

23 PROJECTS & SKILLS: Raspberry Pi, Arduino, Micro:bit

Make:



OUTSIDE
THE BOX:
Build This
LED Cube Orb

DIGITAL FABRICATION 2023

SPEED DEMONS!

SMARTER,
FASTER,
CHEAPER!

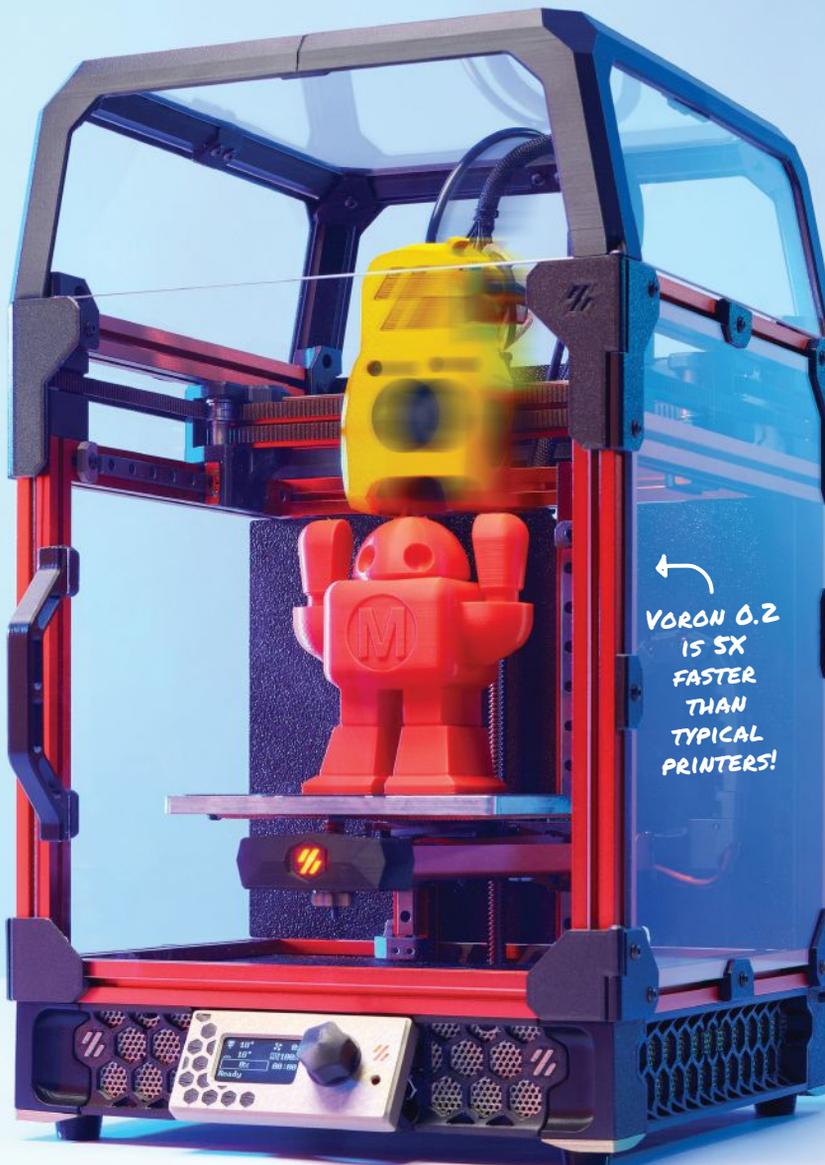
- BLAZING NEW 3D PRINTERS
- Choose the Best Laser
- LASER METAL ENGRAVERS UNDER \$2K

A.I. CURIOUS?

Try out Generative A.I. to create audio, images, text, code & 3D models!

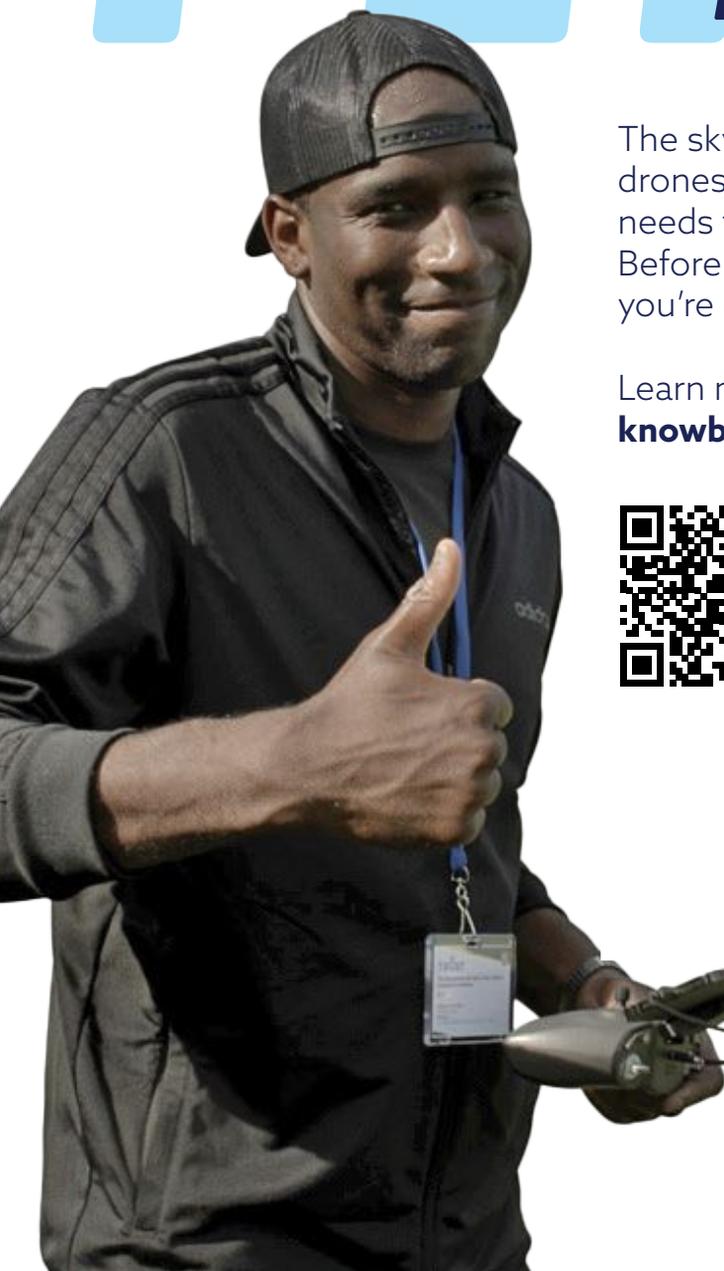


- \$30 Vertical Wind Turbine
- WEARABLE SOFT SPEAKERS
- DIY Ambient TV Backlight
- ZODIAC EMBROIDERY
- Amateur Radio and SDR



VORON 0.2
IS 5X
FASTER
THAN
TYPICAL
PRINTERS!

FLY *RIGHT*



The sky may be the limit for drones, but a responsible pilot needs to follow some simple rules. Before you take off, make sure you're up-to-date on drone safety.

Learn more today at:

knowbeforeyoufly.org/fly-right



UNLEASH YOUR INNER MAKER!

Whether you're 8 or 80, the Maker Shed offers an incredible array of **kits for learning about electronics, engineering, design, and coding.** So what are you waiting for? Dive in and discover a whole new universe of possibilities!

Make:

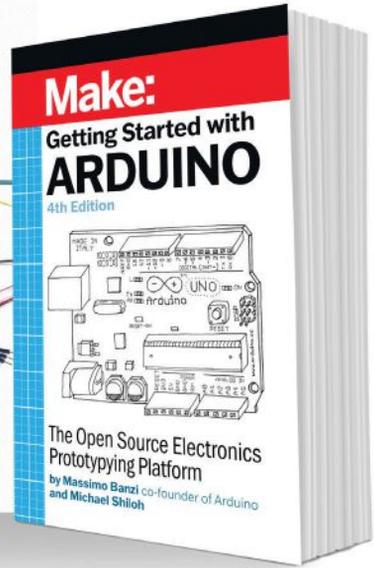
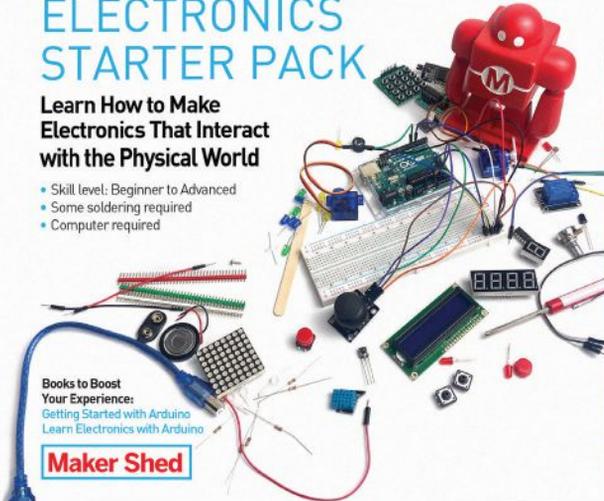
ARDUINO ELECTRONICS STARTER PACK

Learn How to Make
Electronics That Interact
with the Physical World

- Skill Level: Beginner to Advanced
- Some soldering required
- Computer required

Books to Boost
Your Experience:
Getting Started with Arduino
Learn Electronics with Arduino

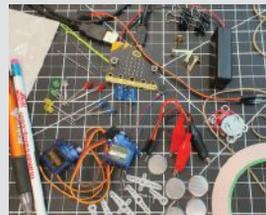
Maker Shed



Make: Arduino Electronics Starter Pack &
Getting Started with Arduino, 4th Edition book



