examples and diagrams on websites, YouTube, and in books. Soon we found ourselves more fascinated with the process and experimentation, rather than the end product of replicating others' radio visions. Hence we refer to our project (and variations of it) as making an *Open Wave-Receiver*.

The fun of building an Open Wave-Receiver is in exploration and experimentation to find materials and environmental conditions with strong enough signal to receive radio waves. These radio constructions can be simple or souped-up, depending upon how the found materials vary the aesthetic or the elements of the circuit.

EXPERIMENTAL MATERIALS: FOUND, FENCES, AND TENT PEGS

Building Open Wave-Receivers enables DIY communications reception, and allows anyone to freely listen to the broad spectrum of radio waves around us. All you need are a few easy-to-procure supplies and, if you want to try it, a neighborhood fence or other receptive antenna proxy.

Why a fence? Antennas are necessary for radios to receive signals, and many things can be antennas. Fences can make great, and very long, antennas! Other materials can work well too; even a tent peg can become a useful part of a radio. Open Wave-Receivers allow us to explore the relationship between different combinations of materials, antennas, and radio waves, creating a new technology literacy, a new medium for artistic expression, and a new way to explore the airwaves in our communities.

We have found making Open Wave-Receivers to be a fun adventure. The ability to use simple scraps to create variety and personalization in each radio makes this a great maker project for anyone wanting to play with radio.

BUILD YOUR OPEN WAVE-RECEIVER

Let's get building! Here's how to make an Open Wave-Receiver from readily available materials. Building it will enable you to listen to airwaves and to reveal the invisible sounds that surround you — transmitted near and far — while becoming aware of how environmental and atmospheric conditions affect radio reception.

1. MAKE THE COIL

Start with your cardboard tube. Using a pin, poke a hole about 1cm from the rim at the top (Figure **A**) and bottom of one side. Thread 5cm of enameled wire through one hole, from the outside in (Figure **B**). Tape the wire to the inside of the tube to hold it in place (Figure **C**). You'll pull it out later to clip to the rest of your circuit.

Wrap your magnet wire approximately 120 times around the cardboard tube (or until you've used your 10 meters of wire). Ideally, the coil should be wrapped tightly and no loops should overlap (Figure **D**). Tuck the end of this wire into the second hole that you poked in the tube to keep it secure, with the end protruding from the tube.

Scrape the enamel coating off each end of the magnet wire using sandpaper or a blade to make bare ends for your connections. Make sure you

scrape around all sides!

Put a strip of tape along your coil to keep the wire secure (Figure **E**), then tape your coil to the board, on its side. Stick a crocodile clip onto one of the stripped ends of the coil (Figure **F**).

2. BEGIN THE DIODE

If you're using a razor blade, prep it by heating it until it turns blue. This creates a thin layer of magnetite, which is a semiconductor — an important part of your diode. Try steel blades such as vintage shaving types or X-Acto or Stanley knife blades. Hold the razor blade with insulated pliers and put it in the flame of a candle or gas stove until the topside turns blue.

Fix your blued razor blade or galena crystal (also a semiconductor) on top of the board, opposite to your coil, using glue or a loop of tape underneath it (Figure **G**, following page). We'll come back to finish the diode later.

> ⚠️ **CAUTION:** Galena contains lead. Its dust is toxic and must not be ingested or inhaled, so care must be taken to handle dust-free samples. Always wash your hands after handling mineral specimens.
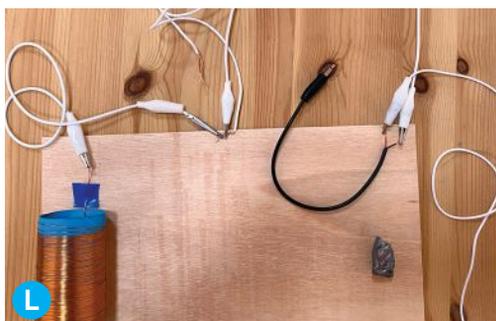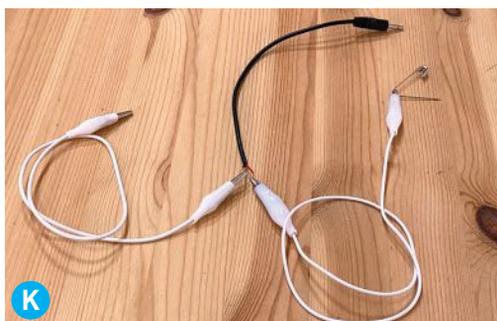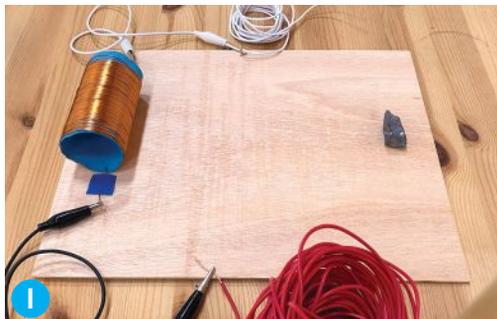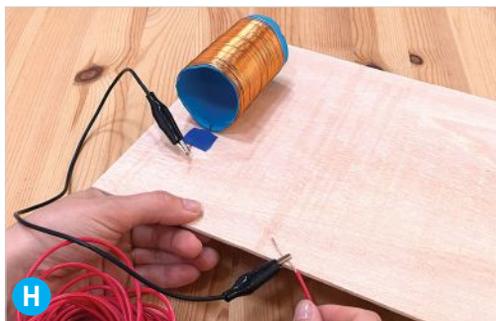
3. WIRE THE ANTENNA

Take your speaker wire (30 meters, or as long as you have) and strip the coating off 5cm at one end of the wire. This wire will be your antenna.

Connect the stripped end to the side of the board between the coil and the crystal or blade, using the other end of your crocodile clip. The clip should now be connected to the coil on one side, and the antenna on the other (Figure **H**).

String your antenna as high as you can in a long line, parallel to the ground, perhaps on a washing line in your garden, but don't let it touch any metal!

4. ADD A GROUND

Take your ground wire and if coated, strip a

section of the insulation off both ends. Wrap one end around a tent peg and push it into the ground outside, or if you're indoors, wrap it around a water pipe or radiator pipe. Use a crocodile clip to connect the other end to the middle of the board, above your antenna, between coil and diode.

Connect the other end of this crocodile clip to the loose wire at the top of your coil (Figure **I**). You've now made half a radio circuit.

5. CONNECT THE OUTPUT WIRE

Take your mini audio plug and strip the end of both strands (Figure **J**). Connect a crocodile clip to each end (Figure **K**).

On the black strand, connect the crocodile clip to the board so that it also connects with the
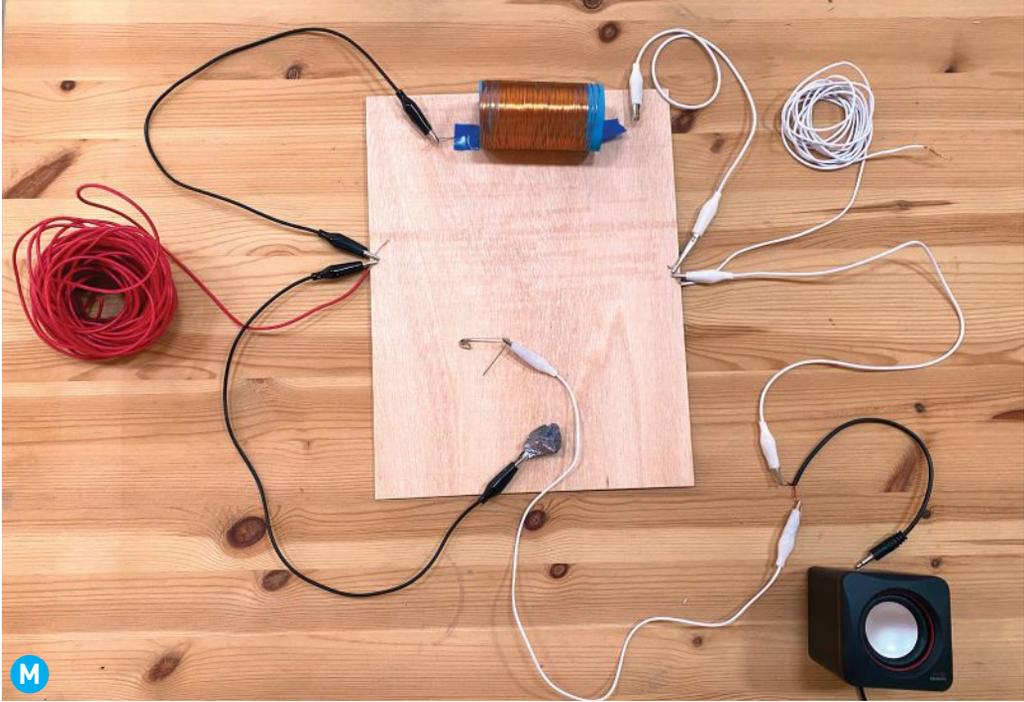
antenna wire, and touches the other crocodile clip positioned there (Figure **L**).

Plug your mini jack into your speaker.

6. FINISH THE DIODE

On the red strand of the audio plug, connect the crocodile clip to a safety pin. This is your *cat's whisker* — the other part of your diode.

Your circuit should now look something like Figure **M**. The white nest of wire is an unconnected ground and the red wiring is an antenna that has yet to be hung. In this model, the safety pin touching the galena crystal completes the circuit.

If you're using a galena crystal for your diode, touch your safety pin directly to your crystal to complete the circuit (Figure **N**). If you're using a blued razor blade for your diode, stab the safety pin into the pencil lead at the blunt end of your pencil stub so it sticks. Touch your pencil point directly to your razor to complete the circuit (Figure **O**). You've built a radio wave receiver!

TROUBLESHOOTING

This kind of radio is powered entirely by the energy of the radio waves, and so the signal is likely to be very weak. You might not hear anything at all when you first assemble your radio. Don't worry though! Wait until sunset, take your radio outside, climb a hill, and string your antenna up as high as you can in a straight line parallel to the ground — these are the conditions that we've found give the strongest signal.

If you're still not hearing anything, look again at the radio circuit diagram. Are your parts in the correct sequence? Have you stripped the ends of your wire enough that your connections are solid? Are all the necessary parts touching, without any extra unwanted contact points?

Some things to test:

- Turn the volume of your speakers up to the maximum. You should hear a hum that gets quieter when your cat's whisker touches your razor or crystal.
- If there's a loud hum, change your ground
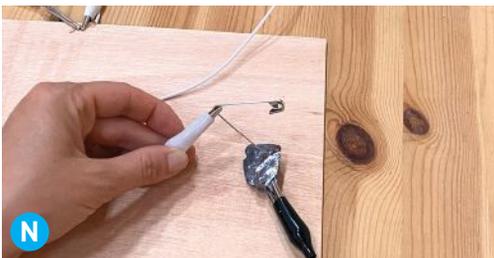
connection. If you're inside, connect to the metal of a radiator or water pipe. If outdoors, really drive your tent peg far into the ground and test it again.

- If your antenna is suspended in the air, change its position. Don't let your antenna wire touch your ground wire.
- Be patient with your diode. Try moving your cat's whisker very gently over the razor blade edge or galena crystal.

LISTENING

Your radio is not just location specific, but time, weather, and season specific! We've found signals to be strongest during "grey line" time — dawn and dusk. Dry conditions will also help.

We haven't included a tuning arm in this build — it's really part of our ethos to listen to the environment as we find it rather than look for a clean signal. (Foxhole designs with a tuning arm are well documented on the internet.) Though signal strength is important so you can test if your radio receiver is working, we feel it is just as exciting to listen to radio that is quiet, perhaps sounds out with strange beeps and hums, or has multiple stations competing rather than one clear signal. We are making audible the invisible radio waves around us and listening to them as they interact with our environment, rather than aiming to filter them to a predetermined mode.

EXPERIMENT!

- Try throwing your antenna up in the air, and hear how the volume increases as it flies.
- Is there a metal wire fence nearby that you could use as an extra long antenna (e.g., a fencetenna)? Clamp it with a crocodile clip.
- Try making a new coil by wrapping another length of enameled wire around a found object.
- See what metal objects you can swap your diode for to detect your signal.

Our experiments, and those by participants in our workshop at Buinho Creative Hub, Portugal, include:

- A rock at the center of the coil, altering its air-core properties (Carlos Alcobia) (Figure **P**)
- Cork bark local to the area as a base-board (Anaïs Schendekehl) (Figure **Q**)

HOW DOES IT WORK?

- The *antenna* picks up radio waves from all directions. Radio waves flow through the metal, creating an electric field, which moves along the length of the aerial to produce an alternating current.
- The *coil* exchanges current with the antenna. It stores the current and smooths it as it runs through the circuit.
- *Diodes* have two parts: a crystal or razor blade and a "cat's whisker." When the two parts meet they act as a gate or semiconductor, only allowing current to flow in one direction. They strip the radio wave, leaving only an electrical signal.
- The *phones* convert the electrical signal into sound.
- The *ground* allows the current collected through the antenna to dissipate and leave the circuit.
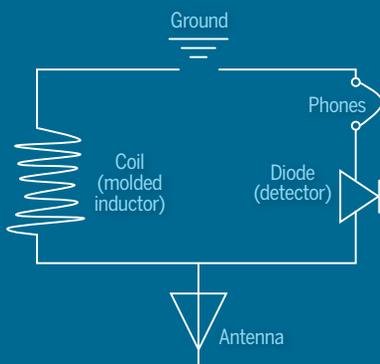
⚠ WARNING: If you're listening through headphones, be mindful that volume increases can be unpredictable. To avoid damaging your hearing, make sure you have a complete circuit with both diode elements touching before you put your headphones on, and take them off before these pieces are disconnected.
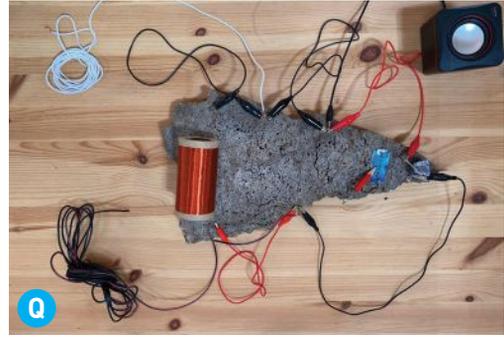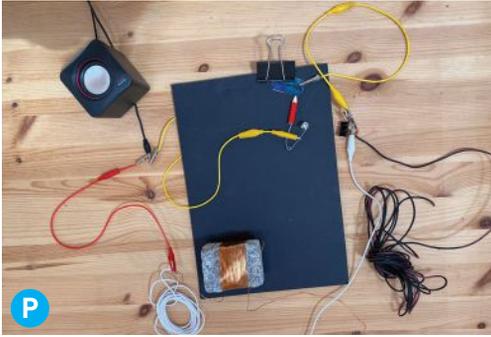
- A wearable radio in the shape of a hat, made from scrap material (Brigitte Hart) (Figure R)
- Tent-peg diode radio — replacing the razor/crystal and "cat's whisker" diode (Hart, Lisa Hall, and Hannah Kemp-Welch)
- Found-object diode radio (Hart, Hall, and Kemp-Welch)
- Roof radio — coil wrapped around a roof tile (Hart, Hall, and Kemp-Welch) (Figure S)
- Multiple diode design, with numerous rusty and blued razors built in (Georgia Muenster) (Figure T)
- Basket-weave coil for a crystal radio, work in progress (Kate Donovan) (Figure U)
- The Fencetenna project was a selection of radio receivers including foxhole, crystal, and shortwave receivers that were connected to fences as antennas, implemented by Shortwave Collective members Alyssa Moxley, Brigitte Hart, Georgia Muenster, Hannah Kemp-Welch, Lisa Hall, and Sasha Engelmann. Behind-the-scenes support came from members Sally Applin and Franchesca Casauay, with thanks to Soundcamp 2021 for inviting us to their event program. ◢

Shortwave Collective: Recordings, projects, and resources for DIY radio at shortwavecollective.net

Get Smart!

Top tips for your workshop — and your life — from our new book

Written by Gareth Branwyn • Illustrated by Richard Sheppard

Like its predecessor, *Tips and Tales from the Workshop Volume 2* draws from the best shortcuts, workarounds, and workshop practices found in the pages of *Make:*, on the Make: Community website (makezine.com), and amongst the wider online maker community.

My great hope is that this second collection will further the conversation even more. Please share with me your favorite tips, tool recommendations, and tales from your workspace (garethbranwyn@mac.com). I love to hear stories about how you learned a useful technique, how you came by a beloved tool, or about how a project went epically great or horribly wrong. Bonus points for project redemption stories.

Let's keep the conversation going …

SHOP ORGANIZATION

PEGBOARD TOOL SHELF
If you have scraps of pegboard, you can mount them on pegboard brackets as a shelf, and even use the peg holes to organize drivers and other similar tools (Figure A).

STORAGE CASES WITH REMOVABLE BINS
If lots of your components, hardware, and other bits and bobs are small, consider investing in plastic portable storage cases with removable bins inside. You can find these at online tool warehouses for $6–$10 each. I bought several dozen during my shop re-org and still have a few in the closet if I need more.

NO-ROLL PENCILS
Here's a great WDITOT (why didn't I think of that?): There are a number of marking tool designs and tool modifications that address the

A

problem of pencils, pens, markers, and scribing tools rolling off of workbenches. And then there's a little flag of masking tape (Figure **B**).

MEASURING AND MARKING
FINDING THE THICKNESS OF A WIRE
If you need to find the thickness of a wire but don't have a micrometer or calipers handy, wrap the wire around a dowel many times in a tight helix leaving no gaps between the coils. Now, measure the width, of say 30 coils (as an example), with an ordinary ruler and divide by that number (in this case, 30). The more coils you wind, the more accurate your measurement. Even if you've got top-quality digital calipers, it's more accurate if you use this wind-and-divide method than if you measure a single thickness.

DETERMINING IF HARDWARE IS IMPERIAL OR METRIC
If you're not sure whether a piece of hardware is measured in metric or Imperial, measure a dimension of it with your calipers and switch between mm and inches. The read-out that is closer to a whole number is likely the system of measurement used.