Makey bit:Mobile Kit &
Getting Started with the micro:bit book



Making Simple Robots Starter Pack with kit
& Making Simple Robots book



Save 15% off select Kits with promo code
MAKE84 at [makeshed.com/kits](https://www.makeshed.com/kits)

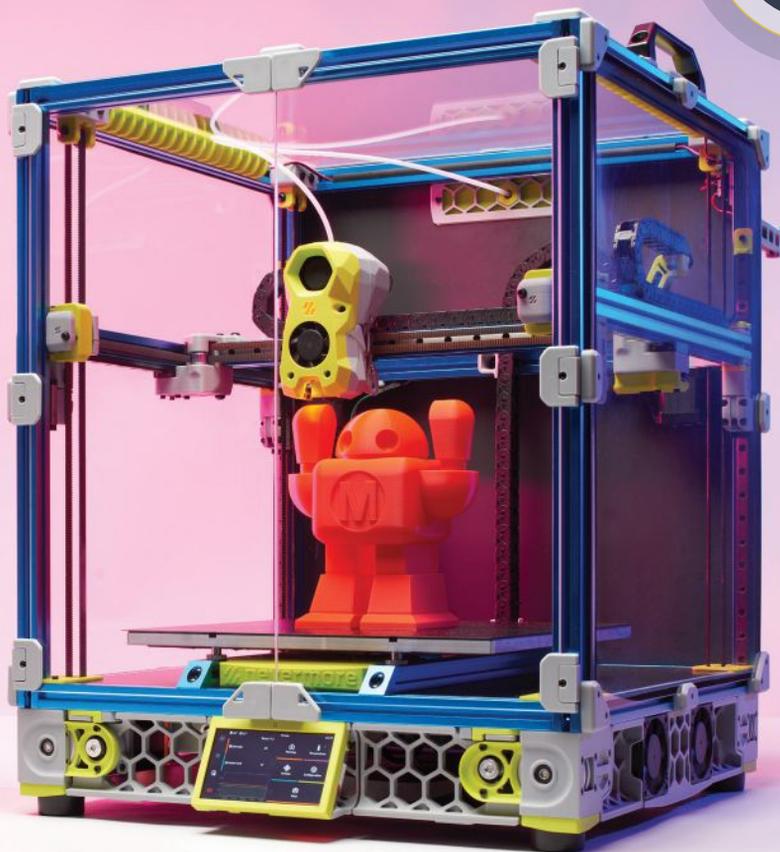
Maker Shed



On the Cover: Portable and wicked fast, the Voron 0 is the little pony that started it all (seen above with its bigger and even faster cousin the Voron 2.4).

Photos:
Mark Madeo and Debra Ansell

24



COLUMNS

Editor's Desk **05**

The latest updates from *Make:* and readers like you.

Welcome: The Amateur Enthusiast **06**

Newly minted ham radio operator Dale Dougherty reflects on the importance of amateurs building community and advancing tech.

MacGyver Challenge: S.O.S.! **07**

Can you MacGyver an ocean rescue signal in time?

Made on Earth **10**

Backyard builds from around the globe.

FEATURES

Unleash the Amateurs **14**

Lessons from the early days of radio show that amateur enthusiasts can take tech farther than companies or governments imagine.

A Beautiful Sight to See Through **18**

Students cut glass and solder to create stained-glass windows at Spokane's On Track Academy.

DIGITAL FABRICATION

Speed Demons **24**

Feel the need? A new generation of smarter machines are 3D printing up to 5 times faster.

3D Printing Gets a Brain **28**

Klipper firmware leverages a full embedded computer to make printers faster than ever.

Start Scanning **30**

3D scanning is easy with phone apps, photogrammetry, and accurate handheld and desktop machines.

CAD Your Way **32**

What's the best 3D design program? The one that fits your style! Narrow your search with these tips.

Print Me! **33**

Find 3D models fast for printing at these popular repositories, each with its own flavor.

Which Laser Should You Buy? **34**

Choose the diode, CO₂, or fiber laser that's right for your cutting and engraving projects.

Metal Blasters 38

Price break: Truly engrave metal for \$2K or less, with a new crop of infrared lasers.

CREATIVE AI

Generative AI for Makers 42

From art to 3D design to text, audio, and code, AI has truly arrived. Learn how it works and how it can help you make and craft.

AI Tools You Can Use Right Now 50

Get your hands dirty making your computer do the creative work. Here are dozens of AI tools to try.

PROJECTS

ORB-sessed 54

What's better than a cube of 150 LED pixels? Why, a sphere of 150 LED pixels!

30 Dollar Wind Turbine 64

Crank out the kilowatts with this ultra affordable DIY vertical axis wind generator.

Bright Lights, Big TV 74

Elevate your home entertainment setup with this Pi-powered ambient television backlight system.

Squishy Tech: Soft Speakers 82

Experiment with making wearable speakers and haptics using conductive textiles.

Anyone Can Use AI 90

Use a micro:bit to build your first AI project. From our upcoming book, *AI Robots*.

Zodiac Embroidery 96

What's your star sign? Stitch your favorite constellation and light it up for all to see.

Amateur Scientist: King of the Ring of Fire 100

Measure twilight glows to reveal the height of Tonga's volcano eruption — the highest ever recorded.

LED Pipe Dreams 104

Build a DIY seven-segment digital clock with glowing, flowing light pipes.

Make a Hygge Book Lamp 108

A few easy cross-stitches and you'll be reading by cozy candlelight.

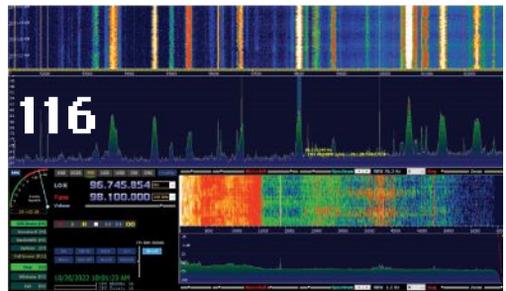
Toy Inventor's Notebook: Mini Infinity Cube 110

Reach for the stars with this simple kaleidoscope.

SKILL BUILDER

3D Scanning Artworks 112

Expert tips on capturing the classics volumetrically.



Getting Started With Software Defined Radio (SDR) 116

Eavesdrop on virtually the entire radio spectrum — for 30 bucks!

TOOLBOX

Toolbox 122

Gear up with the latest tools and kits for makers.

OVER THE TOP

"A Shrine to His Tools" 128

Henry O. Studley's tool chest is a work of art, packing nearly 300 tools into a handcrafted wooden marvel.

Mark Madeo, Andrew Sink, Brenda Shivanandan, Mike Senese, Becky Stern, Terra Gilbert

PRESIDENT

Dale Dougherty
dale@make.co

VP, PARTNERSHIPS

Todd Sotkiewicz
todd@make.co

EDITORIAL

EDITOR-IN-CHIEF
Keith Hammond
keith@make.co

SENIOR EDITOR
Caleb Kraft
caleb@make.co

COMMUNITY EDITOR
David J. Groom
david@make.co

PRODUCTION MANAGER
Craig Couden

CONTRIBUTING EDITORS
Tim Deagan
William Gurstelle

CONTRIBUTING WRITERS
Rhett Allain, Debra Ansell,
Erin Bangle, Sumit Basra,
Austin Beaulier, Kyle Chisholm,
Daniel Connell, Stefania Druga,
Andy Forest, Terra Gilbert,
John Ivener, Greg Gilman,
Bob Knetzger, David Lang,
Forrest Mims III, Kevin O'Connor,
Anuradha Reddy, Reade Richard,
Mike Senese, Andrew Sink,
Becky Stern, Lee Wilkins,
Lee D. Zlotoff

CONTRIBUTING ARTISTS
Bob Knetzger, Mark Madeo

MAKE.CO

ENGINEERING MANAGER
Alicia Williams

WEB APPLICATION
DEVELOPER
Rio Roth-Barreiro

DESIGN

CREATIVE DIRECTOR
Juliann Brown

BOOKS
BOOKS EDITOR
Kevin Toyama
books@make.co

GLOBAL MAKER FAIRE

MANAGING DIRECTOR,
GLOBAL MAKER FAIRE
Katie D. Kunde

GLOBAL LICENSING
Jennifer Blakeslee

MARKETING

DIRECTOR OF
MARKETING
Gillian Mutti

PROGRAM COORDINATOR
Jamie Agius

OPERATIONS

ADMINISTRATIVE
MANAGER
Cathy Shanahan

ACCOUNTING MANAGER
Kelly Marshall

OPERATIONS MANAGER
& MAKER SHED
Rob Bullington

LOGISTICS
COORDINATOR
Phil Muelrath

PUBLISHED BY

MAKE COMMUNITY, LLC
Dale Dougherty

Copyright © 2023
Make Community, LLC. All rights
reserved. Reproduction without
permission is prohibited.
Printed in the U.S. by Schumann
Printers, Inc.

Comments may be sent to:
editor@makezine.com

Visit us online:
make.co

Follow us:
@make @makerfaire
@makershed
makemagazine
makemagazine
makemagazine

Manage your account online,
including change of address:
makezine.com/account
For telephone service call
847-559-7395 between the
hours of 8am and 4:30pm CST.
Fax: 847-564-9453.
Email: make@omeda.com

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.

CONTRIBUTORS

*What's a project you
"keep meaning to get to"
but never quite do?*



Stefania Druga

Berkeley, California
(Generative AI for Makers)
I always wanted to build a
collaborative drawing
robot that can complete
my drawings or draw
side-by-side with me
using a webcam attached
above our canvas and
computer vision.



Anuradha Reddy

Malmö, Sweden
(Make a Hygge Book Lamp)
I keep meaning to make
3D printing designs
from scratch, not simply
modding a design
I downloaded from
Thingiverse.