CUTTING
CORRECTLY SET YOUR BLADE DEPTH
When cutting material on a circular saw, make sure your saw's blade depth is set correctly. You might not think this really matters, but it does. You want your blade to only be ¼" to ½" below the bottom of the material you're cutting. This is not only safer, it helps prevent binding (the blade getting stuck) and allows for a more efficient cut.

PREVENT TEAROUT WITH MASKING TAPE
Sawing through plywood, especially with a jigsaw, can create a lot of "tearout" (where pieces of the material you're cutting give way along the edge of the cut). To prevent this, cover your workpiece with masking tape around the area of the cut. As a bonus, you can draw your cuts/project layout directly onto the tape.

GLUING
A TIP ABOUT GLUE TIPS
Have you ever noticed that many glue bottles

B

THIN
MEDIUM
THICK

C
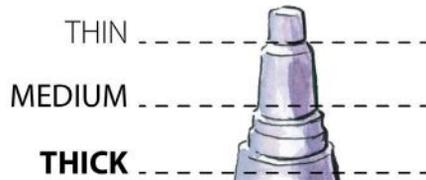
have stepped tips to their applicators? It may be obvious, but still worth pointing out, that these are there to allow you to cut the tip so as to control the amount of adhesive you wish to apply (Figure **C**).

LABELING GLUE FLOW RATES
As stated above, many glue bottle nozzles have two or three steps molded into them to indicate where to cut to establish a thin, medium, or thick flow. If you use a lot of glue in the shop, you might want to have three different bottles with different flow rates cut into their tips for different applications. Label them accordingly.

GARETH BRANWYN is former editorial director of *Make:*, a *Wired* alum, and a current contributor to *Boing Boing* and Adafruit. He also publishes the newsletter *Gareth's Tips, Tools, and Shop Tales* at garstipsandtools.com.

D
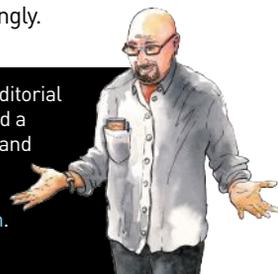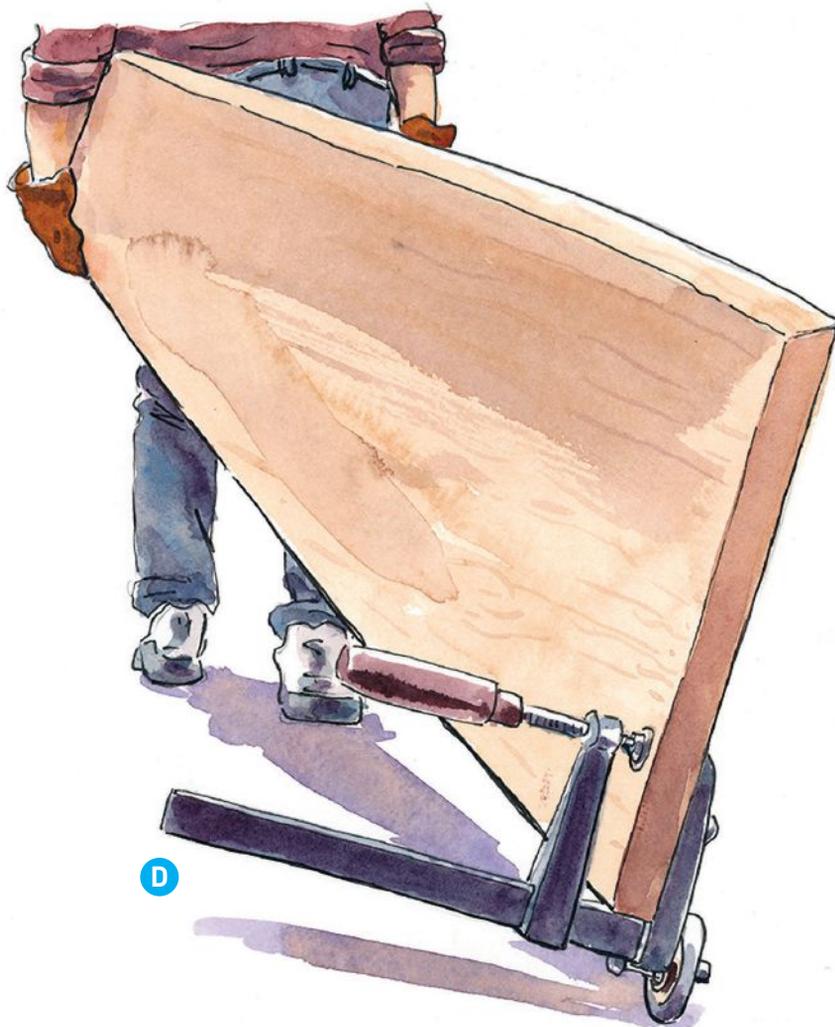
CLAMPING
TURN AN F-CLAMP INTO A WHEEL CLAMP
From the YouTube channel Create (youtube.com/c/create0) comes this brilliant idea. Attach a skate wheel to an F-clamp to create a wheeled clamp that you can use for moving large boards and sheet goods around (Figure D).

SIMPLE CLAMP RACK
Elisha Albretsen of the YouTube channel Pneumatic Addict (youtube.com/c/PneumaticAddict) cleverly used Strong-Tie connectors as the basis for her clamp storage wall. For bar clamps, she attached a short length of 2×4 to the Strong-Tie horizontally, and for spring and band clamps, she attached a vertical

length of 2×4 (Figure E). You can get Strong-Tie connectors — this style is called a *rafter tie* or *hurricane tie* — online and at any home store.

KITCHEN TIPS
GETTING CORK CRUMBS OUT OF WINE
It's inevitable that you're going to have floaters once in a while — pieces of cork that end up in your fancy (or two-buck Chuck) bottle of wine. An easy way to get them out is to use a straw (before serving). Stick the straw down into the bottle's neck and place the end of it over a cork crumb. Place your thumb over the other end of the straw to create suction. Remove the straw and lift your thumb to release the crumb. Repeat to remove any additional crumbs. Pour and enjoy.

KEEP THE TRASH BAG ROLL IN THE TRASH CAN

When I talk about tips, I'm always interested in the ones that stick. I read about this tip in *Family Handyman* magazine and have been using it ever since. I have a "thing" about emptying the trash (perhaps childhood trauma over being the family garbage man). I hate it. For a while, I was triple-bagging the trash can (so that you peel off the inside, full bag and you have another all ready to go). But then I read about just leaving the whole roll of plastic bag liners in the bottom of the can so that you can quickly grab a new bag after you remove the full one. Game-changer.
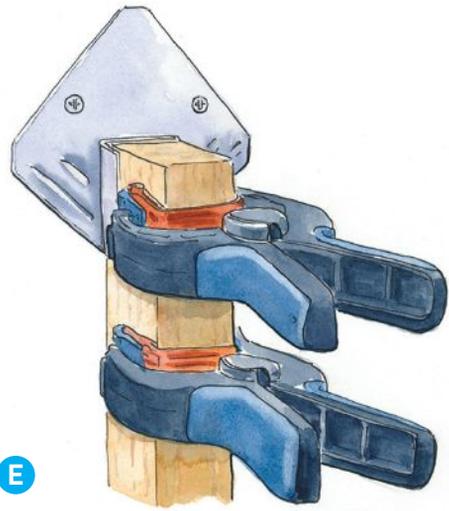
BURGER STACK HACK

How often do you get a restaurant burger, or grill one yourself, and before you're finished horking it down, the soggy bun has lost the will to live and disintegrates in your hands? Here's my fix for your fixin's. Don't place the meat directly on the bun, or the condiments on top of the lettuce. Place the lettuce between the meat and the bun, and between the condiments and the bun. No more soggy burgers.

LIFE HACKS

WHEELBARROW RECLINER

That moment when you realize that your wheelbarrow can also be used as a surprisingly comfy chair (cold beer optional). From the Homestead/Survivalism Facebook group (Figure **F**).
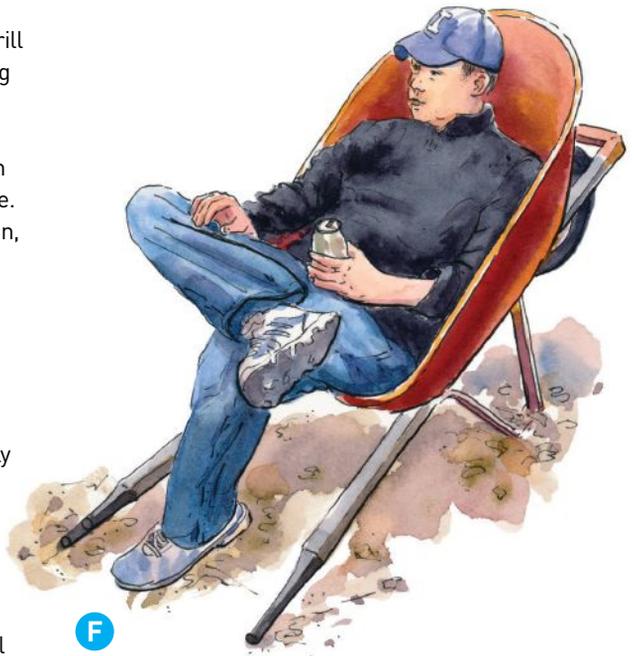
SODA CAPS AND CONTACT CASES

Make: pal Miguel Valenzuela made a wonderful little discovery and posted it to Facebook. A soda bottle cap's threads perfectly match those of a contact lens case (Figure **G**). The discovery was actually made by his 2½-year-old daughter, Charlotte. In response to the posting, Lenore Edman of Evil Mad Scientist Labs reminded us that you can also use contact lens cases as tiny parts holders, especially for tiny surface-mount components. ✦
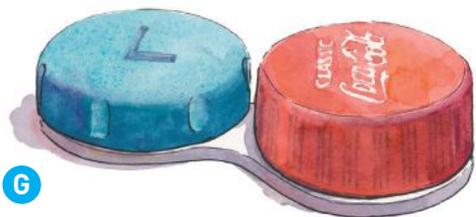
Auto-Return Parachute

This GPS-guided recovery chute steers itself home — you'll never chase a payload again!

Written and photographed by Yohan Hadji

YOHAN HADJI is 17 years old and French. He wants to use flying robots to change the world. Connect @YohanHadji and youtube.com/YohanHadji.

TIME REQUIRED: Several Weekends

DIFFICULTY: Advanced

COST: $300–$400

MATERIALS

- **Steerable parachute, about 0.8m² area** You can sew your own ram-air parachute from F-111 nylon fabric following the resources at github.com/YohanHadji/R2Home, or buy a commercially available single-skin RC paraglider wing, such as Cefics SWIFT. (A custom wing for R2Home is coming soon!)
- **R2Home 3D-printed parts** Download the free files for printing from the GitHub repo.
- **M4 threaded rods, 1m long (2)**
- **Machine screws, M3: 5mm (5), 10mm (5) and 18mm (5)**
- **Machine screws, M4: 20mm (10) and 30mm (10)**
- **Nuts: M3 (10) and M4 (30)**
- **Aluminum plate, 4mm thick, 10cm×10cm**
- **Phenolic rocketry tube, 3" diameter, 30cm long** cut to 22cm
- **Teensy 4.1 microcontroller**
- **R2Home PCB and SMD components** Get the free PCB files and parts list from the GitHub repo.
- **JST-GH PCB connectors: 2-, 3-, 4-, and 6-pin**
- **LiPo batteries, 3S, 500mAh (3)** one to fly and two spares
- **FPV camera** RunCam Split 4
- **GPS module** Matek SAM-M8Q
- **Barometer sensor** BMP280
- **Winch servos (2)** Parallax Feedback 360º High-Speed Servomotor, #900-00360
- **Telemetry transmitter and receiver** 3DR Radio or similar, such as Holybro #17012
- **microSD cards, 16GB or more (2)**
- **Micro servomotor, 9g, metal gear**
- **Ultra bright NeoPixel RGB LED**

TOOLS

- **3D printer**
- **Drill press**
- **CNC mill** or a metal file
- **Screwdrivers**
- **Zip ties**
- **Sandpaper**
- **Multimeter**
- **Soldering iron**

TOOLS USED FOR TEST FLIGHT:
- **DJI S800 drone**
- **A good partner to help :)**

Some people love to launch model rockets, and personally I've always wanted to launch a stratospheric balloon up to "the edge of space." We don't exactly do the same thing for the same reasons, but there's one thing we would all love: to have our payload come back to Earth exactly where we want. Not in the trees, not 200km away, not on a road or in a lake.

How could hobbyists, scientists, and meteorological companies simplify the recovery of their craft?

R2Home is part of the solution — a smart, GPS-guided parachute recovery system. As a generic and fully autonomous flying robot, its job is to make sure your payload comes back exactly where you want it to land. Just send it. R2Home takes care of the rest.

Precisely control the descent trajectory of your rocket or weather balloon experiments and you have more valuable data. Launch many more of them for lower cost; recovery isn't a problem anymore and you've opened the way to reusability.

We can also dream bigger: Drop it around Mars and you've got the first robotic explorer of Mars' upper atmosphere!

Sixty years ago humanity reached space. The next space race is about coming back to Earth in a smart, guided, and safe way.

THE CONCEPT

Let's suppose you are the R2Home robot. The balloon above your head just exploded, or your rocket separated — uh-oh, looks like you're in freefall! Your mission is to deploy a steerable parachute, and guide it to the desired landing point (Figure A). Alright, OK, but how do we get there?

A

Drogue parachute

R2Home body tube

Steerable wing parachute
in deployment bag

B
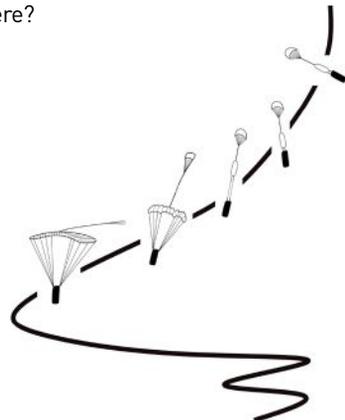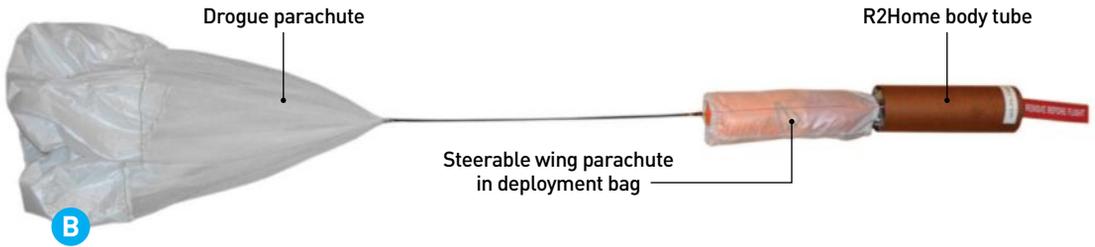
HOW DOES IT WORK?
There are three main components, shown in Figure **B** (from left to right): the pilot or drogue chute, the steerable wing parachute folded in its deployment bag (aka "D-bag") and the R2Home body tube containing all the mechanics and electronics.

DEPLOYING THE WING
How do we deploy the wing, or in other words, how do we go from Figure **C** to Figure **D**?

The wing parachute is folded in the D-bag following a precise pattern to avoid tangles during deployment. We need a way to get the wing out of the D-bag at the right time or right altitude. The drogue chute is used as an extraction force. The deployment mechanism allows us to use this force at the right time.

Before deployment, the drogue is pulling on the orange line on the D-bag (you can spot it in Figure **E**), which is connected to the deployment mechanism in the body tube. As soon as the deployment is triggered, this orange line is released and the D-bag is pulled away from the body tube. The wing chute's lines are then pulled from the bag until they are tight and the chute is pulled from the bag (Figure **F**).

Thus, once the system with the drogue chute has reached its terminal velocity, i.e. about 5m/s when the drag force is equal to the weight, the force exerted by the drogue on the D-bag is almost directly the weight of the system.

The drogue chute is an interesting problem. It's as big as possible for safety — if the wing deployment fails, R2Home is still falling slow enough to avoid destruction. However, after wing deployment, the drogue remains attached to the wing, and therefore if it's too big, it will prevent the wing from flying properly. The solution is to use a "magic" or collapsible drogue chute, which

C

D

E

F

G

H
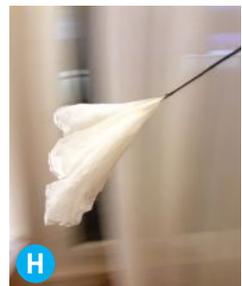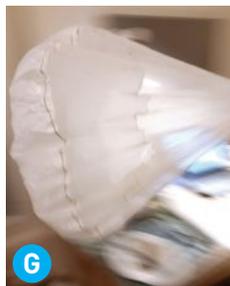
can be both large before deployment, and small after (Figures and).

The automatic deployment of the parachute is triggered by a condition of vertical speed, deduced from the barometer, and altitude, merged between the GPS and the barometer. For example, if we want to deploy the canopy at 100 meters, we look to see if the vertical speed is lower than −3m/s and the altitude lower than 100m, and then the deployment is triggered.

FLYING AUTONOMOUSLY

Alright — so your parachute is opened, well done! Now we want to steer it autonomously to the desired landing point. The first question is how to steer the parachute?

With R2Home you can use a few different types of parachutes. Ram-air parachutes (Figure) or single-skin paragliders (Figure) are both good solutions; the first one is easier to deploy, the second one flies better. The good news is that we can steer both of them the same way!

We use brake lines connected to the right and left trailing edges of the wing. When the right brake line is pulled, the right side of the parachute is braked, and the parachute turns right (Figure). And vice versa for the left line (Figure). To turn, you have to pull one line, and release the other, in a very precise way, over a distance of about 8cm, using servomotors.

A normal servo typically has a rotation of between 90° and 180° (120° on average). However, a rotation of 120° on a small enough spool to fit in R2Home's tube volume would move the brake line only about 2.5cm — not enough.

The solution is to use a continuous rotation servo with a feedback sensor which gives us the position over 360°. This servo has a microcontroller integrated inside (you can see its USB-C connector in Figure) to control the rotation speed of the servo to reach the desired position with a PID control program. It is thus possible to control this servo like a normal servomotor, but on a range of about 360°. This way, we can pull our line more than 8cm. A 3D-printed drum prevents the line from getting out of the spool (Figure).

Now that we can steer the wing, we have to fly it to the right landing point with an autopilot, so

that everything is fully autonomous. R2Home's onboard flight computer (Figure) is based on a Teensy 4.1 microcontroller. Its purpose is to manage the entire system autonomously: to deploy the wing at the right altitude, steer the
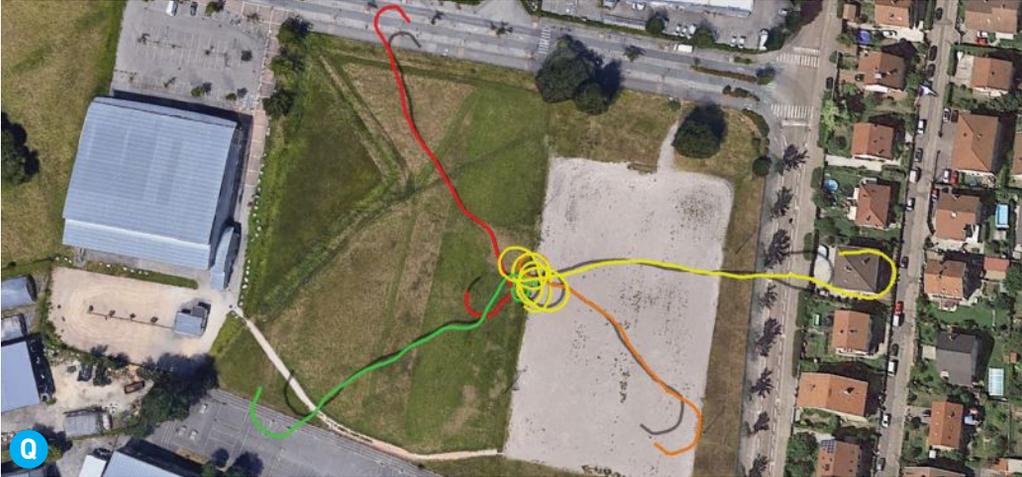
wing, record all flight data at different frequencies depending on the flight mode (climb, descent, canopy flight, etc.), and send data to the ground by radio telemetry (at a lower frequency to save power). It also contains several different power supply circuits, to avoid conflicts between the motors and the control electronics.

The autopilot works as follows: We're trying to move along a course from our current position to our landing position. To move in this direction, we want to correct our current direction, given by the GPS as "course over ground."

Once the direction error is calculated, a command can be deduced — turn left or right — using a PD (proportional-derivative) control program. The larger the error, the larger the command, but if the error decreases very quickly, the command is also decreased to avoid overshooting the desired direction.

Figure **P** shows an example of the autopilot's work with real flight data. The yellow curve is the desired direction, and the red curve is the measured direction. The autopilot is engaged at the very beginning of the graph. The variation around T+100s represents the moment when the system flies exactly over the desired position, and thus the desired direction changes by 180° very quickly.

We can see that the error is corrected without oscillations, but also that the parachute's direction has a slight delay from the command given to it. This delay is almost impossible to remove; a paraglider or parachute wing simply takes some time to turn.

The ultimate test for the autopilot is to bring the system back to a landing point from all directions (Figure **Q**) and see how good it is at coming back home!

BUILDING YOUR OWN R2HOME PARACHUTE

Inside the tube, the R2Home assembly (Figures **R**, **S**, **T**, and **U**) includes the Teensy flight computer, GPS module, and altitude sensor, the
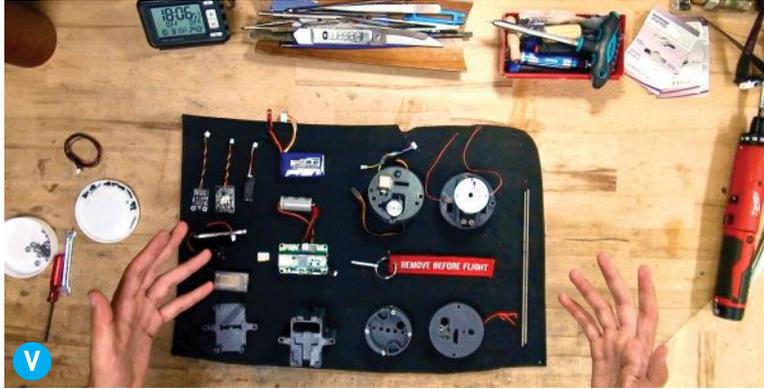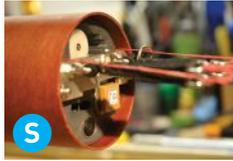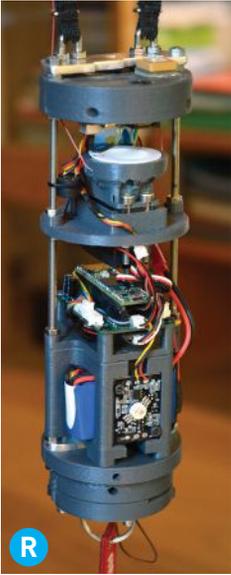
steering servos and a micro servo to release the D-bag, a LiPo battery, and an ultrabright RGB LED — all secured with 3D-printed parts, threaded rod, and various hardware.

Find a complete assembly video on my YouTube channel (Figure V; link in bio) and more info on my project page hackaday.io/project/176621-r2home, but here are a few tips about two major things: rigging your drogue and D-bag, and folding your wing chute for proper deployment.

DROGUE CHUTE AND DEPLOYMENT BAG

The drogue chute is made out of a round piece of F-111 fabric and another round piece of mesh. It's connected with two lines: a thread and a sleeve. The thread is connected to the apex (top) of the chute and runs inside the sleeve (Figure W). The sleeve is only connected to the D-bag. As soon as the wing chute is out of the D-bag, the sleeve is free, and the drogue is closed.

The D-bag is made out of a rectangular piece

of F-111 fabric and sewn like an umbrella cover, if you want to find an example. The width of the rectangle is the perimeter of the D-bag you're doing plus your stitching margin.

FOLDING THE WING

This method of folding the wing is proven to work with R2Home (Figure X), but there might be other ways to do it. First, get it flat on the ground. Then pull the wing and tension all lines. Then gather it into a cylinder while making sure the tip of the wing is always either on the top or the extreme side of the cylinder. You don't want anything (fabric or line) to be after the wingtip.

Y

Z

Aa
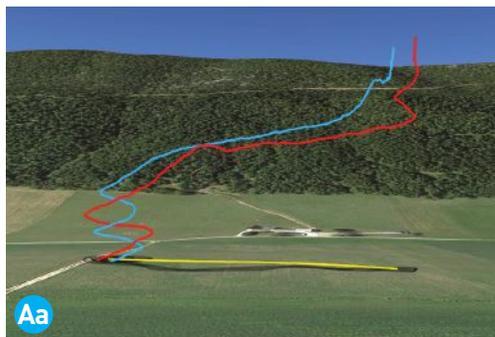
Then fold the cylinder in half and compress it into the D-bag. Finally, place all lines in the spot provided for in the bag.

HOW TO TEST IT?

Testing the system is essential. It took me more than a year of test flights to develop R2Home. At first I attached a motor and prop to it, but the best solution I found is to drop it from a drone. We need a drone big enough to lift about 1kg, and if possible with autonomous flight capabilities. I've been using a secondhand DJI S800 hexacopter (Figure Y) with an INAV flight controller, modified to remotely trigger the deployment of R2Home.

We use this drone to lift R2Home up to 100m high, and 100m away (Figure Z). For the test to be successful, R2Home has to autonomously deploy its parachute at the right altitude, and steer it to the landing point.

Figure Aa shows the GPS traces of two flight tests on the same day, from a similar drop location. The wind was coming from the left of the image, so R2Home had to fly upwind to the landing point. The yellow line is the straight line between drop and landing, about 125m long.

For your flight tests, find the largest field you can — either public but not crowded, or private and you know the owner. If your field is too small, during your first (often failed!) tests you risk losing your system too often.

And here we go — R2Home is back home (Figure 8b), after deploying its parachute at the right altitude and flying all by itself until reaching the desired landing point with precision!

Bb

The autopilot flies in a straight-ish (curved due to the wind) line toward the desired landing point. Once this point is reached, it will naturally rotate around it until landing is achieved.

WHAT'S NEXT?

The R2Home system is now proven to work on low-altitude flight. It took more than a year of flight tests and failures (and learning!) with several prototypes to get there. Next on the list:

- Testing from higher altitude, ~1km, using a balloon or a model rocket
- A smarter autopilot with waypoints and multiple "safe zones" where it can land
- Supporting *you* in building your own R2Home (Figure Cc), to get it flying all over the world!

My ultimate goal is to continue this project up to a flight at 30km altitude, setting new records for such a tiny robot and making R2Home, with your help, a useful and much-used system to make science easier and help us explore the world! ◗

Michael Vergalla

Cc

You too can build your own R2Home, like these built by fellow tester Michael Vergalla!

Intruder ALERT!

Build this alarming project two ways — from bare components and from a Pico microcontroller

Written by Charles Platt with Fredrik Jansson

9VDC

470
555
0.01µF
470
10K
10K
10µF
10K
1N4148
0.47µF
47K
10K
100µF
470
47K
10K
0.47µF
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470

47K
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470
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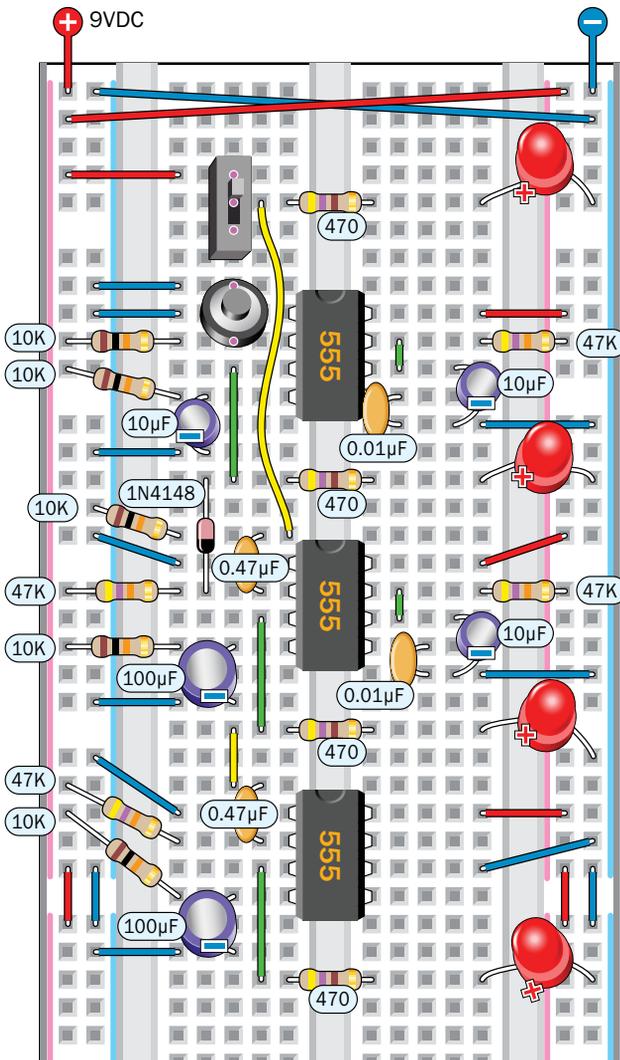
This project is adapted from the staggeringly popular *Make: Electronics Third Edition*, which has been completely re-re-written with most photos and schematics replaced and updated! makershed.com/platt

Make: ELECTRONICS THIRD EDITION Charles Platt
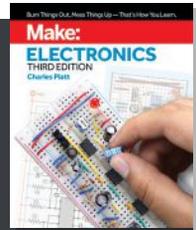
TIME REQUIRED:
1–2 Hours

DIFFICULTY: Intermediate

COST: $20-$30

MATERIALS
» **Resistors:** 470Ω (4), 10kΩ (5), 47kΩ (4), and 470kΩ (2)
» **Capacitors:** 0.01µF (2), 0.47µF (2), 10µF (3), and 100µF (2)
» **LEDs (4)**
» **555 timer ICs (3)**
» **1N4148 diode (1)**
» **Tactile switch (1)**
» **SPDT or DPDT switch (1)**
» **9V battery and battery clip with leads**
» **Solderless breadboard**
» **Raspberry Pi Pico microcontroller (optional)**

During 2021 I started writing a third edition of my book *Make: Electronics.* One of the pleasures of this task was that I could rethink all the circuits, and with the benefit of hindsight, I saw how to simplify one project in particular: The intrusion alarm.

You'd think an alarm should be easy enough. Just place some sensors on doors and windows, wire them to a beeper, and — job done!

But it's not so simple. First, the alarm has to notify you that all the doors and windows are closed before you activate it. Then you need a delay (which I call the Exit Delay) so that you can leave the area without causing the alarm to start making a noise. When you come back, you need another delay (which I call the Last Chance Delay) to prevent the alarm from beeping or wailing till you have a last chance to switch it off. Figure **A** shows what I mean.

The word *delay* suggests a component that measures time. That could be a timer, couldn't it? In fact you can build this circuit entirely with three 555 timers — the old-school chips that have outsold all other chips ever made. Along the way you'll learn about pullup and pulldown resistors, diodes, and coupling capacitors, which can be useful in many other applications

In Figure A, IC1, IC2, and IC3 are acronyms for *integrated circuits*, which are the three 555 timers.

REED SWITCHES

A basic alarm installation often uses pairs of sensor modules such as those in Figure **B**. One module contains a magnet, while the other contains a **reed switch**.

This type of switch consists of a sealed glass capsule containing two magnetized contacts. A magnetic field will push them together (if they are normally open) or pull them apart (if they are normally closed). Figure **C** shows what a reed switch looks like, in case you are wondering, and Figure **D** shows how the sensor works. Letters N and S stand for north and south, the two poles of a magnet.
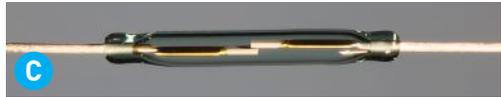
For an alarm circuit, you will need the type of sensor with contacts that are normally open. You mount each magnetic module on a door or a window, and you mount each switch module on the adjacent frame so that it almost touches the

After you check all sensors are closed, the Exit Delay begins.

| **Exit Delay** | IC1 |

When the delay ends, the alarm is now armed.

When any sensor is opened, the Last Chance Delay begins.

| **Last Chance Delay** | IC2 |

During the Last Chance Delay, the alarm can still be shut off.

If the alarm has not been shut off, the audio output begins.

| **Audio Control** | IC3 |

A Each integrated circuit is a 555 timer.

Overview of alarm behavior.

The two modules of an alarm sensor.

Closeup of a reed switch which is about ½" long.
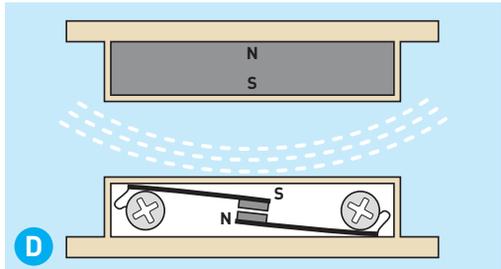
How a reed switch works inside an alarm sensor. The dashed lines represent a magnetic field.

CHARLES PLATT is the author of the bestselling *Make: Electronics*, its sequel *Make: More Electronics,* the *Encyclopedia of Electronic Components Volumes 1–3*, *Make: Tools*, and *Make: Easy Electronics*. makershed.com/platt

FREDRIK JANSSON is a researcher in physics and weather modeling, and coauthor of the *Encyclopedia of Electronic Components Volumes 2 and 3.*
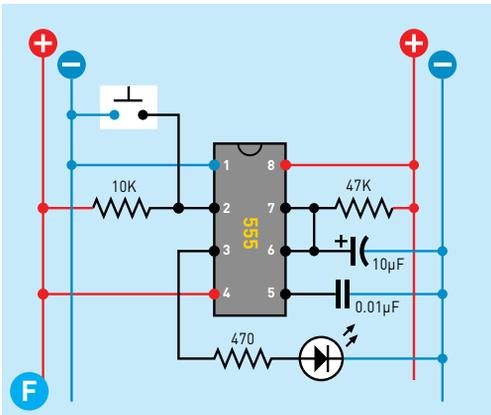
E

Alarm wiring using magnetic sensors.

F

Test circuit demonstrating a timer as you would wire it on a dual-bus breadboard, with a pullup resistor.

G

The circuit in Figure F has been rewired to work with normally-closed alarm sensors and a pulldown resistor.

Charles Platt

magnetic module when the door or the window is shut. In this way, the magnets hold the reed switches closed.

In Figure E, the magnetic modules are blue rectangles while the switch modules are red and the alarm is in a green box. Because the switches are wired in series, if any switch opens, the continuity of the circuit is interrupted. This is known as a *break-to-make* type of circuit, because any break in the circuit — at any window or door — makes the alarm go off. Another advantage is that the circuit will also be triggered if someone tries to interfere with it by cutting the wire.

TRIGGERING A TIMER

Figure F shows a breadboard-layout test circuit for a 555 timer in *monostable mode*. Pin 2 is the "Trigger Pin," and when its voltage is pulled down below ⅓ of the supply voltage, this triggers the timer, which emits a high pulse from Pin 3, the Output Pin. The duration of the pulse is controlled by the 47K resistor and 10µF capacitor, which create a pulse of about 3 seconds. You can learn more about 555 timers from any introductory source about electronics (including my own book, naturally).

You must not allow Pin 2 to float at an indeterminate voltage, so a 10K *pullup resistor* keeps the pin near the voltage of the power supply until the pushbutton bypasses it with a direct connection to negative ground. Pullup and *pulldown resistors* are important features of countless circuits.

I wanted to use the timer in this mode as IC2, the Last Chance Delay timer, but I encountered a problem. When a door or window is opened in an alarm circuit, it doesn't make a connection, like the pushbutton in Figure F. It breaks a connection. I had to revise the circuit as in Figure G, where I have indicated the sensor switches as three normally-closed buttons. Because they are attached to the positive power supply, Pin 2 is normally positive, as shown. But if any of the sensors are opened, the positive connection is cut off, and a 10K pulldown resistor makes Pin 2 negative, which triggers the timer.