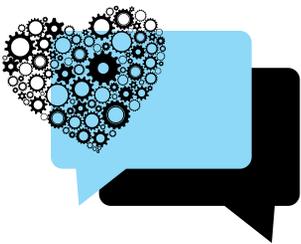
Daniel Connell

Edinburgh, Scotland
(30 Dollar Wind Turbine)
So. Many. To choose one,
the low-tech adiabatic air
coolant refrigerator / air
conditioner.

Issue No. 84, Spring 2023. *Make:* (ISSN 1556-2336) is published quarterly by Make Community, LLC, in the months of February, May, Aug, and Nov. Make: Community is located at 150 Todd Road, Suite 100, Santa Rosa, CA 95407. SUBSCRIPTIONS: Send all subscription requests to *Make:*, P.O. Box 566, Lincolnshire, IL 60069 or subscribe online at makezine.com/subscribe or via phone at (866) 289-8847 (U.S. and Canada); all other countries call (818) 487-2037. Subscriptions are available for \$34.99 for 1 year (4 issues) in the United States; in Canada: \$43.99 USD; all other countries: \$49.99 USD. Periodicals Postage Paid at San Francisco, CA, and at additional mailing offices. POSTMASTER: Send address changes to *Make:*, P.O. Box 566, Lincolnshire, IL 60069. Canada Post Publications Mail Agreement Number 41129568.

PLEASE NOTE: Technology, the laws, and limitations imposed by manufacturers and content owners are constantly changing. Thus, some of the projects described may not work, may be inconsistent with current laws or user agreements, or may damage or adversely affect some equipment. Your safety is your own responsibility, including proper use of equipment and safety gear, and determining whether you have adequate skill and experience. Power tools, electricity, and other resources used for these projects are dangerous, unless used properly and with adequate precautions, including safety gear. Some illustrative photos do not depict safety precautions or equipment, in order to show the project steps more clearly. These projects are not intended for use by children. Use of the instructions and suggestions in *Make:* is at your own risk. Make Community, LLC, disclaims all responsibility for any resulting damage, injury, or expense. It is your responsibility to make sure that your activities comply with applicable laws, including copyright.





FROM THE EDITOR'S DESK

READER INPUT

TEACHING CHAOS, DURING CHAOS

I just wanted to say thank you to one of your writers, Charles Platt. I really appreciate their article on Chaotic Pendulum — cat toy edition (“Chaotic Cat Toy,” *Make*: Vol. 58, page 72). I found this article very, very useful when we had to switch to remote labs in our physics class.

—Dana L, via email



ON WORKING WITH MAKE:

I quickly wanted to thank everyone involved. It was amazing to see BFree in the physical copy of *Make*: magazine (“Perpetual Battery-Free Weather Station,” Vol. 82, page 82). I never had access to the magazine as a kid, as it was more a U.S. thing, but the website and also later the YouTube channel got me started in electronics, so it was super cool to be featured in *Make*!

Thanks a lot. It was a fascinating process.

—Vito Kortbeek, Netherlands

NEW SOCIAL SPACES

MASTODON.SOCIAL

We've been having a blast on Mastodon: the free, open-source micro-blogging platform (à la Twitter), where anyone is free to spin up a server with its own culture and moderation policy. Join us at mastodon.social/@makemagazine.

DISCORD

Our Discord server is growing! Join the #makechat channel and talk about what you're making and see what others are making, too. Discord is a real-time chat platform where users can congregate in channels to discuss topics or share interests. We've also been using Discord to host our “after parties” for online events, like the recent Volume 83 Launch Party and our monthly Hangout & Nerdout. Join the party at makezine.com/go/discord.

LIVESTREAM EVENTS

Speaking of Hangout & Nerdout, picture this: 3 hosts + 3 nerds × 1 topic! Our joint livestream with Hackster covers subjects like Wearables, Art, Space, and Music, and features familiar faces from the pages of *Make*!, like Anouk Wipprecht and Sophy Wong — as well as some new faces that we can't wait for you to meet! The first portion consists of presentations and panel discussion, which is then followed by a fully interactive meetup where you can ask our guests all your burning questions about that month's theme. Dates and times vary, so check out events.hackster.io/hangoutnerdout for details on our next event!



The Amateur Enthusiast

by Dale Dougherty *K1N6WJKW*, President of Make: Community

I recently deleted my Twitter account and I got a call sign.

To become a licensed ham radio operator, you have to pass a test. To prepare you, local amateur radio clubs offer courses like the two-and-a-half day one I took. One of my instructors told me he was a ham because his friends went to Maker Faire Bay Area and came back enthused about becoming hams and he joined them. The lead instructor had been a ham for 48 years, which says something about how endlessly fascinating some people find the art of amateur radio.

What came across in the class was not just the technical information you needed to pass the test but the lore of the ham radio community, its norms and enthusiasm for the practice:

How lucky we are that the U.S. government 100 years ago decided to allocate portions of the radio spectrum for amateurs, explicitly to encourage experimentation. You can imagine what that spectrum's worth today, but we get to use it for free. Look at all the things we can do with it, especially in emergencies. We can't believe there are fewer than 800,000 who accept this responsibility and get these amazing privileges as ham radio operators.

Then the way they talk about radio waves and antennas — it's science that explains how it works, but it's magic that it does. It reminds me of the way I talked about the internet in the early 1990s: *Through your computer, you can make a connection to somewhere far away instantly!*

David Lang's article "Unleash the Amateurs" on page 14 of this issue illuminates the early days of radio and how experimentation by amateurs led to technological innovations. In the early 1900s, he writes, "There was hardly a delineation between amateur and professional as everyone was trying to build better equipment." Amateurs also formed clubs to train people, which had particular value as the U.S. entered World War I and suddenly needed trained radio operators.

Today much of what ham radio equipment does can be done in software, which is called Software Defined Radio (SDR). On page 116, Tim Deagan

writes about how to use the inexpensive RTL-SDR USB dongle to create a powerful radio listening station at home. These devices — developed by amateurs in the 2010s — convert analog radio waves into digital signals that can be processed in software like CubicSDR to tune in an enormous range of frequencies. All of this can done on a Raspberry Pi. The limit of RTL-SDR is that you can receive but not transmit. Transmission requires a ham radio license.

We can also see what amateur makers brought to 3D printing, from early homebrew efforts like RepRap and MakerBot, to today's new "speed demon" 3D printers featured on page 25. "Way more powerful firmware that computes acceleration/deceleration, smarter extrusion, and the machine's own vibration/resonance much better than before, to achieve 200mm/sec speeds instead of being satisfied with 60mm/sec," *Make:* editor Keith Hammond told me. "It's all coming from the amateur community." Klipper is the open source RasPi firmware, and Voron is the leading open source machine that deploys it.

Also in this issue, Forrest Mims, perhaps the world's foremost amateur scientist, explains how you can measure the aerosol clouds from the January 2022 Hunga Tonga volcano eruption — the world's highest — that are still visible at sunset today.

Makers, hams, and citizen scientists share the combination of a technical culture and community. The amateur community is where the real magic is and no one can quite explain why they do what they do. Twitter doesn't have that kind of community and that's why I'm not on Twitter anymore. If you're a ham, I'd love to hear from you. 📻





MacGyver Challenge: S.O.S.!

CAN YOU MACGYVER AN OCEAN RESCUE SIGNAL IN TIME?

By Lee D. Zlotoff and Rhett Allain

We are all MacGyvers now! Make: is bringing Mac back to help you think — and make — your way out of emergencies and disasters. Watch for the next MacGyver challenge on the Make: website (makezine.com), Mastodon (@makemagazine), Twitter (@make), and Facebook (makemagazine) and enter your solutions for a chance to be featured in these pages and win Make: goodies!

THE SCENARIO

You and two people from your team at work have been burning the midnight oil for weeks to submit a project by the deadline — which you've met. And the project's been approved. So, to celebrate and enjoy some much-needed R&R, the three of you head out for a day of ocean fishing on your well-appointed motorboat. What's more, you've all agreed to leave your phones on shore to guarantee some time without screens. After a spectacular day with lots of freshly caught fish in the cooler, you discover that the engine won't start. And, for all its bells and whistles — like a motorized anchor winch — your boat has no radio. And you can all see the skies are quickly darkening and there's a storm headed your way.

THE CHALLENGE

Using whatever you can find from the boat and the list of items below, how can you come up with a way to signal for help before you and your mates become food for the fishes?

WHAT YOU'VE GOT

And it's *all you've got*:

- Any part of the boat
- Flotation devices
- Fire extinguisher
- Drinking water
- Fishing gear
- Anchor and chain
- Snorkeling gear (but no scuba)
- A 5-gallon container of gasoline plus whatever's in the boat's tank
- A basic tool kit, including a Swiss Army Knife
- Duct tape, of course
- An unopened box of 30-gallon black trash bags

TURN THE PAGE FOR SOLUTIONS!



LEE ZLOTOFF is an award-winning writer, producer, and director of film and TV, including *MacGyver* (1985–1992). His new production, *MacGyver: The Musical*, casts a different audience member as Mac at each performance. macgyver.com



RHETT ALLAIN teaches physics at Southeastern Louisiana University. He was technical consultant for the *MacGyver* reboot (2016–2021) and an advisor for *MythBusters*. He blogs about physics fun at rhettallain.com.



MacGyver Challenge: S.O.S.!

OUR SOLUTION

Create a radio transmitter. Impossible? Not so fast. We're going to build the first kind of radio: a *spark gap transmitter* (aka *wireless telegraph*). The idea is to produce electrical sparks that broadcast radio waves on a broad range of frequencies.