Next I ran into another problem. What if someone should open a door or window, and leave it open indefinitely? The voltage on Pin 2 will
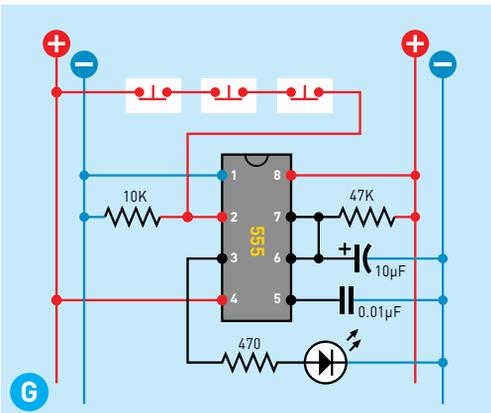
stay low indefinitely, creating a Last Chance Delay that lasts indefinitely. If the delay doesn't end, the alarm will never start to make noise. Not good!

My answer was to insert a *coupling capacitor* and a pullup resistor, as in Figure **H**. So long as all the switches are closed, everything is stable. The voltage to Pin 2 remains positive, and the timer doesn't do anything. But when a switch is opened, the pulldown resistor (on the left) takes over, causing a short negative pulse to pass through the capacitor.

This is the odd thing about capacitors. They block DC current, but if you change the voltage suddenly on one side, a short pulse of current seems to emerge on the other side. This is known as *displacement current*, and at the risk of promoting myself, I have to tell you that I explain this concept elsewhere in my book *Make: Electronics*. The concept is often misunderstood, so I have included a thorough explanation in the Third Edition.

This circuit in Figure H will only work if the resistors and the capacitor are chosen correctly. How did I know what values to use? Well, I didn't! I just tried various values while using an oscilloscope to check the voltage on Pin 2, until I found an arrangement which worked reliably. A pullup resistor of 47K, a pulldown resistor of 10K, and a capacitor of 0.47μF was a good combination.

> **NOTE:** Oscilloscopes are much cheaper than they used to be. For around $100, you can buy either a handheld oscilloscope or a "virtual oscilloscope" which plugs into a USB port on a computer and generates a higher-res display. This is a very valuable tool if you want to build circuits.

Maybe my arrangement with two resistors and a coupling capacitor seems complicated, but it keeps the timer happy, and if you want a circuit to function reliably, the components must be happy at all times.

THE EXIT DELAY

Having figured out how to trigger IC2, my next step was to think about IC1, which creates the Exit Delay. During this delay, IC1 has to prevent IC2 from being triggered when you open a door to leave the area.
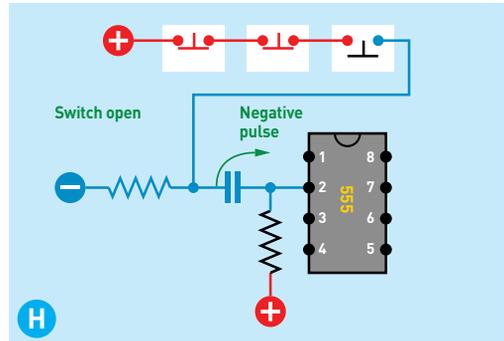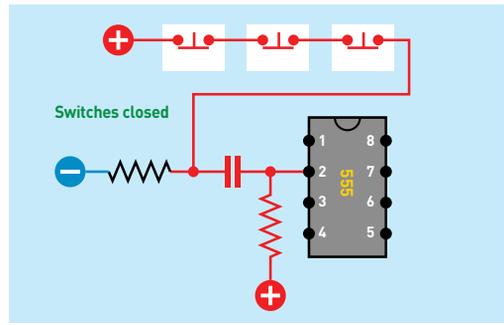
Simplified schematic showing how a coupling capacitor works.
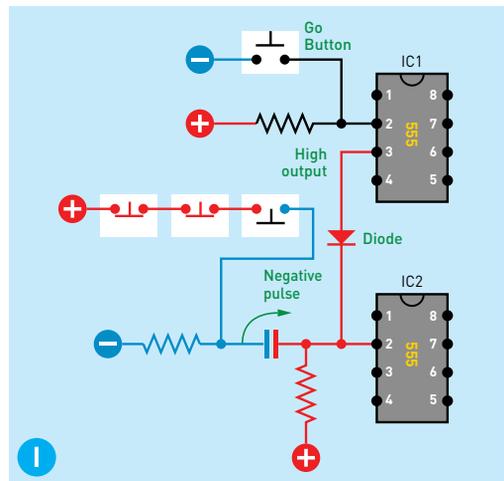
IC1 now controls IC2 through a diode.

Figure **I** shows a simple way to do this. First, you press the "Go Button" when you're ready to go, and this starts a single high pulse as the Exit Delay from IC1. (No need for a coupling capacitor with the Go Button, because you will only press it briefly. You won't sit there holding it down.)

The high output from IC1 passes through a diode that connects directly with the Trigger Pin

of IC2. While this is going on, if an opened door or window creates a negative pulse, it's not powerful enough to get through, because the voltage through the diode overrides it.

How could I know this? By testing it. That was the only way.

I added a diode because the output from IC1 is normally low, when it isn't being triggered, and I didn't want the low output to get through to IC2.

THE SEQUENCE

The sequence may be hard to understand, so I'll sum it up. You press the Go Button to start IC1, and it generates a high output that lasts long enough for you to leave the area. Now IC2 doesn't notice if you open a door, because the voltage from IC1 prevents IC2 from being triggered.

At the end of the exit delay, IC1's output goes low, but this is blocked by the diode, so it doesn't have any effect on IC2. The pullup resistor now keeps Pin 2 high on IC2, but if any door or window is opened, the negative pulse breaks through and triggers IC2.

When IC2 is triggered, its output goes high for a limited time — long enough for you to switch off

the alarm, if you're the one entering the space. If you don't switch off the alarm, the output from IC2 goes low at the end of its cycle, and this will start some noise — somehow. I haven't described that part yet.

Figure **J** may help to clarify the sequence, in theory at least.

THE NEVER-ENDING NOISE

When I saw that the output from IC2 would drop from high to low at the end of the Last Chance Delay, I realized I could couple it through (guess what) another coupling capacitor, to trigger IC3. This connection is shown in Figure **K**, which shows the components at a moment when none of the timers is active.

Now, let's suppose there is an intruder, and IC2 triggers IC3. How long should its output stay high? Well — indefinitely! You want the sound of the alarm to continue until an authorized person (such as you) turns it off.

Fortunately there is a way to wire IC3 so that when its output starts, it never stops. This is known as *bistable mode*. The timer will deliver a high output until you shut it down. The secret is to
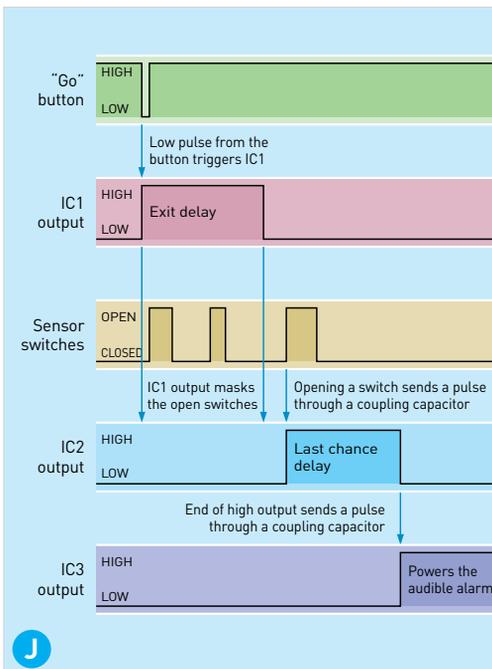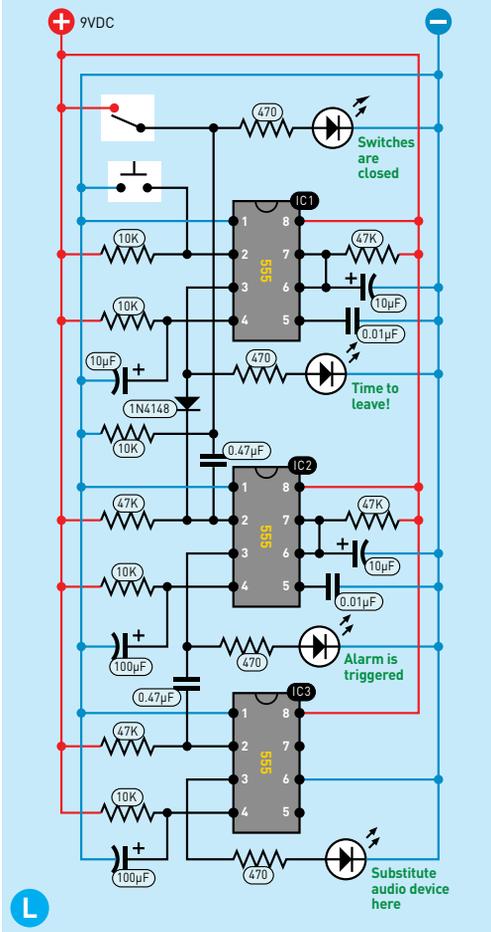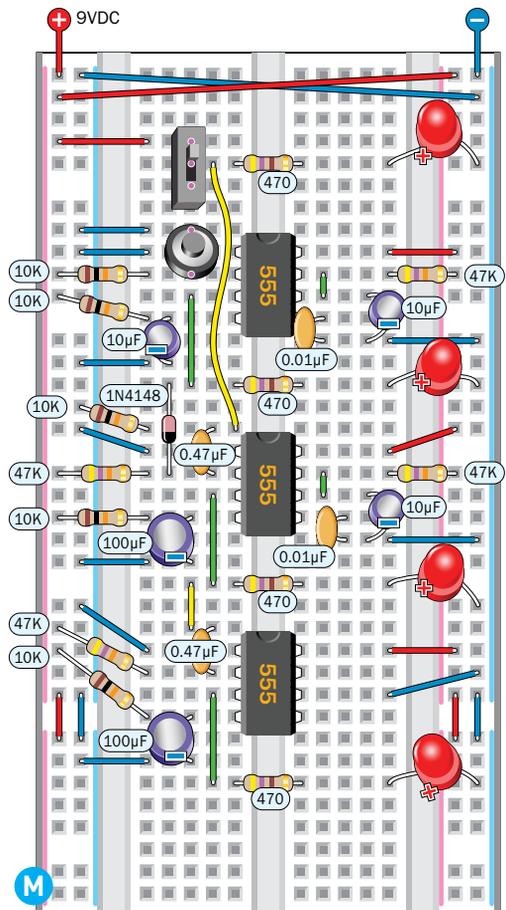
Sequence of events when the alarm is working.
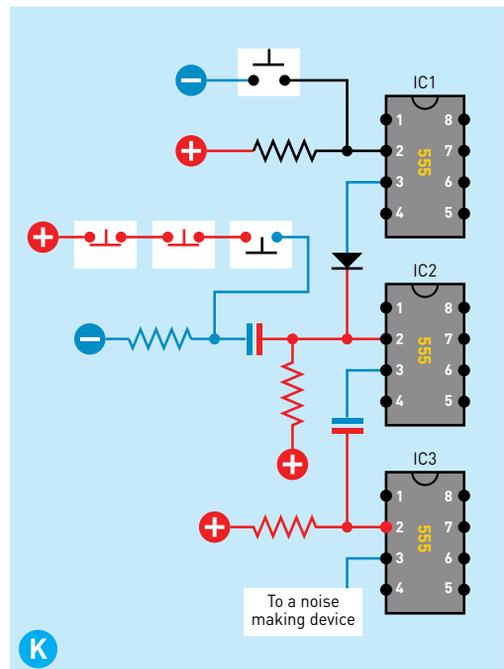
Simplified schematic showing how the third timer completes the basic circuit.

The complete circuit (without a noise maker).

The breadboarded version.

eliminate the timing capacitor which is normally attached to Pin 6, and wire Pin 6 to negative ground. You can see this in Figure **L**, which shows a complete schematic for the circuit. The only thing missing is some kind of noise maker, but that could just be a piezo beeper which has an audio circuit built in. Figure **M** shows how the circuit can be breadboarded, using LEDs for testing purposes.

HERE'S YOUR TESTING PROCEDURE:

- First close the switch at the top of the breadboard, which simulates closing all the doors and windows where the alarm system has been installed. The top LED lights up to confirm the continuity.
- Now you can press the Go Button, triggering IC1, which lights the "Time to leave!" LED. While this is on, the Exit Delay is in effect. You can open the sensor switch and nothing will

happen. The circuit allows an exit delay of only 3 seconds for testing purposes, but that's sufficient for you to open and close the sensor switch (the door).

- At the end of the Exit Delay, the second LED goes out. Now the alarm is armed and ready, and if you open the sensor switch, this allows a negative pulse to trigger IC2, which begins the Last Chance Delay. During this period, the third LED lights up to warn you that you have one last chance to switch the alarm off.
- At the end of the Last Chance Delay, the output from IC2 drops to a low state, which sends a negative pulse through the coupling capacitor to trigger IC3, which switches on and keeps itself switched on, because it is wired in bistable mode. The last LED lights up to tell you that if you substitute a noise maker on the output of IC3, it will start making noise (and keep making noise until you turn it off).

To increase the delays from 3 seconds to 30 seconds, replace the two 47K resistors on the right with 470K resistors.

If you're wondering about the purpose of the 10µF and 100µF capacitors on the left, they prevent the 555 timers from triggering themselves when you first apply power to the circuit.

FINISHING TOUCHES

Naturally if you want to create a finished version, you would solder the components to perforated board and put it in a project box. Figure **N** shows some components with a template for drilling holes in the lid of a box. I added an extra oscillator circuit to drive the speaker. Figure **O** shows it assembled.

One word about installing sensor modules on windows and doors: Remember, they have to be in *series*, not in parallel. Figure **P** shows how to do this with two-conductor wire.

I skipped some details in describing the project here, because I don't have unlimited space in the magazine. You'll find more explanations in my book — together with a confession describing how the circuit didn't work properly in the first version that I tried. I was happy when that happened, because when something doesn't work, it's always a valuable learning experience.

USING A PICO

You can, of course, use a microcontroller instead of 555 timers. My collaborator Fredrik Jansson likes the new Raspberry Pi Pico chip, because it's so powerful and so affordable, so he wrote some code for it in MicroPython to behave the same way as my circuit, as shown in Figure **Q**. His comments in the code show you what the alarm program is doing at each step; you can type it in as you see it here, or download it from the project page at makezine.com/go/intruder-alert.

Fredrik's breadboarded circuit for the Pico is shown in Figure **R**, using sensor switches that are normally closed, and adding a reset button to boot the Pico. The components look wonderfully simple, but of course you do have to write the program, upload it, test it, track down your syntax errors, and upload it again.
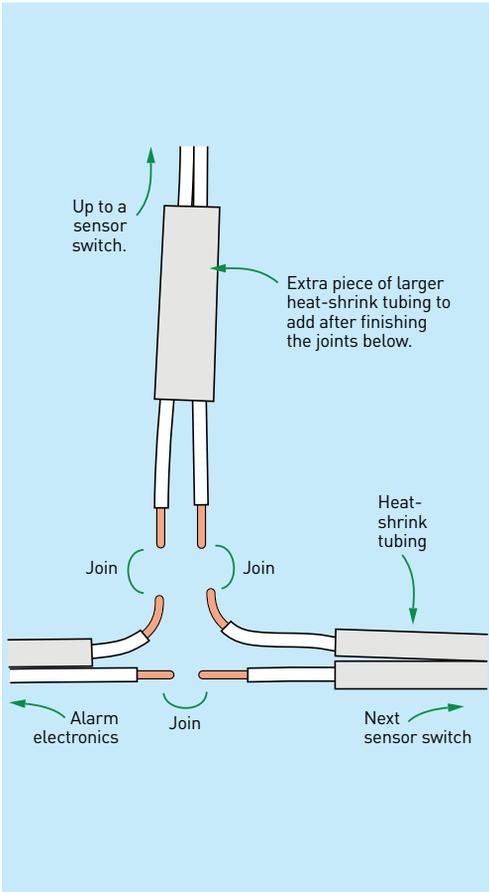
Personally I prefer old-school components,

N

Components and layout for a project box.

O

The finished installation.

Charles Platt

because I think they're fun — and you will learn about concepts such as diodes, pullup resistors, and coupling capacitors as you go along. ◉

```
# Raspberry Pico version of Make: Electronics alarm

from machine import Pin
from time import sleep

# LED outputs
l1 = Pin(17, Pin.OUT) # Switches are closed GP17
l2 = Pin(16, Pin.OUT) # Time to leave       GP16
l3 = Pin(14, Pin.OUT) # Alarm is triggered  GP14
l4 = Pin(15, Pin.OUT) # Alarm!              GP15

# Inputs with pulldown
go = Pin(8, Pin.IN, Pin.PULL_DOWN)        # Go button
sensors = Pin(20, Pin.IN, Pin.PULL_DOWN) # Sensor switches

# show sensor state on LED 1
l1.value(sensors.value())

# function to be called when the sensor pin changes
# show sensor state on LED 1
def sensors_change(p):
    l1.value(sensors.value())

# connect function to the sensor pin change interrupt
sensors.irq(trigger=Pin.IRQ_RISING | Pin.IRQ_FALLING,
            handler=sensors_change)

# The alarm logic starts here

# Wait for GO button press
while go.value() == 0:
    pass

l2.value(1) # time to leave
sleep(10)   # exit delay
l2.value(0)

# wait for sensors to open
while sensors.value() == 1:
    pass

l3.value(1) # alarm is triggered
sleep(10)   # last chance delay
l3.value(0)

l4.value(1) # Alarm!

# the alarm stays on until reset/power-off
while True:
    sleep(1)
```

P How to wire a branch in your sensor network.

Q Source code for a Raspberry Pi Pico microcontroller.
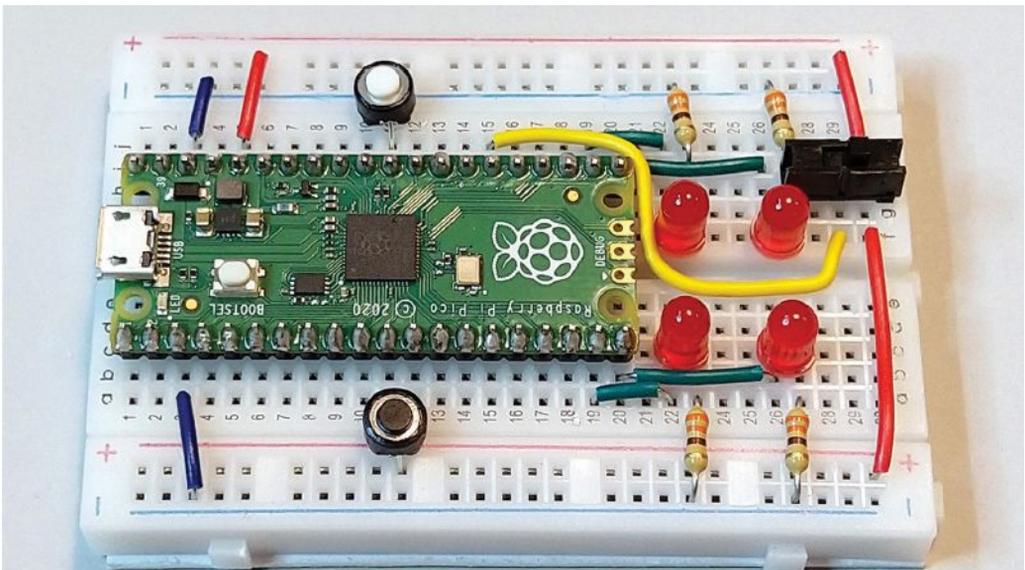
R Breadboarded alarm circuit using the Pico.

Neverending Quotes

Get an everlasting stream of wisdom from Reddit, by glancing at a little e-paper box

Written by Vanessa Bradley

VANESSA BRADLEY is a reluctant coder, efficiently learning and forgetting languages every time she wants to build something. She is a Brit based in Switzerland.

We're going to show you how to make a little box of almost infinite wisdom — a cute display that scrapes highly-rated quotes from Reddit and displays them for you. We call it Neverending Quotes.

The finished project is a little e-paper ticker that sits on your desk, periodically pops on the internet, and brings you back a quote that people have voted as interesting. It lets you enjoy a neverending stream of wisdom at a glance, without going on the internet and drinking from the information firehose, falling down a rabbit hole, or being "nerd sniped" (XKCD joke).

It's an easy build that's suitable as a first project. It's also a nice way to get to grips with GitHub if you haven't used it before.

REAL INTELLIGENCE

If you ask somebody what AI is, they'll tell you it's artificial intelligence. But if you ask somebody what intelligence is, you'll probably get a less convincing answer. We're not sure what intelligence is, but we are sure that people have it, so ideally we would avoid AI and just stick to regular I — real human intelligence.

Reddit uses a voting system called "karma": someone submits a post and if people like it, or dislike it, they vote it up or down. It's a really simple mechanism, but behind every vote, there is a human brain. A "subreddit" like r/quotes is the brilliance of Reddit — it's a neverending stream of interesting quotes that's supplied and curated by people. The quotes are better than any database you can find, in that they're limitless, they come from the internet and beyond, and they're curated by thousands of human brains, not an algorithm.

The Neverending Quotes box is essentially just an e-paper screen attached to a Raspberry Pi Zero mini computer, and uses our open source Python code. The code picks a highly rated quote from r/quotes, tidies it up a bit, and then displays it on the screen, giving your brain a little wisdom boost. And another, and another. You can buy one on our website (veeb.ch), or build one yourself. Here's how.

1. CONNECT THE HARDWARE

Plug your Waveshare e-paper "hat" into the
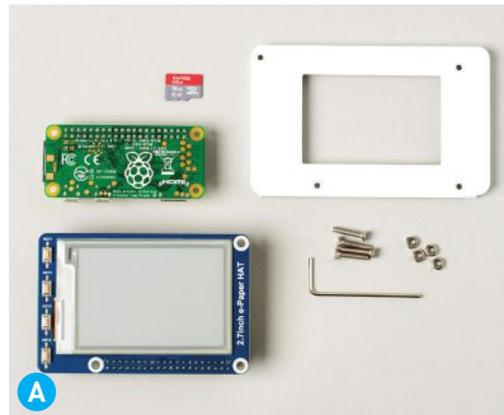
Martin Spendiff

headers on the Raspberry Pi Zero (Figure A). Then plug the Pi into its power supply. That's it!

2. SET UP THE RASPBERRY PI

These instructions assume that your Raspberry Pi is already connected to the internet, happily running **pip**, and has **python3** installed. If you've never set up a Pi before, follow the Getting Started guide at projects.raspberrypi.org.

If you are running the Pi headless, connect to your Raspberry Pi using SSH.

First, enable the SPI interface (**0**=on, **1**=off) by using the command:

```
sudo raspi-config nonint do_spi 0
```

3. INSTALL THE PROJECT CODE

Our Python script, **edify.py**, displays randomly chosen, highly rated quotes from Reddit (r/quotes). It can also be configured to display a word of the day, or an a item from a flashcard text file (selected at random, according to weightings in the config file *config.yaml*).

First, clone Waveshare's e-paper libraries and our **edify** script:

```
cd ~
git clone https://github.com/waveshare/
e-Paper
git clone https://github.com/veebch/
edify.git
```

Move to the **edify** directory, copy the example config to *config.yaml*, and move the required Waveshare library over to the **edify** directory:

```
cd edify
cp config_example.yaml config.yaml
cp -r /home/pi/e-Paper/RaspberryPi_
JetsonNano/python/lib/waveshare_epd .
rm -rf /home/pi/e-Paper
```

Install required Python3 modules using **pip**:

```
python3 -m pip install -r requirements.
txt
```

If you'd like the script to persist once you close the session, use **screen**. Start a screen session:

```
screen bash
```

Run the script using:

```
python3 edify.py
```

Detach from the screen session using Ctrl-A followed by Ctrl-D. The unit will now pull data every 60 minutes (or whatever is specified in the configuration file) and update the display.
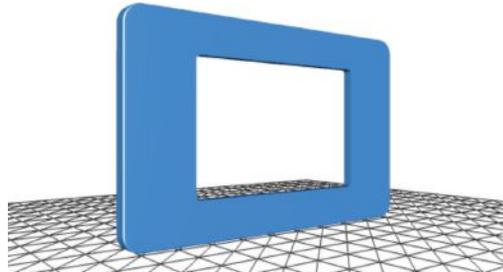
4. CONFIGURE (OPTIONAL)

To adjust the refresh time (in seconds) you can edit the update frequency (Figure **B**) using:

```
nano config.yaml
```

5. ADD AUTOSTART

If you'd like the script to start automatically every time it is plugged in:

```
cat <<EOF | sudo tee /etc/systemd/
```


Martin Spendiff

```
system/edify.service
[Unit]
Description=edify
After=network.target

[Service]
ExecStart=/usr/bin/python3 -u /home/pi/
edify/edify.py
WorkingDirectory=/home/pi/edify/
StandardOutput=inherit
StandardError=inherit
Restart=always
User=pi

[Install]
WantedBy=multi-user.target
EOF
```

Now enable the service you just made and reboot:

E

F

```
sudo systemctl enable edify.service
sudo systemctl start edify.service
sudo reboot
```

6. PUT IT IN A FRAME

If you have access to a 3D printer, our STL files for a front panel (Figure C) can be found at github.com/veebch/btcticker/blob/main/frames/Frame%20v6.stl.

If you want to buy a frame, which includes a full enclosure, screws and a hex key, and an optional laser-cut acrylic backplate for the Pi (Figure D), check out veeb.ch/store/p/ticker-enclosure.

THE WISDOM MUST FLOW

Done! Your Pi currently scrapes quotes from Reddit (Figure E and F), or grabs something from a text file you can designate, or scrapes a "word of the day."

The Python code could easily be adapted to scrape from other sources. We use this same setup for our Cryptocurrency Ticker (Figure G), which you can find at veeb.ch/store/p/cryptocurrency-ticker and github.com/veebch/btcticker. Use your imagination!

G

Fractal Vises

Makers are reinventing a cool tool from 1913, using 3D printers. The story so far...

Written by Christopher Borge

Christopher Borge, Evan DeLosh
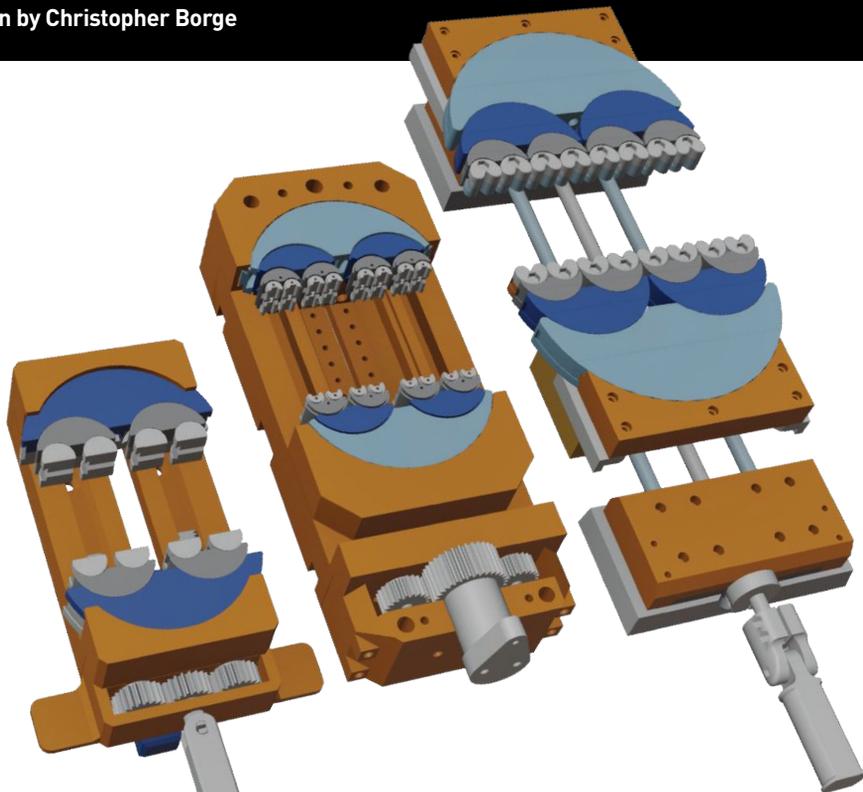
The video that started it all on June 24, 2021, by Hand Tool Rescue.

CHRISTOPHER BORGE is a hobbyist designer and 3D printer in South Australia. He works in media and is studying for a marketing degree.

If you were on YouTube in June 2021, there's a good chance you were recommended the video "Rare Antique Fractal Vise [Restoration]" by Hand Tool Rescue. The video showed a unique vise patented in 1913, and for most of us, it was like nothing we had ever seen (Figure **A**). It immediately gained traction, receiving over 12 million views to date.

MINDS BLOWN

Described as a "device for obtaining intimate contact with, engaging, or clamping bodies of any shape," the so-called fractal vise features 30 semicircular jaw components connected to the main jaws of a vise (Figure **B**). The smallest set of jaws is nested within the next largest set, and so on, using carefully machined dovetails which allow them to pivot to virtually any arrangement when closed around an object. The mechanism was enthralling to watch and commenters immediately started inquiring about the availability of such a tool.

At the same time, many commenters thought perhaps a 3D-printed version could work to allow the masses access to such a cool tool. One design was posted on Thingiverse the same day the video came out, by Evan DeLosh of Michigan (username Clerick), whose "Antique Fractal Vise Replica" showed his 3D model of the fractal jaws (thingiverse.com/thing:4893545). It got some attention but did not actually show the jaws printed and working, so ultimately lost momentum (Figures **C** and **D**).

Seeing this, and with my experience designing models for 3D printing, I thought I would have a crack at designing my own version of the entire fractal vise. It would take five days to design and print the first functional version, and I posted a video June 30 showing my experience so far.

My original design was very basic; it lacked the smallest, fourth set of jaws, and was pretty much just an experiment to see how well the mechanism would translate to 3D printing. But my design was only the first, and many more vises would appear from different designers over the coming weeks.
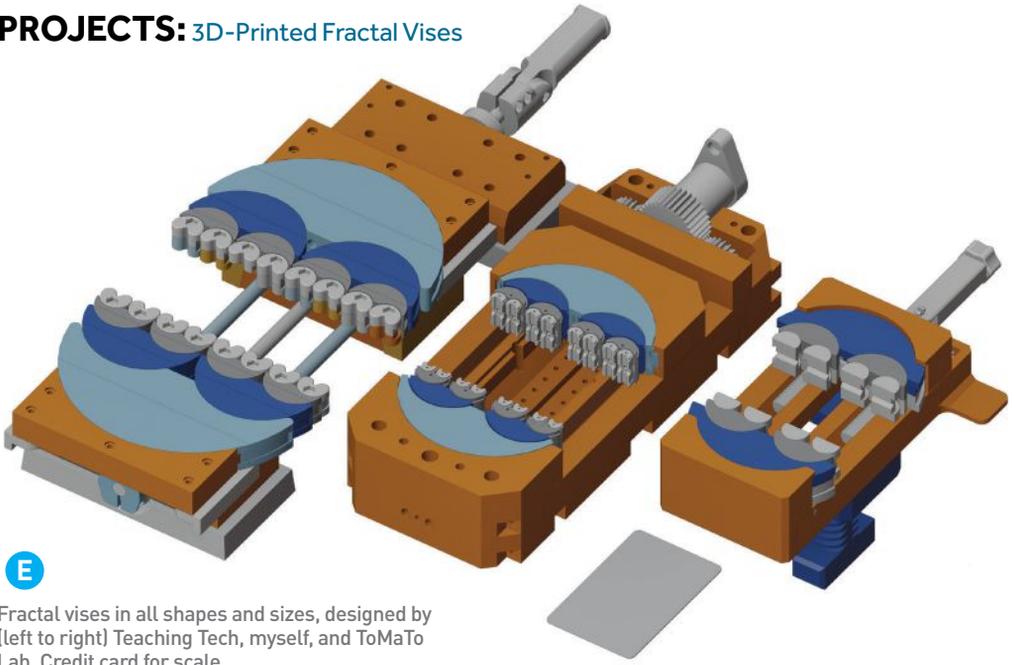
Same-day design of fractal jaws by Evan DeLosh (Clerick), with dovetails for free rotation.

Ⓔ Fractal vises in all shapes and sizes, designed by (left to right) Teaching Tech, myself, and ToMaTo Lab. Credit card for scale.

VISE VARIATIONS

Currently there are over a dozen different fractal vise designs on Thingiverse alone, too many to compare them all here. I've chosen three of the most popular designs that also have a lot to differentiate them: the vise by Michael Laws from Teaching Tech, the fully printed vise by James Chiang aka ToMaTo Lab, and my own V2 design (Figure Ⓔ).

Summarized in the table below, the three designs are very different even on the most basic level.

DIFFERENT DESIGN GOALS

Each design had a unique set of goals, aside from replicating the original mechanism. Michael's was designed to be as easy to print as possible, specifically compared to my original design — which is completely fair. Both of my designs use single-piece prints with support for the dovetails on the jaws. This does work but requires a very well-calibrated 3D printer — there's no way I could do it on my old I3-B clone, for example. His solution is to split the jaws in half and bolt them together later. This allows the dovetails to be

	Borge V2 thingiverse.com/ thing:4931700	**ToMaTo Lab** thingiverse.com/ thing:4909196	**Teaching Tech** thingiverse.com/ thing:4904044
Max span	**60mm**	**50mm**	**Infinite**
Mounting options	**T nut, screw to bench**	**Bench clamp, screw to bench**	**TPU feet**
Parts, printed	**41**	**39**	**78**
Parts, non-printed	**60**	**0**	**200**
Print time (approx.)	**3–4 days**	**1½–2 days**	**2–3 days**
Material required (approx.)	**650 grams**	**275 grams**	**500 grams**
Number of jaw sets	**4**	**3**	**4**
Open source	**Yes**	**Yes**	**Yes**
Number of leadscrews	**2**	**2**	**1**

printed with no supports (Figure **F**).

This solution also allows him to constrain the jaws so they can't turn so far as to fall out. Because he is closing two halves together he doesn't need to slide the jaws on, as with my design, and this allows his jaws to have a lip to keep them on. (On the original metal tool, a small grub screw was used to achieve this but I found it too fiddly for the scale I was printing at.) The ToMaTo Lab design also uses these split jaws for easier printing.

Another of Michael's goals was to use as little plastic as possible. Instead of using a large, 3D-printed bed to attach the jaws to, his design is based around four modules that attach to metal rods similar to the ones used in 3D printers. You can make his vise as wide as you want, restricted only by the length of rod available. In comparison mine and ToMaTo's are of a fixed length, although the files for all three designs are open source and could be modified easily to be longer.

Because of these design choices, Michael's vise uses the most non-printed hardware out of the three. ToMaTo Lab's is the opposite: James' design is very similar to my own, using two leadscrews geared to a single handle, but his major design goal was to be entirely 3D printed. He achieved this using clever techniques such as designing the leadscrews to be essentially rectangular (Figure **G**). This allows them to lay flat for printing but still act as screws in the assembled vise. The rest of his design is held together by well-placed clips and friction.

As for my design, my main goal with V2 was to make it as functional as possible. With this in mind I included several extra features to make it versatile: mounting points for accessories like magnifying glasses, helping hands, and lights (Figure **H**), holes to run the wires for a backlight, and a rail system to attach support plates if an object needs more support from underneath (Figure **I**).

I also tried to make my design as rigid as possible. I did this with my usual technique of running threaded rods the length of the print which I then tighten to compress the print and make the plastic more rigid (see "3D Printed Wood Lathe," *Make:* Volume 79). Using overall smaller, thicker jaws helps with the sag that I
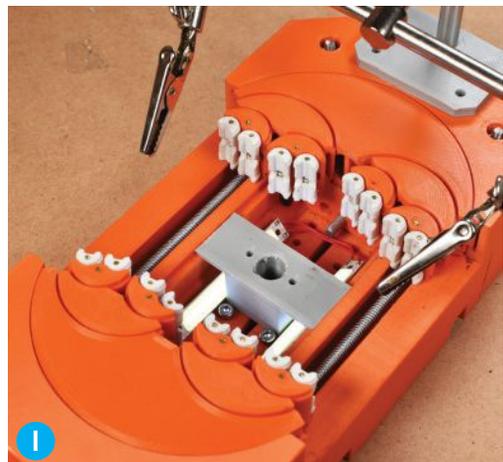
The Teaching Tech jaws require no support material, making them easier to print.