Of course, you need a battery to supply the electrical current. It won't have enough voltage for large sparks, so you'll boost it by building an inductor: basically a coil of wire, maybe wrapped around a ferromagnetic core, like iron. An inductor produces a voltage that's proportional to

the rate of change of current. So that means we need to turn the current on and off very quickly.

One trick is to use this same inductor as an electromagnet that pulls a wire off a contact to stop the magnet, which immediately makes the wire reconnect and turn on the current again, and so on (this is the idea of an electric buzzer). With that, you just need to take another wire to tap an electric contact — and remember your Morse code — to send a radio signal.

MOST PLAUSIBLE SOLUTION

Much like our solution, David Honess (via Mastodon) says to "make a very basic oscillator that works at radio frequencies" and then send an SOS, though he leaves off the details.

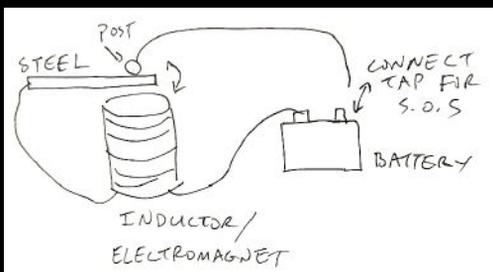
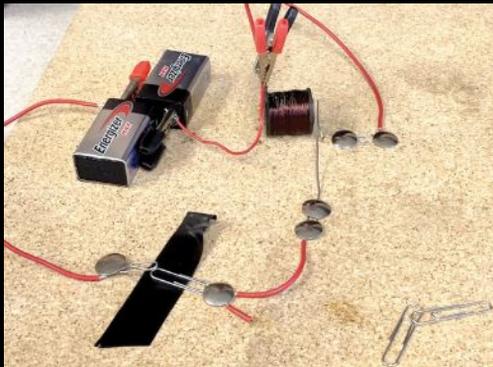
MOST CREATIVE SOLUTION

Mike Fish (on the *Make*: blog) and @AreScoops (Twitter) both thought to take the battery and two conductors in the water to create electrolysis, separating the H_2O into hydrogen (H_2) and oxygen (O_2). Collect the hydrogen gas with a trash bag to make an impromptu balloon to signal for help.

Very creative, but making enough hydrogen would take time. Another problem is the trash bags — great at holding trash, not so great at holding hydrogen (but should work in a pinch).

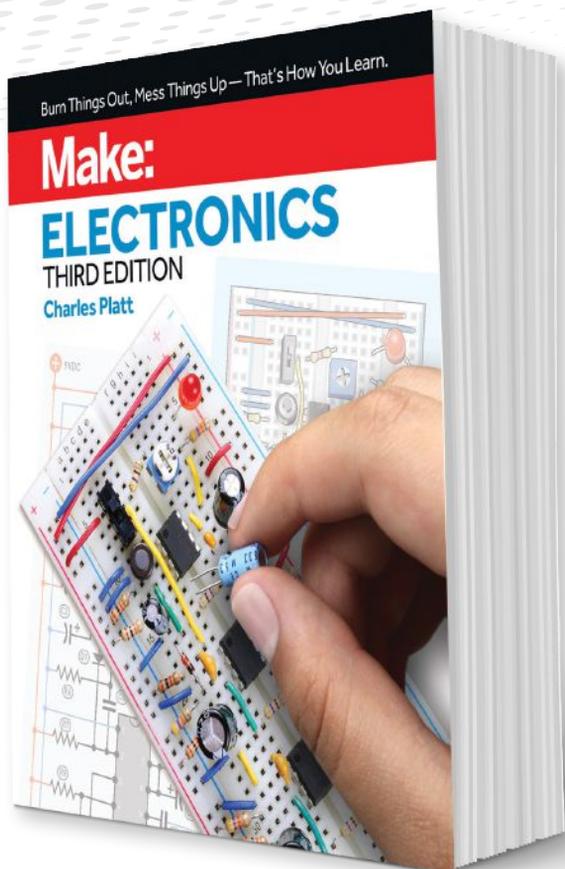
HONORABLE MENTION

Derek Fox (Facebook) would remove the engine's alternator and spin it manually by wrapping a cord around the shaft. With each pull, it creates a current. Connect to the boat lights for a signal. 🗨️



Make: Books

LET CURIOSITY LEAD YOUR
LEARNING JOURNEY



Make: Electronics, Third Edition

by Charles Platt \$34.99

NEW COLOR ILLUSTRATIONS!

Starting with basic concepts, this friendly and comprehensible guide takes the reader step-by-step toward circuits of increasing complexity. The principle of Learning by Discovery, pioneered by Charles Platt, uses hands-on experiments to create a lasting and entertaining learning experience.

OTHER GOODIES TO GRAB:

Make: Calculus

by Joan Horvath and Rich Cameron
\$29.99

Robot Magic

by Mario Marchese
\$24.99

Making Simple Robots, Second Edition

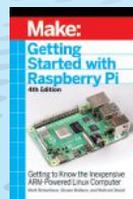
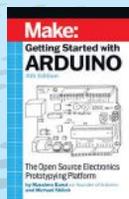
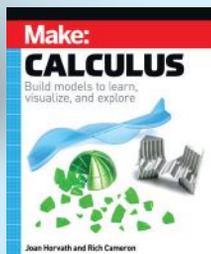
by Kathy Ceceri
\$24.99

Getting Started with Arduino, Fourth Edition

by Massimo Banzi and Michael Shiloh
\$19.99

Getting Started with Raspberry Pi, Fourth Edition

by Shawn Wallace, Matt Richardson,
and Wolfram Donat
\$24.99



Make: Books are also available on [amazon.com](https://www.amazon.com)

Save \$5 off these titles with promo code **DOESCOMPUTE** today!

makershed.com

MADE ON EARTH

Backyard builds from around the globe

Found a project that would be perfect for Made on Earth?

Let us know: editor@makezine.com



FLEXIBLE FLORAL CIRCUITS

TYMKRS.COM

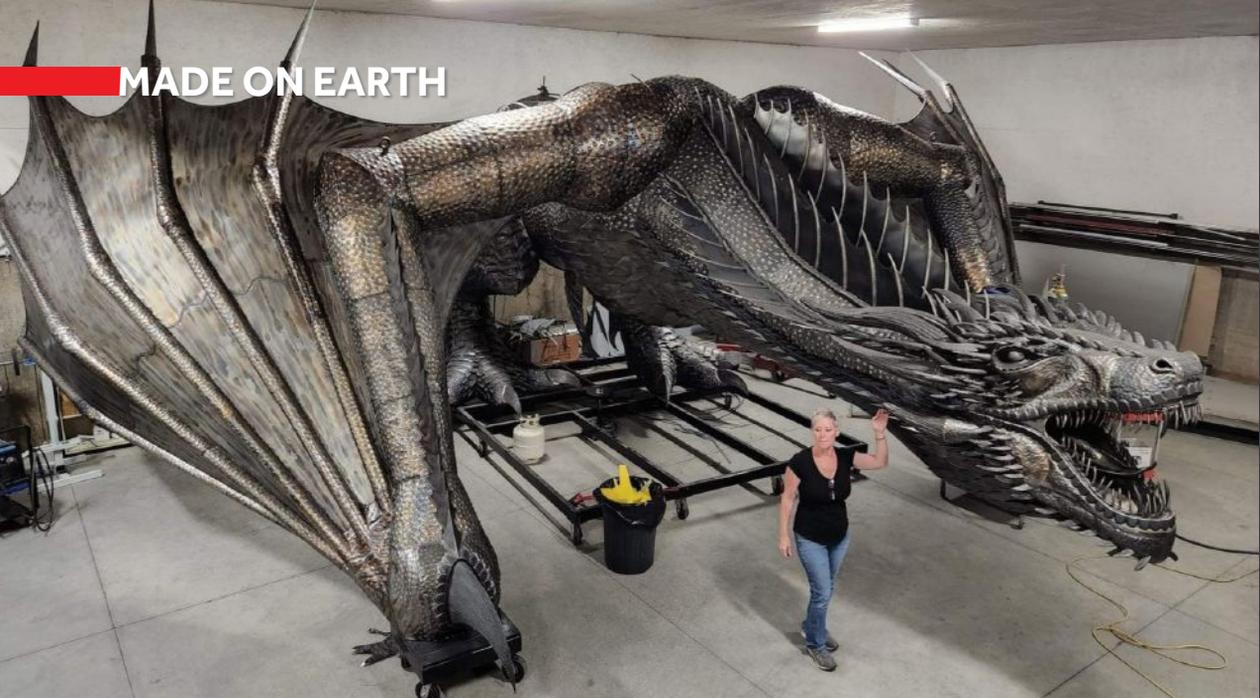
In the world of hobby electronics, the concept of making the circuit itself — the components, the wires, the underlying material — into an artwork is a well-respected endeavor. People have been making pretty circuits, or sneaking tiny designs etched into the functional engineering, since the dawn of electronics. Having such a rich history, it's even more impressive when something new blossoms out of that fertile soil.

Atdiy of the **Tymkrs** (pronounced "Toymakers") came up with this interesting new take on artistic PCB design, harnessing the somewhat newly approachable flexible PCB services out there. Her idea was to use the flexible materials to emulate the petals of a flower, while carrying the electricity to light up tiny LEDs mounted to it.

Just like some of the most sought-after plants in the world, this one went through a peculiar gestation period. Her initial concept designs were produced and sat in storage for years between attempts to make this project work. Constructing circuits with flexible PCBs takes a delicate touch, and Atdiy had to learn how to work with her flower to get it to bloom. Out of 20 attempts, only 13 petals survived.