By cutting flats on the screws, ToMaTo Lab makes printing them much easier.

My design with some add-ons in place, such as helping hands.

A backlight and support blocks mounted in the "trench" of my vise.

Christopher Borge

Optional flexible TPU jaws (bottom) compared to the regular rigid type (top).

My fractal vise, mounted on a common 3018 style CNC machine.

found problematic when using thinner jaws. I also designed a second variety of the smallest set of jaws, which replaces them with a rubber-like TPU part that is much easier to make but is less dynamic (Figure J). Overall I went with a small but bulky form factor to try to make it as rigid and useful as possible.

These different designs, their unique qualities, and their rapid creation really exemplify some of the best features of 3D printing technology and the 3D printing community. All these designers encouraged others to work from and improve their designs to get the best result for people to enjoy, and this open source mindset is what's enabled 3D printing to get to the stage it's at so quickly. Since all these designs are open source, if there's a feature you like from one, it's easy to modify another to include it!
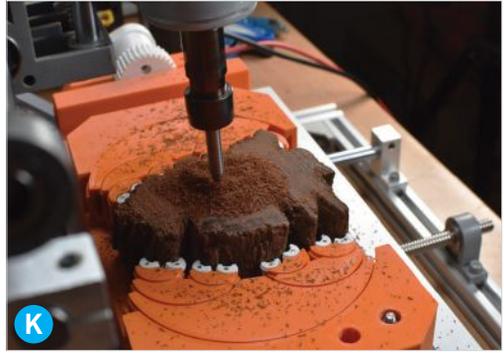
WHAT ARE THEY GOOD FOR?

A good way to describe fractal vises is as a solution in search of a problem. They have a lot of uses, but if you don't have a specific need for one it can be hard to think of anything. Fortunately I've had a lot of people comment on my videos, and describe how they'd use a fractal vise:

- Holding knife parts / knife handle parts
- Painting and gluing model parts
- Engraving oddly shaped rocks
- Engraving small items, specifically coins and Zippo lighters.

I've also heard from people who have disabilities that make holding things most people would take for granted difficult.

The use that I demonstrated was as a milling

vise for a CNC machine. This was a good test since the machine wasn't going to be "careful" with the vise — if the vise was going to fail, the CNC wasn't going to stop putting pressure on it. For my demonstration I used a very strangely shaped piece of timber that would be difficult to clamp otherwise without losing a lot of its top face (Figure K). Because it was clamped from the sides I was still able to do facing operations to smooth out the piece. This test was of a simple noughts and crosses (tic-tac-toe) board and the vise held up well (Figure L).

Fractal vises are a fascinating example of the maker community working together to spread a new (or is it old?) technology. If you're interested in any of the designs mentioned here, the 3D files and build guides can be found posted by their respective makers on Thingiverse. Just search "fractal vise" to see these and many more. ⊘

The vise held up and produced a good result.

Christopher Borge

1+2+3 Felt Eyeballs
They're easy and creepy!

Written and photographed by Jane Curthoys

Eyeballs are my favorite things to make. They're simple, they look awesome, and they're creepy. I wear them as brooches, wrap their stem around things, or add them to houseplants. They also make great Halloween toys not made of plastic.

1 STALK

The eyeball's fleshy tail has a bendable, posable wire armature. Use a length of wire double the length you want the stalk to be. Coat the end in glue, then wrap tightly in red wool, stabbing into the wool as you go. Continue gluing, wrapping, and stabbing to cover the whole wire.

2 EYEBALL

Bend the wire in half, a little off-center. Wrap white wool around the red at the bend. Attach it firmly by stabbing it with your felting needle, then add more to build up a white eyeball.

For the pupil, shape a small disc of black wool and stab gently to attach. Felt your iris color in a circle around the pupil. To make it more realistic, add a lighter shade around the pupil and blend into the outer color. Add a curved white highlight to create the illusion that the eyeball is glistening.

3 MORE FLESH

Wrap red fluff around the eyeball and felt it on, from the edge of the eyeball to the tail, so it tapers smoothly. Stab toward the tail so no red wool gets pushed into the white eyeball where it might show. For a smooth surface, make sure the needle stays in the wool as you felt.

That's it! Add a pin to make it a brooch, or bare wire to make flying eyeballs, or some green wool to make plant eyeballs. For more tips and photos, visit instructables.com/Felt-Eyeballs. ⊘

JANE CURTHOYS lives in a cottage in Devon, England, with two kids, and has been creating art her whole life. She loves wool because it's natural and so versatile. See more of her creations at janecurthoys.com.

(A)

BOB KNETZGER is a designer/inventor/musician whose award-winning toys have been featured on *The Tonight Show*, *Nightline*, and *Good Morning America*. He is the author of *Make: Fun!*, available at makershed.com and fine bookstores.

Resurrecting Vintage Toys

Prepare for silly surgery! Try these tricks to refurbish broken toys

Written and photographed by Bob Knetzger

As I get down to the bottom of my pandemic "job jar," some cool old toys I've collected are finally getting some attention. Can they be brought back to life? Here are some tips and tools for refurbishing broken toys from any era.

PULL STRING TALKERS

This 60s-vintage Mattel Charlie the Tuna hasn't talked in years (Figure Ⓐ). With concentric annuli and hill-and-dale modulation, these mechanical sound toys are worthy of resurrection. You can learn more about how they work at makezine. com/2012/01/20/good-vibrations-groovy-mechanical-sound-players (Figure Ⓑ).

The most common problem: pull the string and nothing happens. Often all that's needed is a new drive belt. Easy fix — if you know the tricks! In short, remove the pull string voice unit by unstuffing the doll, crack the plastic module open, clean out the disintegrated drive belt mess, replace the belt, and then reassemble.

There are many good DIY demo videos on YouTube, so watch a few of those for detailed, step-by-step instructions. Here are some pro tips from an ex-Mattel toy designer that you won't find online:

For opening cloth doll bodies, a stitch ripper neatly cuts the thread along a seam without damaging the cloth. Often you can reuse the old holes in the fabric again when re-stitching.

Opening up old plastic toys can be tricky. Sometimes you can split a glued-together joint by cutting a small slit with an X-Acto and working your way around. But be careful: old plastic is brittle! If needed, you can open up a plastic module by using a heated blade to melt a slot at the seam. A soldering iron at low temp with a blade tool can also work. I use a sculptor's heated waxer with a paddle tip.

Repair broken bits using the good ol' super glue/baking soda hack. Sprinkle some baking soda on a fresh CA glue joint; repeat with more glue and soda to slowly build up more material. This pull-string guide eyelet broke free of its mounting; CA glue + baking soda makes a strong, if ugly, repair (Figure Ⓒ on the following page).

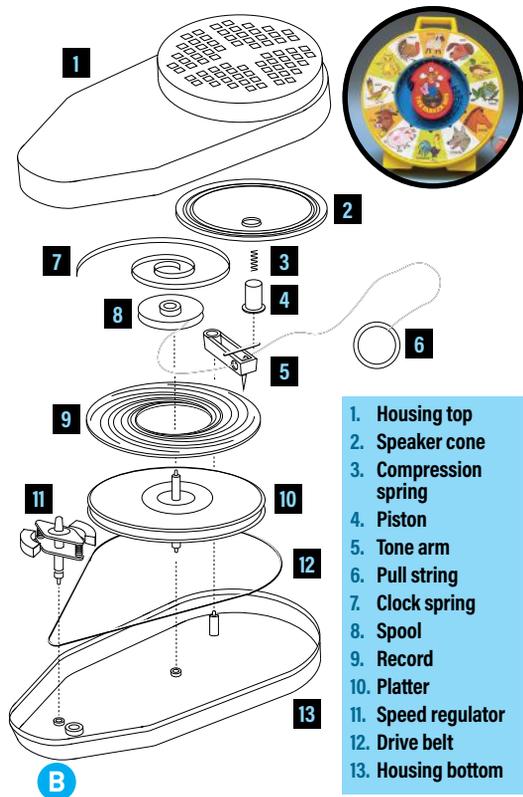**Test all cleaners on an unobtrusive area first.** Don't use any product that dissolves, smears, discolors or otherwise ruins the plastic or paint.

MATERIALS

- » **Solvent cleaner** like Goo Gone or denatured alcohol
- » **Teflon grease**
- » **Silicone spray**
- » **MEK solvent**
- » **Scrap styrene plastic**
- » **Polycaprolactone molding plastic**
- » **Foam cleaning pads**
- » **Cotton swabs** such as Q-tips
- » **Sugru moldable glue**
- » **Cyanoacrylate (CA) glue** aka super glue
- » **Baking soda**
- » **Replacement drive belts, heater wires, etc.**

TOOLS

- » **Seam ripper**
- » **Hemostat**
- » **X-Acto knife**
- » **Small screwdriver**
- » **Hammer**
- » **Tweezers**
- » **Needlenose pliers**
- » **Modeler's saw and files**
- » **Hot cutter**
- » **Drill with miniature numbered drill bits**

1. Housing top
2. Speaker cone
3. Compression spring
4. Piston
5. Tone arm
6. Pull string
7. Clock spring
8. Spool
9. Record
10. Platter
11. Speed regulator
12. Drive belt
13. Housing bottom

C

D

E

F

Good old soap and water should be good for most plastics. Beware of Goof Off and other solvents that may attack polystyrene or doll paint. Mr. Clean Magic Eraser wipes can work wonders, but go easy!

Use a Q-tip to apply a small amount of Teflon grease to the axles inside. It won't attack the plastic and will last longer than Vaseline. Just don't get any on drive belts! For other toys with exposed parts, try lubricating with white graphite or silicone spray (oil or grease will attract dust and dirt).

The center of the speaker cone has a small compression spring and tiny piston that rides in a sleeve. Lubricate that too with a thin smear of the Teflon grease (Figure D); it acoustically couples to the speaker for better mechanical sound transmission.

Tune up the speed regulator. The spring-loaded die-cast speed regulator works by friction: when it spins, the arms swing out by centrifugal force and rub against the housing, slowing it all down. The spring-loaded arms pull in, stop rubbing, and then speed up again as it finds an even speed. The problem is the felt pads become hard and smooth with age and then run too fast. To fix, score some ridges around the inside of the track with an X-Acto. Also scuff up the texture of the felt with a screwdriver (Figure E). Test and repeat for best speed.

Strengthen the case. For better joints on styrene housings, add an overlapping splint of thin styrene and a drop of MEK solvent to bond. Butt joints are always weak but the extra layer of a splint adds real holding power — adhesives are strongest when loaded in shear!

It's very satisfying to bring these old toys life back to life. My 50-year-old Charlie the Tuna doll squawks again in the New Yawk character voice of actor Herschel Bernardi, the long-time spokesfish for "Stahkist" Tuna. Go online at makezine.com/go/resurrecting-vintage-toys to hear Charlie talk!

HEATER TOYS
Vintage make-and-play toys like Vac-U-Forms, Thingmakers, or Strange Change Machines are still fun to play with, but the heaters often burn out (Figure F).

G

H

I

J

K

L

M
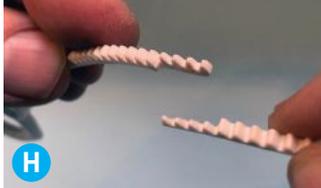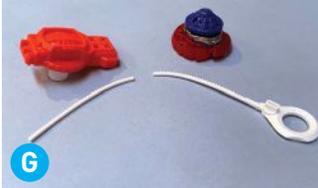
These aluminum and steel toys were never meant to be opened or serviced, but it is possible. Watch how-to videos and get replacement heater wires (and fresh Goop!) at creeplepeeplestore.com.

METAL TOYS

Metal toys and trucks can be disassembled with hand tools and a little patience. Some tips:

- Pry apart crimped joints by inserting a screwdriver and tapping with hammer.
- Untwist tab-in-slot connections with a needlenose pliers.
- To remove a rivet, drill the back out — but just a little! You can then squeeze the ring of peened-over ends back together with a needlenose and work the rivet out the hole in one piece. If you're lucky you can even reuse the same rivet later for reassembly. This trick can also be used to open up mushroomed-over posts on the bottom of die-cast cars.

PULL-STRIP SPINNING TOYS

Sometimes you'll have to fabricate or mend parts, especially those that take a lot of abuse, like the pull strips from spinning tops or flywheel toys. If you just glue the broken polypropylene toothed strip, like a Beyblade's Ripcord (Figure G) or

a vintage Kenner SSP car's "T-Handle Power Stick," it won't be strong enough to use. Instead, create a rugged, overlapping joint by trimming the strips in mating halves (Figure H). Tack the parts together with CA glue. Drill holes through both halves with a tiny #68 drill and then insert snipped-off bits of steel pins. Grind the pins flush for smooth action (Figure I).

MOLDING DUPLICATE PARTS

To make duplicate parts, I use Sugru for fast mold making. I needed a replacement yellow car token for an action game (Figure J) so I molded some Sugru around a sample token and let it cure (Figure K). To keep the Sugru from sticking to the part, lightly coat it first with some cooking spray.

Then I used polycaprolactone plastic (available online as Polydoh, InstaMorph or Polymorph) to create parts with the mold. Just heat the plastic in boiling hot water, and when softened, press firmly into the mold (Figure L). The final part will have the exact shape, and with smooth, integral color (Figure M). A painted part would be too sticky to slide along this plastic track. You can cut and drill the polycaprolactone — it's tough and strong, too. 🌀

Prank'd!

Practical jokes are fun to make and even funner to deploy

April 1 is right around the corner, so choose your victims now and start building these tricks, hoaxes, and booby traps from the pages of *Make:* and beyond — from simple classics to high-tech masterpieces.

USB battery pack
12V battery
Horn
Relay board
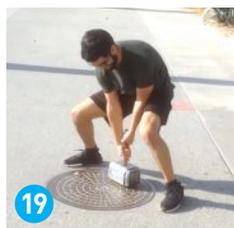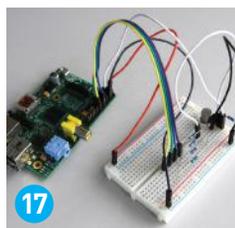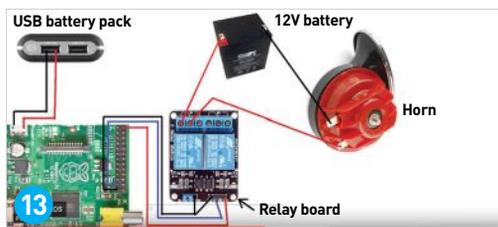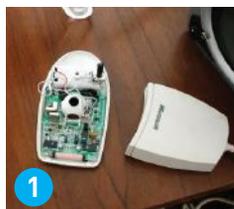
COMPUTER SABOTAGE

1 EVIL MOUSE PRANK *by John Edgar Park*, *Make:* Vol. 15
Cursed cursor has a mind of its own.
makezine.com/projects/evil-mouse-prank

2 ESP8266 RICKROLL CAPTIVE PORTAL
by Jaime Idolpx
"Free Wi-Fi" trap is never gonna log you on.
hackaday.io/project/12709-esp8266-mobile-rick-roll-captive-portal

3 DAYTRIPPER *by DekuNukem*
Laser tripwire triggers BadUSB script of your choice. github.com/dekuNukem/daytripper

PRACTICAL CLASSICS

4 FRIENDLY FAKE-OUTS *by Bob Knetzger*, *Make:* Vol. 52
Phony spills from easy-mold plastic.
makezine.com/projects/friendly-fake-outs

5 TANTALUS CUP *by William Gurstelle*, *Make:* Vol. 35 and *ReMaking History*, Vol. 1
Dribble glass deploys classical Greek science.
makezine.com/projects/build-tantalus-cup-hidden-siphon-prank-friends

6 MAGNETIC AXE PRANK *by Mike Warren*
Bandsaw + grinder + extreme patience + neodymium.
instructables.com/magnetic-axe-prank

SEIZE THE AIRWAVES

7 TV-B-GONE HOODIE *by Becky Stern*, *Make:* Vol. 22
Covertly turn off TVs with a secret zipper switch.
makezine.com/projects/tv-b-gone-hoodie

8 WAVEBUBBLE CELLPHONE JAMMER
by Limor Fried
Drop all the calls. ladyada.net/make/wavebubble

9 RASPBERRY PIRATE RADIO *by Sam Freeman and Wynter Woods*, *Make:* Vol. 38
Broadcast your own FM micro-station.
makezine.com/projects/raspberry-pirate-radio

MOTION TRIGGERS

10 MONKEY COUCH GUARDIAN
by Mark Frauenfelder, *Make:* Vol. 34
makezine.com/projects/monkey-couch-guardian

11 MOTION ACTIVATED WATER GUN TURRET
by Jason Poel Smith
Clang — or squirt — when intruders are detected.
makezine.com/projects/motion-activated-water-gun-turret

INFERNAL NOISES

12 BOOM STICK *by Edwin Wise*, *Make:* Vol. 13
makezine.com/projects/boom-stick-air-cannon

13 INTERNET-CONTROLLED CAR HORN
by Lewis Callaway
Big loud sounds to startle.
makezine.com/projects/new-project-internet-controlled-horn-prank

14 EVASIVE BEEPING THING *by Brad Graham and Kathy McGowan*, *Make:* Vol. 14
makezine.com/projects/evasive-beeping-thing

15 ANNOY-O-BUG *by Alex Wulff*, *Make:* Vol. 59
Maddening, high-pitched electronic beeps.
makezine.com/projects/prank-friends-chirping-blinking-throwie

GROSS-OUTS

16 HEAD IN A JAR *by Mike Warren*
Hmmm, what's in the fridge?
instructables.com/head-in-a-jar-prank

17 FART DETECTOR *by Raspberry Pi Foundation*
Air sniffer sounds the alarm when they cut the cheese. projects.raspberrypi.org/en/projects/fart-detector/0

SUPER POWERS

18 INVISIBILITY SHIELD *by Ian Charnas*
Pounce on the unsuspecting.
instructables.com/Invisibility-Shield

19 THOR'S HAMMER (MJÖLNIR) PRANK
by Allen Pan
Hidden microwave electromagnet (and fingerprint sensor) defeats everyone but you.
youtube.com/watch?v=0_8Xhzt5YQI ✆

MORE PRANK RESOURCES:
- *The FAT Manual* by Free Art and Technology (FAT) Lab, fffff.at
- *Pranks!* and *Pranks 2* edited by V. Vale, researchpubs.com
- *The Art and Science of Billboard Improvement* by Billboard Liberation Front