In the end, her sculpture serves as a beacon of creativity, and reminds us that there are always new discoveries to be made, even in areas that we thought to be fairly well explored. —*Caleb Kraft*





A DANCE WITH DRAGONS

[YOUTU.BE/JXW27KKY-E4](https://www.youtube.com/watch?v=JXW27KKY-E4)

Game of Thrones was an immensely popular TV show for much of its running. There were very few people who didn't gaze at the gorgeous dragons on screen in the later seasons and wonder what it would be like to stand in front of one of these beasts; to feel the blistering heat as they stretched out their necks and exhaled plumes of flames. Sculptor **Kevin Stone** doesn't have to imagine: he's brought this experience to life.

This 15,000lb stainless steel sculpture of Drogon, the biggest of the dragons from the show, stretches over 55 feet long and is 30 feet tall in his crouching position. If he were to spread his wings, he would be over 100 feet wide!

The real icing on this cake, however, is that when constructing the sculpture Stone also had a "poofier," a propane-powered flame system, designed so that this dragon really can breathe fire. After over two years of work hammering, shaping, welding, and generally sculpting Drogon out of steel, Stone will have to say goodbye. Drogon is headed on to his final home, a private owner who is just waiting for the time that they can step outside their house and say "Dracarys" to unleash a dragon's fury. —Caleb Kraft



Kevin Stone

EARTH SQUARED

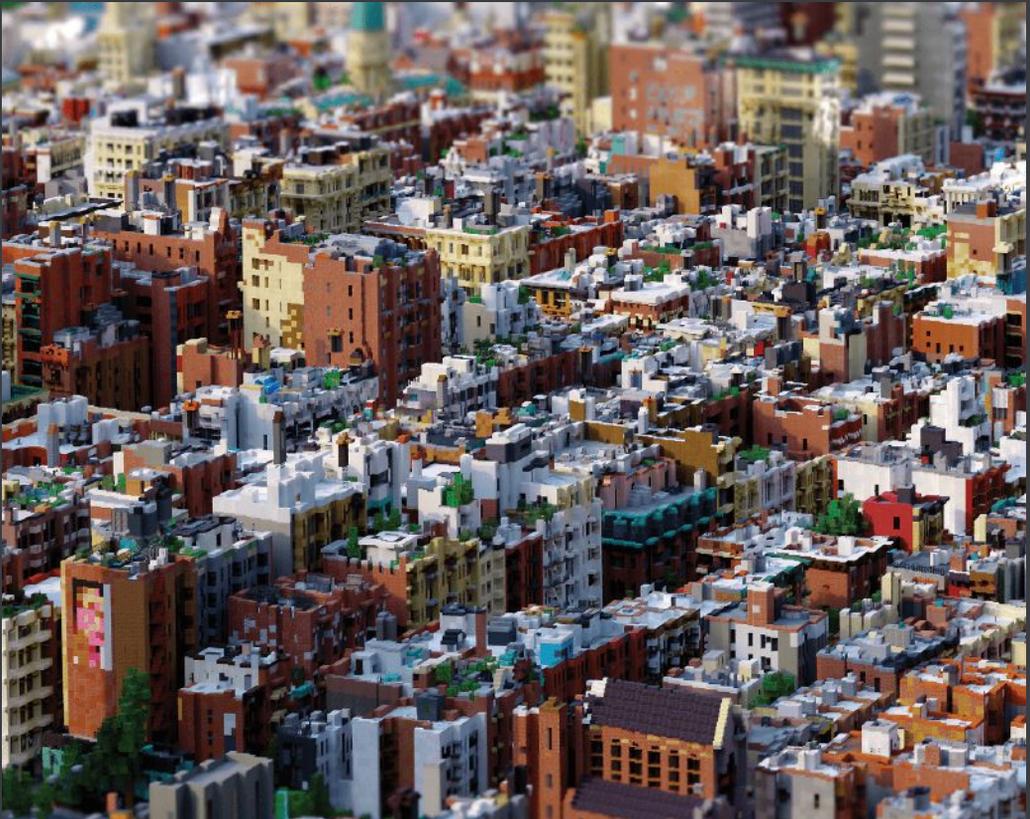
BUILDTHEEARTH.NET

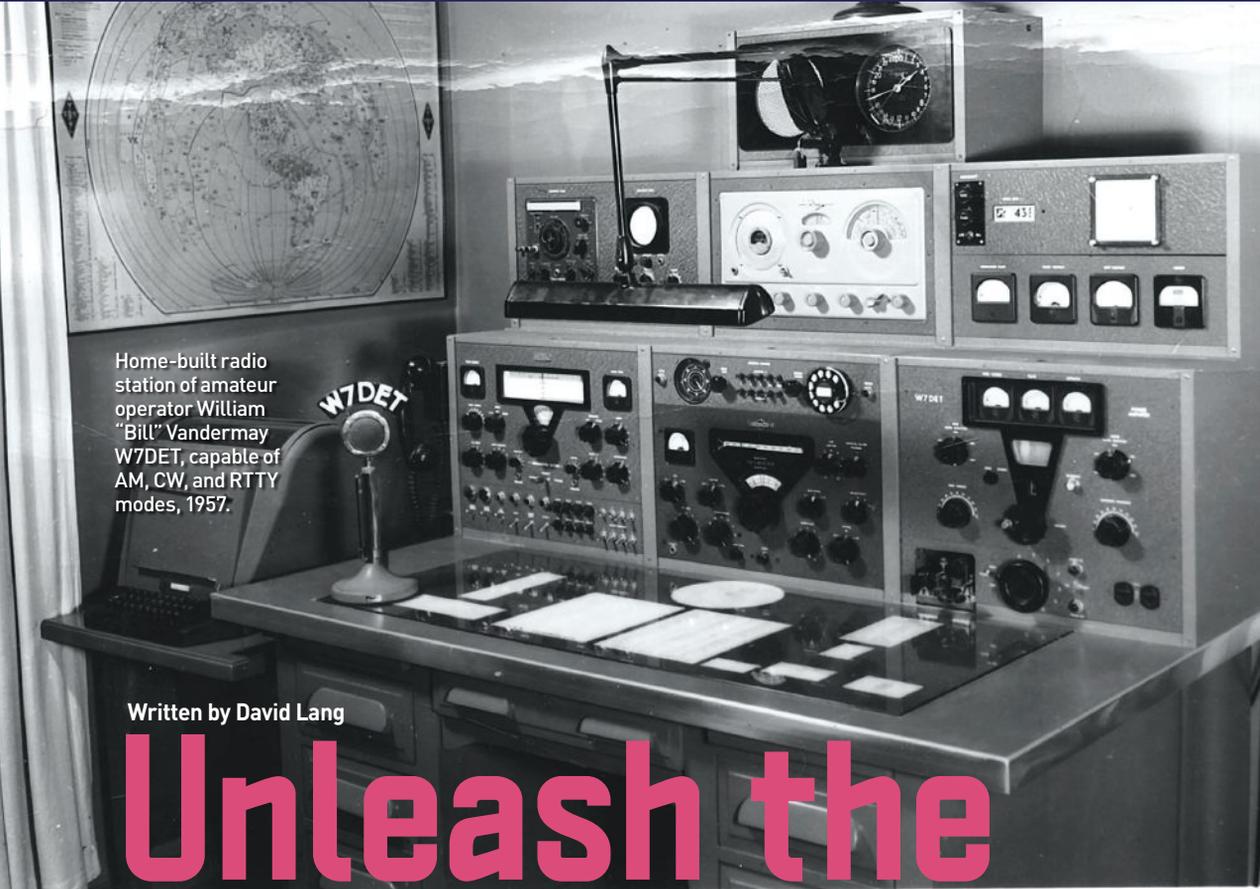
Building a 1:1 scale model of planet Earth in *Minecraft* used to be a pipe dream. But now, a YouTuber named **Pippen** is leading the effort to make it happen, with thousands of builders working across the globe on 80 teams.

Though the project is only in infancy, the cityscapes rendered so far, as well as the massive organization through Discord servers, show the historic collaboration is off to an impressive start. 100,000 buildings have been built, per Pippen, who rallied players to join the cause after discovering the *Minecraft* terrain modification that makes a 1:1 recreation of the planet possible. Pippen did what YouTubers do best, and immediately made a video to showcase the little-known mod to his subscribers. “And so that video went nuts,” he tells *Make*. “We ended up getting over 200,000 members, and we’ve been working on the project ever since.”

Now, there are about 170,000 people in the network of Discord servers dedicated to each virtual country, and more are welcome to join an existing team or create their own. For Pippen, who works full-time as a leader, builder, and video producer for the project, this is a work of art “beyond imagination,” and may one day serve as a digital record of our civilization. “Aliens or future civilizations would be able to discern what human civilization was like through our map,” he explains.

But before extraterrestrials can ever marvel at this virtual Earth, the project needs a boost from artificial intelligence. Even though they have some tricks using Google Earth to help outline various structures and game mods to make building faster, it takes a human 15–60 minutes to create one building, leading Pippen to estimate completion at current pace in *80,000 years*. The solution is automation, and he’s optimistic an AI tool will eventually produce one building per minute, making completion possible in “decades, if not years.” —*Greg Gilman*





Home-built radio station of amateur operator William "Bill" Vandermay W7DET, capable of AM, CW, and RTTY modes, 1957.

Written by David Lang

Unleash the AMATEURS

They'll take tech farther than companies or governments imagine. Lessons from the early days of radio



DAVID LANG is the executive director of the Experiment Foundation and the author of *Zero to Maker*. davidlang.com

Guglielmo Marconi's early experiments in wireless communication, particularly his radio transmission during the 1899 America's Cup yacht races, had sparked broad interest in the nascent technology. The press was closely covering these developments, which helped Marconi's popularity but also tantalized others who longed to try and re-create his tests. They got their wish when *American Electrician* published detailed construction information. This initial wave of amateur experimenters were in luck, as Marconi's design could be built with parts that were readily available.

A DIY DECADE

The first decade of radio, from Marconi's trans-Atlantic feat onward, was a period of rugged experimentation and lawlessness. Inventors raced for technological advantage. There was hardly a delineation between amateur and professional as everyone was trying to build better equipment. Reginald Fessenden's invention of the radio-frequency alternator was the first device to produce a continuous wave. Lee De Forest created the audion, or three-element vacuum tube, which amplified and improved the received signal. Competing inventions from Marconi, De Forest, Fessenden and others were all fuel for the development of the technology. But it was the discovery of the crystal detector, when used as a simple and inexpensive tuner for the receiver, that truly enabled the home experimenters.

Amateur "wireless clubs" formed across the United States at both the local and national level. The national organization, the Wireless Association of America, published *Modern Electrics* to document and disseminate information. The circulation of the publication shows how quickly the field of amateur radio operators was developing. Within a few months

of launching in January 1909, they had more than 3,000 subscribers. By the end of 1910 that number had swelled to 10,000, then to more than 50,000 by March of 1911. In addition to *Modern Electrics*, resources like the *Wireless Blue Book*, which listed the member stations across the country, and A.P. Morgan's book, *Wireless Telegraph Construction for Amateurs*, contributed to the knowledge base.

REGULATION AND INNOVATION

The authorities were constantly trying to stamp out amateur radio operators. As early as 1904, the President had appointed a board to address the growing concern of wireless telegraphy. Both the Navy and the Army had set up radio stations, recognizing the potential for communication and military use. They wanted to utilize and control the technology. One of their biggest problems was interference, made worse by the growing legion of amateur operators across the country. The Navy determined to reign them in.

The issue grew into a series of legislative battles. From 1902 to 1912, dozens of bills dealing with radio regulation were introduced in Congress. Only one passed, which mandated radio communications on ocean steamers. The amateurs withstood the regulatory assault during this period mostly by luck. The Marconi Company was the chief opponent of most of this legislation, thinking that continued amateur interference would force the Navy to buy superior equipment (theirs, of course). The amateurs were also starting to recognize their own power, even without formal representation. The networks of clubs and their thousands of members were proving a strong enough collective to survive, however disorganized they may have been.

It was enough to endure, but not enough to articulate a strong position. The legislators took a different strategy. Instead of trying to eliminate

the amateur operators, they would box them in: give them the wavelengths below 200 meters. The working theory at the time — held by all, professional and amateur — was that shortwave radio was mostly useless. The longer the better, or so the popular thinking went. Ships were using wavelengths between 450 and 600 meters, for example. The bill passed the House and was signed into law in August of 1912. The Radio Act of 1912 had set the stage for the next wave of amateur innovation.

The amateurs mostly fell in line. More than 5,000 amateur and private stations — roughly half of what was thought to exist at the time — applied and received licenses to operate after the first full year under the new law. The growth of the hobby wasn't deterred by these restrictions, mostly owing to the popularity of wireless clubs.

Amateur innovation continued. A 22-year-old named Edwin H. Armstrong had built a radio laboratory in his attic. Using a De Forest audion, he got the idea to re-amplify the signal by arranging the tube to feed the output circuit back into the input. The result was a clearer signal and much stronger amplification. Armstrong's invention would eventually lose out in a major court battle for priority with De Forest himself, but it showed the eagerness and ability of amateurs to improve the technology. The tools were getting better with use.

A LEAGUE OF THEIR OWN

The next major innovation was not technical, but organizational. Hiram Percy Maxim, an accomplished inventor who had recently taken up radio and set up the Radio Club of Hartford, had needed to send a message to Springfield, Massachusetts, to inquire about the purchase of a vacuum tube. Springfield was out of calling range for Maxim, so he devised a workaround: an acquaintance in a midway location, a fellow amateur by the name of Windsor Locks, would relay the message to the seller. The experience seeded an idea: create a network of amateur stations to serve as "relays" that would adhere

to a common code for passing messages to far-flung destinations. Such a network, Maxim theorized, could help to bind the diversity of clubs and stations into a unified group. In May of 1914, the American Radio Relay League was born.

Supported by dues-paying members, the League grew quickly, and the proficiency of relay transmission improved with operational practice. By the end of 1915, amateurs had regained the level of high performance they had enjoyed prior to the debilitating Radio Act of 1912. "With home-made equipment, often not exceeding a hundred dollars in total cost, and in the despised 200-meter region, they were frequently outperforming government and commercial plants representing investments of thousands of dollars," wrote League historian Clinton DeSoto.

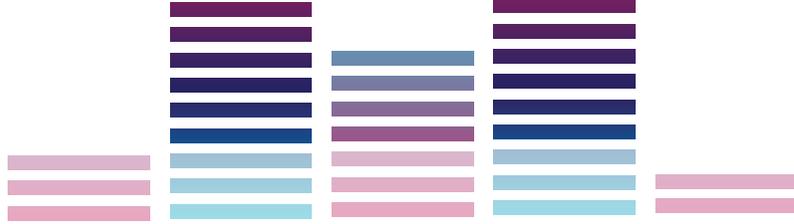
With the League, amateurs now had a layer of coordination at the national level. They were capable, numerous, and organized. And just in time.

AMATEURS SAVE THE DAY

In April of 1917, the United States entered the Great War, now called World War I. Suddenly, the U.S. military was in dire need of a trained and capable radio corps. Lacking the time to train a large force, they turned to the amateur ranks.

The Navy called Maxim. They needed five hundred operators in less than two weeks. Moreover, they were lacking in equipment. They asked the amateurs not only to join, but to bring their tools and station apparatus along. The League sent out the call over the airwaves. Within 10 days, the Navy had the operators they needed.

The Army followed suit, commissioning League secretary Clarence Tuska to train operators. "I have turned out a whole lot of operators for the Air Service and have become pretty well acquainted with the type of humans it takes to make a first class radio operator," Tuska wrote. "The first sort of a student we looked for is an ex-amateur. He seems to have had all the experience



and all we have to do is acquaint him with a few special facts and he is ready for his Army job. ... A man without previous experience is almost hopeless.”

All told, it's estimated that up to 4,000 amateur radio operators served in the military during WWI. They performed with the highest marks and helped win the war.

BIRTH OF BROADCASTING

Once back home, the amateurs picked up the pieces of the organization they had paused. They also picked up the pace of exploration on the frontiers of radio technology. As it turned out, the “worthless territory” they were given below 200 meters wasn't so worthless after all. And this time it wasn't just the military taking advantage of the amateur experiments. The world was following their lead into the emerging era of broadcasting.

Throughout the first decade of radio, Marconi, De Forest, and the inventors-turned-entrepreneurs were busy trying to grow their businesses. That meant finding customers who would pay for their services. The Navy was one. Marconi and others were also trying desperately to disrupt the existing communication business of the time: the telegraph. They thought their technology was replacing the telegraph and the telephone — a new form of one-to-one communication. While they were busy analyzing what the business was, they failed to imagine what the technology could become.

The bureaucracies — corporate and military —

dismissed the amateur operators, even as their numbers swelled and the hobby boomed. But the amateurs were prototyping the cultural use of radio. The phenomenon was emergent. “Listening in” to broadcasts became a popular activity. People were curious about how other people were living and radio became a window into a new world.

By 1922, companies and newspapers began to catch on. Broadcasting was here and it was going to be huge. It was an overnight success two decades in the making. Herbert Hoover, then U.S. Secretary of Commerce, organized a conference to promote and understand this “astounding” development in American society. The rest — the rise of broadcasting and its influence on our modern world — is now history, even as the role of the amateur is less well known.

THE NEXT GREAT AMATEUR SCENE

It always happens to amateur technology scenes; they become footnotes. Makers and coders remember Woz; the world remembers Jobs.

But for those of us who care about the next technological frontiers and their cultural implications, the lessons are as important today as they were a century ago. The development of personal computing and the web would have been impossible without the contributions and mutual skill-building undertaken by amateur developers. Today's amateur scenes are breaking new ground in technologies of all kinds, from artificial intelligence to drone racing to 3D printing to autonomous vehicles.

The best (and fastest) method for understanding how a new technology will fit into society? Give it to the amateurs — the people gathered for the love and thrill of the tool itself — and let them show the way. 🎯



Claire Koziel solders a panel as part of an advanced student collaboration. Claire says soldering is her favorite part of the process and she has mastered the skill to the level of teaching many of the beginning students how to do the same.



Written and photographed
by Erin Bangle

A *Beautiful* Sight to See Through

Students cut glass and solder to create stained-glass windows at Spokane's On Track Academy

I completed my first stained glass project in fourth grade with the help of a neighbor who had a small glass studio in her home. It was monstrous work, but I thought it was beautiful and I proudly displayed it in my room for years. I have no idea what happened to it, but I do remember how proud I was that I built it myself. I loved choosing from all the gorgeous colors and glass textures — and I was trusted with all those fancy tools. I knew how to do something no one else did.

With a passion to create those same feelings in my students, I began a stained-glass program 13 years ago in a portable classroom at On Track Academy in Spokane, Washington ([facebook.com/ontrackacademy](https://www.facebook.com/ontrackacademy)). I have crawled on hands and knees through barns, garages, and yards across the Inland Northwest to stockpile stashes of glass and tools.

Once the supplies are in place, students learn how to stay safe: Broken glass is sharp and soldering irons are hot. Chemicals do not belong in your mouth and safety glasses are our friend. They learn the science of how glass is made, how it gets color and texture. We discuss why glass is important to humans; and then we create with it.

Stained glass is a craft that is hard and unusual. It's one part art and one part science. It requires several steps and it's expensive. Even with patience and skill you will at some point start over. Repetition is your ally. Dreams, and monstrosities, are built here. Both are welcome.