New From Make: Projects

Discover and share projects at makeprojects.com

Written by Dan Schneiderman

1 RASPBERRY PI ZERO W NIXIE CLOCK
Hans Jørgen Grimstad @hansj66
Embrace your inner steampunk with this Raspberry Pi-powered clock kit. Inspired by a decade of Nixie tube projects and developed as an exercise to improve project design, this kit can send you back in time. makeprojects.com/project/raspberry-pi-zero-w-nixie-clock

② LIGHT CANVAS
Luis Ferreira @luisfferreira

Who says you need paint to create a painting? Through a blend of physical movement tracked by a Leap Motion sensor, and glowing lines provided by a hidden LED matrix, you'll find that not only will your canvas light up, but you with it. makeprojects.com/project/light-canvas

③ THERE IS NO DANA ... ONLY ZUUL
Jonathan Pfeiler @PfeilerFabricate

Create your own *Ghostbusters*-style Terror Dog by slicing open a dragon skull, sculpting a body and detachable arms with insulation foam, and adding in some bright LEDs for a Halloween (or Valentine's Day) display to remember. I ain't afraid of building no ghost. makeprojects.com/project/there-is-no-danaonly-zuul

④ DIAL-A-GRUE 2.0
Mitch Patenaude @dialagrue

Relive classic text computer games via rotary phone! With the aid of a Raspberry Pi and Jasper, an open source voice response framework, you can play quintessential early computer games by speaking into the phone. Built-in titles include *Colossal Cave Adventure*, *Moonglow*, and *Guess the Animal*. makeprojects.com/project/dial-a-grue-20

⑤ UPCYCLE FURNITURE: VINTAGE OFFICE DRAWER
Omer Orbach @OmerOrbach

Built from a vintage metal office drawer that was dumped next to a garbage can and wooden vintage legs found lying around, this upcycled office drawer found new life as mid-century-style furniture. All it took was a little woodworking magic, a dash of TLC, and fresh paint. makeprojects.com/project/upcycle-furniture---vintage-office-drawer

⑥ AIRZOOKA ARCADE
Tom Heck @Tom_Heck

Woosh! Try your hand at smoke ring target shooting! Thanks to a fog machine and a cardboard fog distribution channel, this interactive exhibit can host multiple challengers at any time at any Maker Faire. makeprojects.com/project/airzooka-arcade ⊘
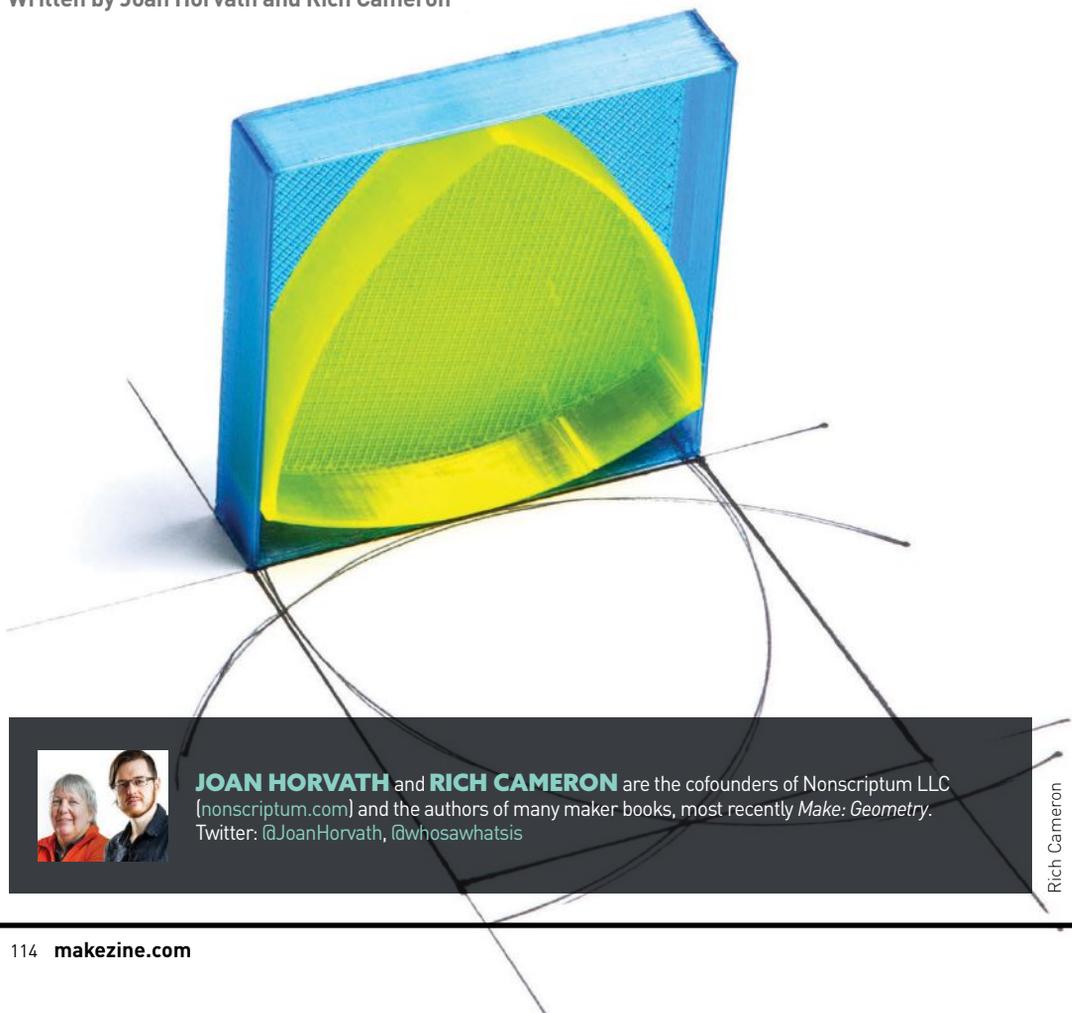

DAN SCHNEIDERMAN is a maker, space enthusiast, co-chair of Maker Faire Rochester, and Community Manager at Make:. Share your cool projects at makeprojects.com!

MEDIEVAL
ARCH
HACKS

Geometry rules! Bring out your inner Gothic architect with a compass and the materials of your choice

Written by Joan Horvath and Rich Cameron

JOAN HORVATH and **RICH CAMERON** are the cofounders of Nonscriptum LLC (nonscriptum.com) and the authors of many maker books, most recently *Make: Geometry*. Twitter: @JoanHorvath, @whosawhatsis

Rich Cameron

One of the cool things about geometry is that the same principle can underlie a medieval church window and a design for a weird, Maker Faire-appropriate bicycle wheel. In this adaptation of material from our recent book, *Make: Geometry,* we'll show you how the two are related, and how to draw either one at any scale.

Let's start with medieval cathedral, or fortress, construction. One of the challenges of any structure is making windows and doors that will bear the weight around and above them. An early solution was the *circular arch*, which is an opening in a structure that is half a circle (Figure **A**). The simplest way to lay one out is to pin one end of a rope and swing it around that pivot.

Then, someone hacked the design and came upon the *Gothic arch* (Figure **B**). It is created by drawing two circles of the same radius. Each circle is centered at the base of the other arc. Gothic arches are much stronger than circular ones, since more force from material above the arch is transmitted downward through the base rather than pressing straight down on unsupported bricks. By the way, the term *Gothic* was used in a snarky way at the time by traditionalist architects, to imply association with the barbarians who destroyed Roman civilization. Improvements aren't always appreciated when they are first introduced!

Now, what about that bicycle wheel? It, and the Gothic arch, both arise from the 2,000+ year-old construction of an equilateral triangle (one with all sides the same). Try it with us to see how!

1. Grab yourself a drawing compass. Any kind will do, but the most common attaches or incorporates a pencil on one side (Figure **C**). We'll call the point that isn't the pencil the "needle point."

In a pinch (or to draw a really big version) you can use a loop of string instead of a compass. Put your pencil point inside the loop, hold down the other end of the loop as the center of the circle, and draw.

2. Set your compass points a convenient distance apart. This distance will be the length of the equilateral triangle's sides, and you will leave them that way for the rest of the process. Draw

A

B

C

D

E

F

G
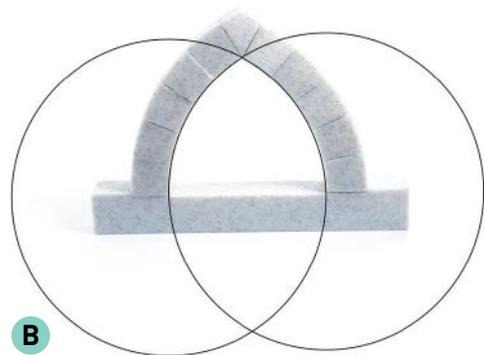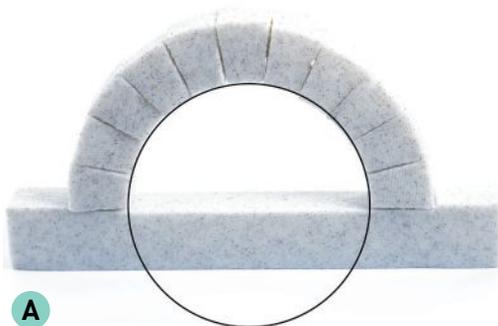
a circle. One corner of the triangle will be at the center of this circle (Figure D).

3. Put the needle point at any point of the circle you just drew. This point will be the second corner of the triangle. Draw another, intersecting circle of the same radius there (Figure E).
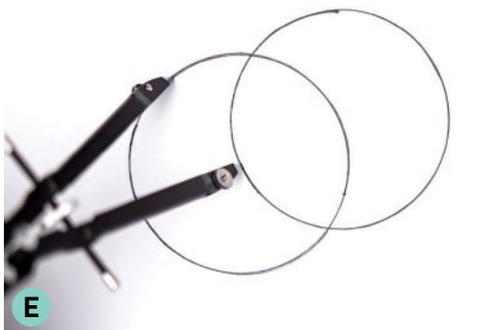
**4.** Now put the needle point at one of the places where these circles intersect (Figure F).

5. Draw a third intersecting circle (Figure G).

6. You'll see there is a shape like a rounded triangle in the middle. This shape is called a *Reuleaux triangle* (grey shaded in Figure H), pronounced "roo-low." Connecting all the vertices of the Reuleaux triangle gives you an equilateral triangle.

7. Keeping one straight side and two rounded ones gives us our Gothic arch (Figure I).
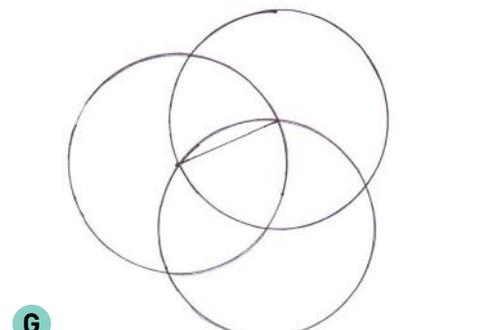
What happens if you start making smaller arches within the arch? Here's what we did (with a 3D-printed version) to create a *tracery* (Figure J), the supports that would have held glass panes in a stained-glass window. Try creating a window frame as shown in Figure I, then split into halves. Experiment with progressive repeating designs. The three intersecting circles we tucked into the remaining space in the big arch are called a *trefoil* — the same as the outside of the three intersecting circles in Figure H. (If you want to find out how to 3D print the tracery shown here, or the other 3D prints in this article, check out our *Make: Geometry* book.)

Now, let's return to the Reuleaux triangle that we constructed along the way. Draw one as we describe above on cardboard or something stiff, and cut it out. You will discover that the triangle will roll, just like a circular cutout would! That's true because the width of a Reuleaux triangle is constant. (Why? Think about how it is constructed with intersecting circles, and remember that the distance from the center of a circle is the same everywhere on that circle.) However, the distance to *its own center* from all points on a Reuleaux triangle's perimeter is not equal.

Rich Cameron

This means that you could in principle make a Reuleaux triangle wheel, but it would need a complicated mechanism to work since the center of rotation does not stay in the same place as the wheel rolls. People have made bicycles with Reuleaux triangle wheels, but they are complicated. Rather than rotating around a fixed hub, the centers of the wheels are mounted on a linkage that allows the center to move up and down, with rollers or another low-friction surface resting on top of the wheel to keep the frame's height constant. If you cut a Reuleaux triangle out of cardboard, you can see that it rolls easily along a flat surface, but is not rotating around any one constant axis.

Finally, what happens if we confine a Reuleaux triangle in an appropriately sized square, as in Figure **K** ? It will turn freely. Actually, if you were to make a Reuleaux triangle drill bit, it could be used to drill out a square hole with slightly rounded corners.

CONCLUSION

We've seen here that a simple compass construction of an equilateral triangle can take us down a couple of very divergent paths. We've shown examples on paper (and with 3D printed examples we talk about more in *Make: Geometry*) which you could transfer to other, sturdier mediums if you wanted to make more substantial examples. Maybe you'll come up with the next step in Gothic making — appreciated 1,000 years from now, even if too *avant garde* for the present! 🧭
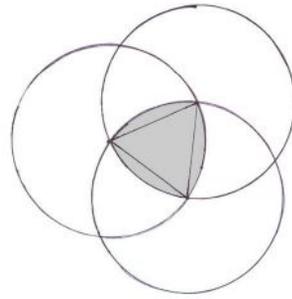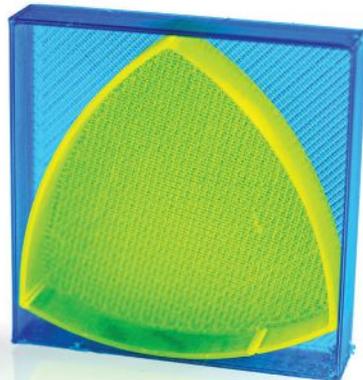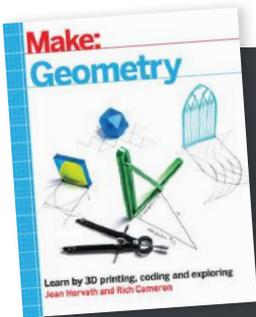
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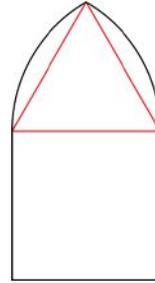
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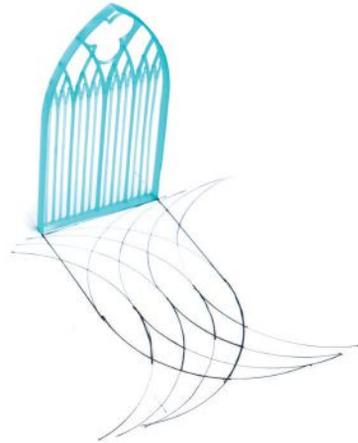
J

K

Our new book *Make: Geometry* is for anyone learning geometry, or those who learned a long time ago and are trying to repress the painful memories. This book gets at the practicality of geometry, without losing the puzzle-solving and aesthetics that also make it joyful to learn. Available at Maker Shed (makershed.com/products/make-geometry) and other fine retailers.
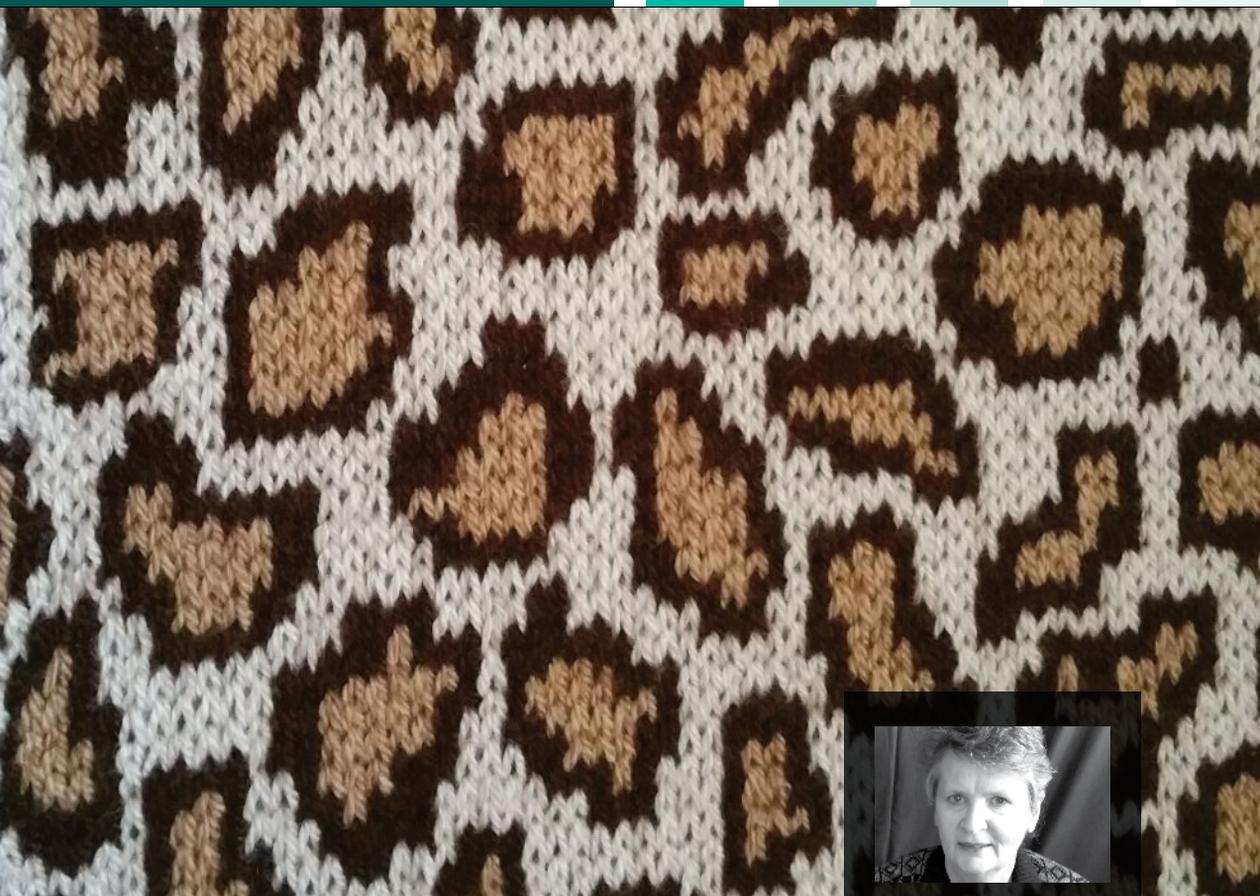
ADRIENNE HUNTER
is a lifelong crafter and maker, mostly in textiles. As a fun complement to her day job in tech, she exhibits machine knitting at Maker Faires and knitting events, along with her friends from the Machine Knitters Guild of the San Francisco Bay Area.