GIRL POWER

When I was in high school in the early 90s, girls were still steered to home economics and boys to industrial arts. Girls were not taught to build — but here I am now teaching girls to solder. It's really something special when I have a room full



Rachel Peterson solders a stained-glass panel. Her piece took three awards in a statewide art competition and is now part of a student exhibit on tour throughout the State of Washington.



Rachel Peterson polishes a panel created during a collaboration with advanced design students from our local community college.



ERIN BANGLE "Queen of Awesome," has been teaching for 23 years. When not teaching, she's working on glass projects, taking photos, or feeding her kids. Or doing all three. [facebook.com/ErinEmmaSideHustleGlassArt](https://www.facebook.com/ErinEmmaSideHustleGlassArt)

of young women soldering.

One of my prized students, Claire, lives for it. "The only thing better than soldering is when I get to teach the boys to solder," she says with an animated grin. Daily, she wields an 800-degree soldering iron with confidence and skill and says that teaching others to use it is her favorite part of the day.

I affectionately call Claire a "2.0" — one of

FEATURES Glass and Grit

several returners to the program after a year in it. She is proficient in stained-glass building and has mastered complex designs. Others like her have passed a series of tasks and tests, and in this capacity, they can help co-teach and share what they know with their peers.

“CREATE WHAT’S NEXT”

I am part of a teaching team that includes yearbook, 3D modeling, laser cutting, and rapid prototyping. The stained-glass program began as a “something-different,” so to speak, activity for students to try. We wanted to build something not offered anywhere else. I don’t think anyone ever imagined it would one day be an award-winning part of our material science program.

Stained glass is just one of our tools to help students stay connected and “create what’s next” — our motto — in their lives.

I want to be clear; we are not trying to create future stained-glass artists. We are engaging students to stay in school and grow the confidence to find their way to post-secondary education and ultimately a career they will enjoy. We operate on a block schedule, so students have the time to focus on projects and master skills before moving to their next activity.

At On Track Academy, we serve the underserved, which includes any student looking for something different than a traditional high school can provide. In the process of engaging those who had been labeled un-engageable, we found ourselves serving a broadening population of students with needs that the stained-glass elective program fulfills. No matter their background, they all share one thing in common: Our students have grit.

STUDENTS BECOME TEACHERS

The days of portable classrooms are over. We’re now housed in a brand-new, multi-million-dollar school building that is state of the art. In my classroom, we now have access to a kiln and will incorporate glass fusing into the program this year. When the weather is nice, we can open the garage door and take in fresh air. We got a chance to put it on display to the public last spring when we expanded our role by offering a night class for adults. Once a week for nine weeks, the 2.0s



Najahna Smith plans the next pieces for a large panel of birch trees titled *Faded*. The piece eventually took home a first-place prize in a city-wide Holocaust art competition.



Student Emma Daniels stands over three of her adult students for a lesson in cutting glass during a weekly night course taught by advanced stained-glass students to adults in the community.

taught stained glass to adults in our community.

The students shined brighter than the glass.

Fellow teachers, a couple of architects, and even college professors, furrowed their brows, dug in, and ... proceeded to struggle. They didn’t have to look far for help though. A 17-year-old with purple hair and lavender boots with 6-inch heels was there to the rescue. She had the skill set to cut even the most persnickety pieces of glass we have to offer.

Their voices quivered a little during week one as they explained the different types of glass and the science behind how they are created. The following week, my students were showing their adult pupils how to solder and cautioning them on what to do if they burned themselves. It was a beautiful sight.

MAKING A *Stained Glass Window*

Here is the 10-step process we follow to make stained glass windows.



1. COLLECT THE TOOLS

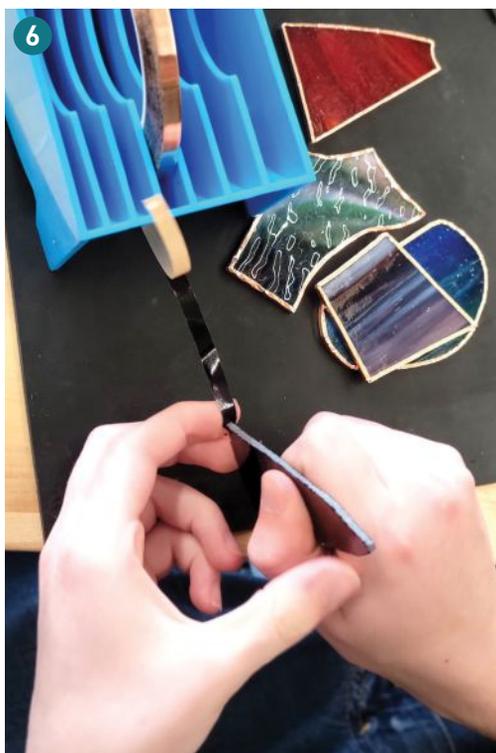
Safety glasses, glass cutters, various glass breaker pliers, glue sticks, and you're going to need a soldering iron and solder, and probably Band-Aids. These are just the basics. You will add to your tool kit as you improve.

(I asked the students what Step 1 should be and one said, "Get a small loan, because everything is so expensive.")



2. MAKE YOUR PATTERN

Sometimes we use a pattern we found, but I teach my advanced students to start designing their own. You can find countless options online, but our endgame is to create original work. Our students like to create their patterns using Procreate, a popular digital illustration app.



3. TRANSFER TO GLASS

There are different ways to tackle this step, but the technique we use is to cut out the pattern and glue it on the glass.

4. CUT

You don't cut the glass like a piece of bread. You use your glass cutter to score the glass in the direction you want to cut, then break it neatly along that score line. With practice, deep curves and other detailed breaks can be made. We use breaker pliers to finish the job, and sometimes we

turn the glass over and tap the other side to finish breaking a score.

5. GRIND

We use a grinder to get the glass to the exact size for the pattern. We can now smooth out rough edges and snags. We then clean and dry each piece of glass.

6. COPPER

Each piece must now be wrapped in copper foil tape. This is because we will next solder the glass

together — and solder won't stick to the glass. It will, however, stick to copper. The foil is sticky on one side and we burnish the tape — that is, rub it using a burnishing tool — to the glass so it is secure. If it's not, your piece will fall apart.

7. SOLDER

Soldering alone has several steps and it takes a lot of practice. The solder is one part tin and one part lead, and it will stick to the copper foil, but only after you apply a layer of a chemical called flux. We use the soldering iron to melt hot solder to strategic spots on the piece to tack them all in place so they won't move. Then, completely cover any copper we can see by soldering a smooth “bead” line down each seam. If the glass gets too hot, it can crack. If you use too much flux, your solder lines will bubble and not look as neat. Soldering is an art form.

8. CLEAN

We use Dawn and baking soda to scrub the piece clean. It's important for it to be clean and flux-free for the chemical process in the next step to work.

9. PATINA

Patina is now applied to the clean solder lines. Patina creates a chemical reaction that instantly gives the solder lines the nice, dark finish that naturally would occur over time. We rinse the piece clean one more time.

10. POLISH

We polish our pieces using black car polish, if our solder lines have been stained black with patina, or with other products if we left them natural silver. This step is most important because when you're done, you then show it to everyone who will look, and brag about how awesome you are. You also take pictures and post on social media and let everyone bask in your coolness.



...

Since this all began, there has never been a year in which I did not find myself marveling at the efforts and abilities of my students. Their tenacity and determination transfers to building glass creations, beautifully. Despite their challenges,

they cheerfully “rise and grind” for the chance to build something magical out of stained glass. And they can tell you in detail and with confidence each step they took along the way. 🎯

DIGIFAB 2023

NEXT LEVEL

What's new in digital fabrication? So much! Suddenly 3D printers are vastly smarter and five times faster. Laser engravers can cut metal for under \$2,000, and cheap workhorse diode lasers are everywhere. Pro-level 3D scanning is on your phone, and 3D design software has a flavor for every style of maker. Now's the time to level up!

CONTENTS:

Speed Demons.....	25
Blazing Benchies.....	27
Why Klipper Rips.....	28
Scanner in Your Pocket....	30
3D Design Your Way.....	32
Best 3D Model Repos.....	33
Which Laser to Choose.....	34
Metal Blasters.....	38

SUPERCHARGED: Anker's first foray into 3D printing, the AnkerMake M5, is fast and smart.



Written by Sumit Basra



SUMIT BASRA

is a maker, video producer, and engineer. He loves taking projects from initial ideas to finished products.

SPEED DEMONS

FEEL THE NEED? A NEW GENERATION OF SMARTER MACHINES ARE 3D PRINTING **UP TO 5 TIMES FASTER**

3D printing is great but it's always been sloooooow, with average print speeds for extruder movement around 60mm/sec. But in the past year or two, that number has gone up quite a lot, with some printers printing reliably at a blazing 250 or even 300mm/sec. That means a 4-hour print could take just 48 minutes!

There's a ton of reasons to want faster 3D printers — lower cycle times for prototyping, quicker turnaround for orders, and just higher throughput when printing batches of parts — so it's not surprising that manufacturers are constantly pushing for more speed.

But it's not just mechanical tweaks; there are smart new electronics and software going into this push too. The addition of more powerful computers such as Raspberry Pi, combined with the open-source firmware Klipper, allow for far better motion control and faster processing of commands to increase both speed and precision. Some machines even have onboard AI to monitor the print and keep it on track. Notably, these innovations are coming from both industry newcomers and amateurs in the 3D printing community ("3D Printing Gets a Brain," page 28).

You don't need to go out and buy a new printer. With a Pi, an inexpensive accelerometer board,

and some new software, you can breathe new life into an old machine with higher accuracy, quality, and speeds. But if you're in the market for a new machine, there are a few solid options that're fast right out of the box, with extra smarts that make the printing experience much more seamless.