PIXEL
KNITTING
PART 2

Double bed jacquard knitting makes the most of your hacked machine —and looks neater too

Written by Adrienne Hunter

In *Make:* Volume 77, we discussed the Brother knitting machines made in Japan in the 1980s, how their electronic patterning works, and how the maker/crafter community is hacking them to knit custom pixel art. Now we'll level up with two add-on devices — a *ribber* and a *color-changer* — to produce a two-layer fabric known as *double bed jacquard (DBJ).* It's a close relative to the hand-knitting technique of double knitting.

When you use a knitting machine without a ribber, the resulting fabric curls at the edges; it's the nature of single stockinette knitting. For many purposes (garments, wall hangings) the curl can be dealt with in finishing but for a project like a scarf or blanket, you want your knitting to lie flat. The double bed jacquard technique will do just that. Also, single-bed colorwork can leave long strands on the back of the piece; DBJ incorporates the strands inside the knitting so it's neat on both sides.

Adding a ribber means that we now have two sets of needles opposite each other, so stitches can knit from either direction (Figure **A**). Its basic purpose is to do alternating columns of knit and purl stitches, or *ribbing*, to make neat edges for garments. But it can do much more; here we'll combine that function with a colored pattern from the computer to make a patterned DBJ fabric.

DBJ is knitted using one yarn color at a time; each yarn knits just the needles designated for its color on that row and lets its yarn slip past the other colors' needles on the front, only knitting the backing in that area. So it takes multiple passes to build each row. The color changer makes the yarn-change process much more convenient, but it only operates from the left end of the machine, so each color knits two passes, across and back, knitting only that color for both passes. The computer separates out the colors to control which needles knit in which pass.

HOW DOES DBJ BUILD THE PATTERN?

First, consider a two-color pattern (Figure **B**). Let's say that the color A (gray) stitches have already been knitted for row 1, and we're at the left having just switched to color B (red.) On its left-right pass, color B fills in its stitches to finish row 1, and on its right-left pass it knits the red stitches of row 2. Then we switch back to Color A;

A — Main bed / Ribber / Color changer
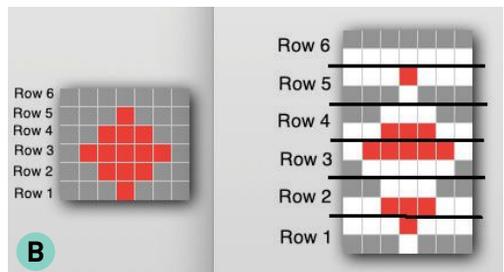
Two-color double bed jacquard; the actions on the right result in the image on the left. Knitting diagrams are read from bottom to top.

Front / Birdseye backing / One-row stripe backing / Two-row stripe backing / Back
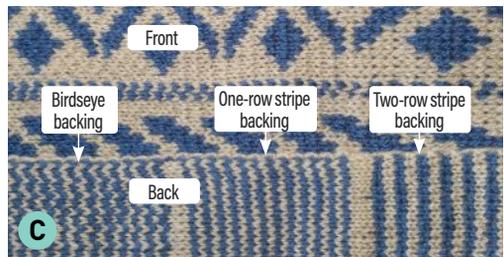
Different settings affect the width and feel of the fabric.

left-right it fills in the gray stitches to finish row 2, and on its way back it knits its gray stitches for row 3. By using this interlocking ABBA sequence, any arbitrary 2-color pattern can be knitted.

There are various ribber settings that can give different backing effects. The most basic is *two-row stripes*; for every two finished rows on the front there are four on the back, two of each color. You can adjust the tensions somewhat to minimize any stretching. Another common method is *birdseye*, which is the one patterning that the later Brother ribbers can do, a mechanical setting that allows knitting on alternating needles. This results in a staggered stripe effect and a balanced fabric with two finished rows on the back, not four (Figure **C**).

In 2022 Sarah Spencer's tapestry *Stargazing* will go on display at the State Library of Victoria, Australia. To create it, she invented a new algorithm for 3-color machine knitting. starmap.heartofpluto.co
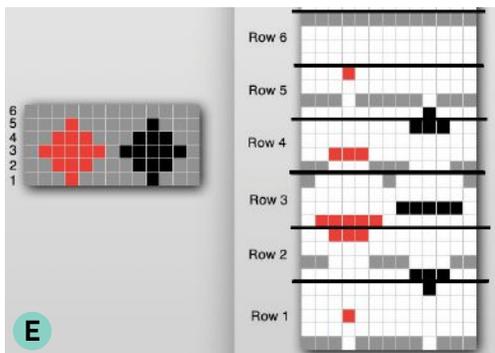
Spencer's algorithm: By adding a minimum number of extra passes, any pattern can be knitted without conflicts.

DBJ WITH MORE THAN TWO COLORS

But what if our pattern has 3 colors per row, like the leopard print in Figure **F**? Each color goes across and back, filling in its color for row 1 then row 2. But what if a given needle needs color C in row 1 and color B in row 2? By the time color C is trying to knit row 1, color B has already knitted row 2 on that needle. You'll get small distortions in the pattern, or worse, drop stitches, making it impossible to get the results you wanted.

Multiple solutions to this problem have been used over the years, none ideal. The simplest is for each color to only knit in pattern left-right, and on the return pass only knit on the ribber. That way the colors never conflict, but the result is 3 to 6 rows of backing for one completed row of the front! The pattern looks stretched and the backing tends to show through.

Another common solution is to knit pairs of two rows the same: if row 1 and row 2 are the same color sequence then each color in turn can fill in its color for both rows, without interfering. For geometric patterns this can be a good solution, not so much for a design where you want as much detail as possible. A knitted stitch is already quite a large pixel in an image, so stretching it or doubling its height is best avoided.

Since the 90s, commercial software has been available that can analyze images to find conflicts and suggest changes. But reordering the colors can lead to operator mistakes, and the back doesn't look as neat; and rearranging pixels can spoil the picture.

SARAH'S ALGORITHM

You may have noticed the awesome *Stargazing* project in 2018, where Sarah Spencer, an Australian software engineer, not only knit this super-impressive large-scale tapestry — 9 feet by 15 feet! — but came up with her own algorithm for 3-color DBJ to do it (Figure D). She can knit any arbitrary 3-or-more color pattern without color conflicts, with a minimum number of extra passes, and keeping to an ABC order. As far as I can tell, Spencer's technique is new. She has kindly posted it as open source code on GitHub (github.com/chixor/knitting_machine); you can follow her work at twitter.com/HeartOfPluto_.

Spencer's work was developed from the *Adafruit hack* (github.com/adafruit/knitting_machine) which uses the floppy drive connector on old knitting machines, but her core algorithm can be applied anywhere and was incorporated into *AYAB* software (ayab-knitting.com) at v0.95.

Spencer's algorithm does not analyze the image; instead it determines the minimum number of extra non-patterning rows to insert so that conflicts can never happen (Figure E). Each color can always knit in pattern on its left-to-right pass (row 1) but on its right-to-left pass (row 2) it can only pattern *if it has just completed a row* so it is starting a new one. Otherwise on right-to-left it knits on the ribber only. The effect is that each finished row has only one extra pass per row for 3-color, or 2 extras for 4-color, and any arbitrary pattern can be knitted. 2-color behaves the same as the ABBA algorithm, no extra passes needed.

KNIT YOUR FIRST DBJ SCARF

A good first project in DBJ knitting is a two-color scarf (Figure F, at right) to match the Fair Isle hat we knit in Part 1 of this article. You can find complete instructions at makezine.com/projects/machine-knit-a-jacquard-scarf.

The leopard-pattern scarf that's also shown (Figure F, at left) was made using Spencer's algorithm in AYAB; the instructions are the same as the two-color scarf except you choose the "Heart of Pluto" setting in AYAB and tell it you're using 3 colors, then set up 3 yarns in your color changer and cycle through them in turn. The leopard pattern can be downloaded from the scarf project page as well.
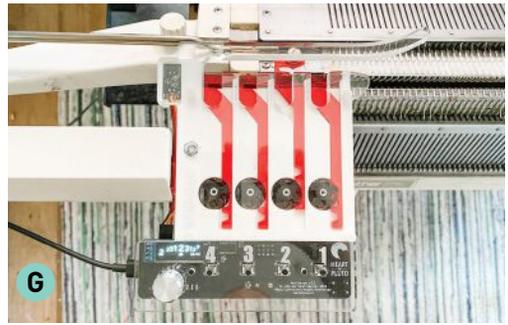
Prototype Arduino-controlled AutoChanger for switching colors, designed by Sarah and John Spencer.

Sarah Spencer, Christian Capurro

MOTORIZE IT!

Using a home knitting machine is a human-powered endeavor; the carriage moves easily enough but even so it can be quite a workout. Now add in multiple extra passes per row to make DBJ, and the obvious question becomes, can we motorize this? Yes, Brother manufactured a motor and they come available from time to time on the used market. Spencer's video shows it in action at youtube.com/watch?v=OVQi05Lsd34.

COLOR CHANGERS

The color changer for most Brother machines is hand-operated: You slide the carriage into the device, press a button to mechanically select the next color, and it gets picked up as you push the carriage back out to begin its next pass. This is easier than looping yarns in and out by hand, but still tedious. Especially if you have a motor — it's silly that you still have to sit there and press a button every two passes. Only Brother's last, rare model of knitting machine (KH970) has an automatic changer.

Enter Sarah Spencer again. With husband John, she has designed an Arduino-controlled, servo-based color changer (heartofpluto.co/autochanger). It is freestanding and does not depend on control signals from the knitting machine (Figure G). You tell it the color sequence you want, and the arrival of the carriage triggers it to switch to the next yarn in sequence.

So now we've introduced you to the two main methods of doing color work on a domestic knitting machine: Fair Isle (or stranded color work) and double bed jacquard. There are many more variations on these for you to explore! ⊘

Yeti Smartbench Portable CNC STARTING AT $5,417 yetitool.com

Yeti Tools set out to create a CNC router capable of cutting a full sheet of plywood (8'×4') that was also portable enough for one person to bring to a job site. They really nailed that balance with this machine. After the initial learning session, I'm able to assemble the Smartbench in only a couple minutes. That's pretty amazing for something capable of full-sheet cutting.

Many portable CNC systems ride directly on the material being cut, meaning their depth control is limited at best. Since this uses an actual gantry (with rack and pinion!), it has a not-too-shabby 5.9-inch Z-height, meaning it can also do 3D routing.

The Smartbench also has safety features I'm not used to seeing on CNC routers, which makes me think this might be perfect for a school or makerspace setting, especially one with limited floor space for permanent setups.

—*Caleb Kraft*

See an in-depth look and video of it in action at **youtu.be/_Sd6ssfnzKU**

Goliath Portable CNC Robot

$3,890 goliathcnc.com

The Goliath has been at the top of our "cool tech we'd like to play with" list for some time. We saw the prototype a few years ago at Maker Faire and have been eagerly waiting its release ever since.

This CNC router is an omni-wheel driven robot that literally drives around on top of your material while cutting. The team at Goliath has done an incredible job not only on the fit and finish of the machine itself, but also in the extremely complicated software trickery that allows it to cut without messing up where it plans on driving in the future.

The Goliath is small enough to fit in a backpack or duffel bag, which is truly impressive — but keep in mind that it doesn't have the rigidity of a machine with a gantry. You'll have to slow a typical job way down to compensate for cut depth and feed rate (moving speed). Despite the slower speed, I was impressed with the little robot's ability to pull off acceptable cuts, and am still blown away by its software magic. —*Caleb Kraft*

Watch us test it out:
youtu.be/jjzR1uRH7MQ
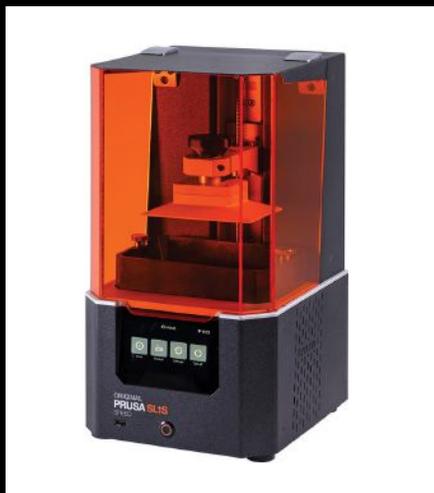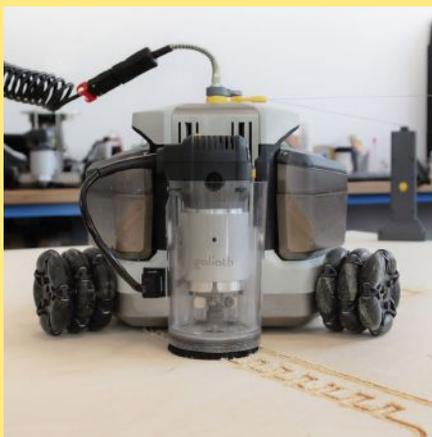
Prusa SL1S Speed Resin Printer

$1,999 prusa3d.com/original-prusa-sl1

While many other companies are pushing for cheaper and cheaper printers, it appears Prusa is angling for a more impressive feature set. The SL1S Speed, as the name implies, takes the quality you see from the SL1 and gives it a turbo boost. In our tests we saw print speeds 2x–3x faster than those of the earlier model. This means the difference between tossing in a print and forgetting about it until the next day, or printing something real quick over lunch.

The performance and quality of the final prints are quite impressive, but the price tag may mean that only those who need that speed, along with Prusa's customer service and reliability, loosen their purse strings for it. I'd say they're targeting quasi-professionals and small businesses that really need these features.

—*Caleb Kraft*

We made a video of this one too:
youtu.be/nAdjeXFhTTM

More Toolbox recommendations from the Make: staff

You can't go wrong with these gadgets and devices that our team regularly use in their day-to-day lives.

Digital Angle Finder

$35

Get your table or mitre saw blade set to the exact angle with this little device. Its magnetic backing lets you affix it to the base or blade, then it tracks its angle so you can position it to just the right place. Additional uses include determining how off-kilter a surface is and finding the angle of a ramp. Some models also includes an angled laser line projection, for lining up shelves or photos on a wall.

Canary Cardboard Cutter

$14 makershed.com

Cardboard is all around us these days, and is a great material for crafting and art making. The Canary cutter makes it so easy to cut it apart for any of your needs.

Lego World Map

$250 lego.com

Almost 12,000 pieces come together into a 41-inch map that you'll be proud to hang on your wall. And make no mistake, you earned it!
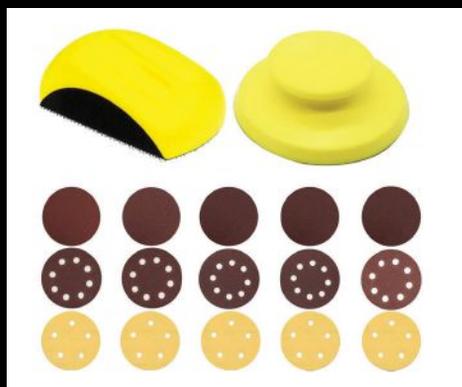
Sanding Blocks

$13

Got an assortment of 5" sanding discs? Put them to use in spots where you need to sand by hand, rather than with your orbital sander.

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- ITEEA's STEM Showcase
- Engineering by Design Labs
- And more!

The 2022 Conference will take place at the beautiful Caribe Royale Resort. Uncover a Floridian escape where the sun is warm and the welcomes are even warmer, Caribe Royale is a destination that offers all the connection you could ever imagine right within reach.

For the latest conference information, go to
www.iteea.org/ITEEA2022.aspx

Headband Magnifier With Light

$16

For engraving, crafting, model making, extracting your child's loose tooth, or any other activity that requires utmost precision.

Laser Tape Measure

$25 mileseey.net

Using a tape measure beyond 10' requires a second person to hold things in place. And what if you want to measure something considerably further than that, like 165 feet away? This tool makes those measurements as simple as a click of a button.

Japanese Weeding Sickle

$16

Don't let its size fool you. This is ruthless on weeds, even the pesky and invasive bittersweet vine. Thoughtfully comes in a right- or left-handed configuration.

Dewalt Cordless Chainsaw

$240 dewalt.com

Lightweight, go-anywhere tool for cutting branches and small trees.

Fake it until you make it, then make it again, cut it up, nail it down, screw it up, cut to the chase, **make a mess with it**, confess to it, digress from it, undress with it, bench press with it, think less of it, obsess over it. Just make.

You need to stop with the judgements and blame-gaming, the defending, upending and pretending, the **finger pointing** and over analyzing every itty bitty thing.

Don't wait for permission or a commission, or for a grad school admission, don't ask your physician. Just **start making**, forsaking, heart breaking, **coffee caking**, **corn flaking**, jailbreaking, belly aching, **profit taking**, claim staking, nap waking, **trouble making**, muckraking, shit taking, earth shaking, undertaking. **Just make**.

Face your fear, lean in to it, embrace it, use it **to power your tools**, float your boat, make things you're afraid of, things you're **ashamed of**, things that make you scream, paralyze you, **turn you on**, put you off, and freak you out.

Look, just don't with the excuses, the insults and abuses, the nitpicking, boot licking, pan sticking, sniping, criticising, proselytizing, scrutinizing and prying, the **white lying** and over the top trying.

You are not perfect and neither is anyone else. Stop worrying, trying to keep up, **don't care** what other people think, do, have, look, like, hate, love, **screw all of that**.

By David Darts, NYU

Just
Make.

Push your anxiety off a cliff and them bring it back to life so you can jump on it, **kick it in the nuts**, and toss it in the river with concrete boots.

Suck it up, spit it out, bite the bullet, shoot from the hip, start at the beginning, jump in the middle, do an end run, **whatever it takes** to just start and keep making

Something. Anything. Everything.

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