With companies like AnkerMake and Bambu Lab, high-speed and consistent 3D printing has quickly become significantly more accessible. And if you're looking for a less "plug and play" solution, the Voron project is a great way to get a custom printer that's exactly what you want.

ANKERMAKE M5

Made by the same company best known for their charging tech, the AnkerMake M5 is an i3-style printer that can print up to 250mm/sec right out of the box with 0.1mm detail. With a build volume of 235×235×250mm, there's plenty of room for pretty much any project. Along with size and speed, you also get some intelligence: a 1080p camera and dual processors for AI error recognition and notification, live monitoring, and remote access to your printer.

Starting at \$799, the M5 appears to be a good combination of speed and reliability — in YouTube reviews of the preview machines (it's still in pre-

order at the time of this writing). With the optional V6 Color Engine to print up to 6 colors, the AnkerMake M5 has the potential to unlock a new level of creativity with 3D printing. But all of this does come at a cost — the design is proprietary. If something were to go wrong, there wouldn't be an open source option for repairs, only those provided by AnkerMake.

BAMBU LAB X1

Bambu Lab's X1 3D printer isn't just fast. Along with print speeds that push 250mm/s, there's a suite of sensors for AI-powered calibration — accelerometers, force sensors, and lidar — so the X1 prints reliably and consistently. This, combined with lightweight rails, a high-performance hot end, and a sturdy chassis, help make the process of 3D printing easier and faster. And a build volume of 256×256×256mm is plenty of space to print large parts or larger batches of smaller parts.

Starting at \$999 with the base model X1, Bambu Lab has been able to make a fairly plug-and-play 3D printer that's also optimized for speed. Much like AnkerMake, Bambu Lab also has their own optional Automatic Material System that supports up to 4 colors and can be linked with other units to print up to 16 colors and take prints to a whole new level.

VORON

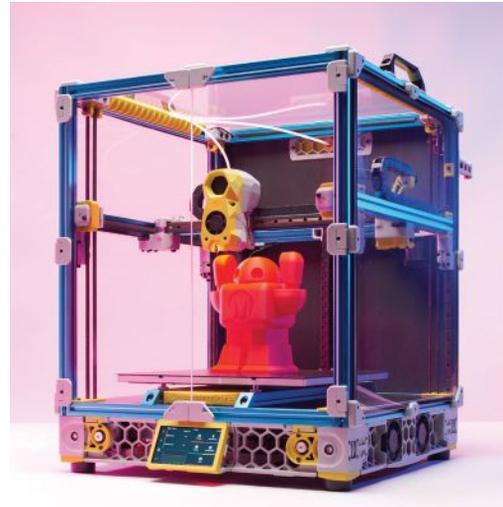
The Voron project (vorondesign.com) is an open-source set of printer designs that are quiet, consistent, and really fast. Rather than sell you a full printer, Voron compiles a list of parts that you need to buy and provides STL files for the printed parts. There's even a configurator so you can customize your setup and get the exact list of parts you need. You can also buy a kit from vendors such as LDO Motors.

Started in 2015 by Apple engineer Maksim Zolin, Voron quickly gathered a community of dedicated engineers and amateurs with the common goal of "creating production-quality printers you can assemble in your kitchen."

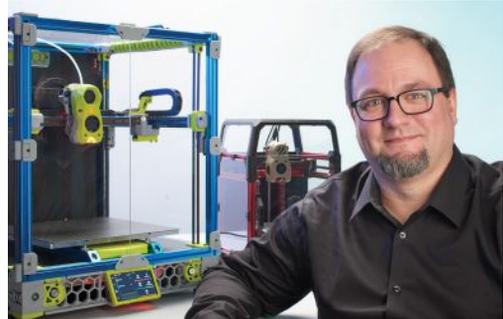
Since Voron just provides a BOM, the price does vary based on the size, configuration, and source of parts that you pick. But Vorons are built for Klipper, designed to push 200mm/s while printing



STRAP ME IN: Multi-color Makey printed on the Bambu Labs X1 using their Automatic Material System.



HOME-BUILT HOT ROD: Wicked fast and reliable, the Voron 2.4 takes a variety of high-performance extruders.



BORN FREE: Apple engineer Maksim Zolin founded the open-source Voron project.

Sumit Basra, Mark Madeo

consistently without constant repairs. The latest design, Voron 2.4, has been clocked at 350mm/sec with excellent part quality. It may not have the AI features you get from the X1 or M5, but if you're looking for a printer that you can customize and rely on, a Voron is the way to go.

I know they look cool, but what really makes a machine a Voron? That's a question that gets asked a lot, actually. Aesthetics are in the front of people's minds, but being able to build this from commodity parts and being able to print this at home is a big part. It's really one of the few remaining RepRap projects where you're actually truly getting off-the-shelf parts, printing your own custom parts, and then putting it all together in your garage. These are engineered to do fast prints, unattended, and for a long time.
—Maksim Zolin at Midwest RepRap Fest 2022

ALTERNATIVE SPEEDSTERS

If you prefer something outside the traditional, Cartesian-style FDM printer, there's plenty of speed to be found with delta and resin printers. The FLSun Super Racer delta definitely lives up to its name, hitting 200mm/s. On the resin side, the Phrozen Sonic Mega 8K prints 70mm/hr (vertical) with a massive 330×185×400mm volume, while the much smaller Prusa SL1S Speed claims to be the fastest at 80mm/hr.

GAME CHANGED

There are lots of superfast 3D printers out there, and lots that are incredibly reliable, but these new printers that can do both — consistently print fast — are a game changer. It's just the start of a new wave of 3D printers that will continue to refine the user experience and get rid of the guessing for things like "Is my first layer going to stick?" or "Will this print be OK overnight?"

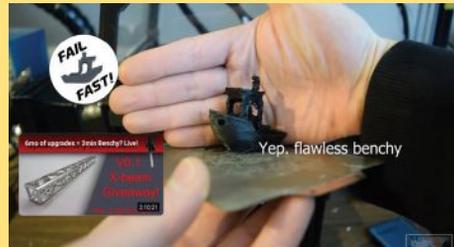
Both Bambu Lab and AnkerMake are relatively new to the market, with these being their first printers. And open source options like Voron and Klipper are only the start of what the maker community is capable of doing; high-speed features are now being added to Marlin and RRF firmwares as well. If this is what we have now, I'm excited to see what comes next. 🚀



FLSun Super Racer



Phrozen Sonic Mega 8K



Blazing Benchies!

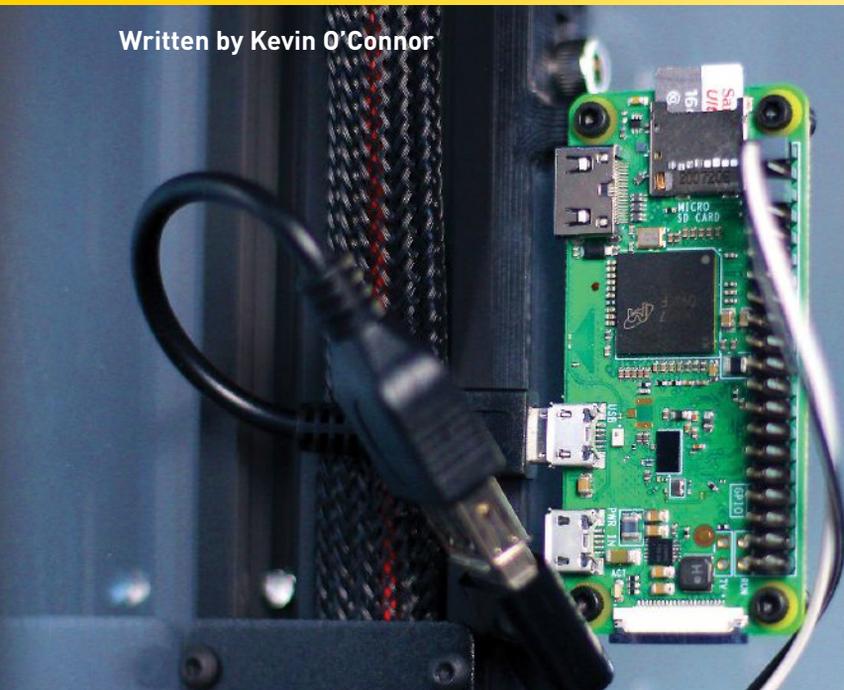
The cute little tugboat named Benchy (3dbenchy.com) is a very popular file to 3D print to benchmark your machine, hence the name. Of course, being a benchmark file, it seemed the perfect tool to use when the modding community took a page from the classic car community and started really hot rodding their 3D printers, hitting insane speeds of 600, 1000, even 1500mm/sec.

This group of intrepid tinkerers posts their exploits on YouTube and it can be thoroughly entertaining. The machines move so quickly they look like they're about to vibrate to pieces! Just for example, the channel Fail Fast! managed to produce this Benchy in 2 minutes 43 seconds on an over-amped Voron 0 (youtu.be/uQh1aNwr4Aw). For comparison, my stock 3D printer takes roughly 90 minutes!

Of course, at that speed, quality left a lot to be desired — fast but ugly! — but I've seen others print beautiful Benchies in less than 10 minutes. —Caleb Kraft

3D PRINTING GETS A BRAIN

Written by Kevin O'Connor



KEVIN O'CONNOR

is the original author and current maintainer of Klipper (klipper3d.org). You can support this open source project at ko-fi.com/koconnor or patreon.com/koconnor.

KLIPPER FIRMWARE LEVERAGES A FULL EMBEDDED COMPUTER TO MAKE PRINTERS FASTER THAN EVER

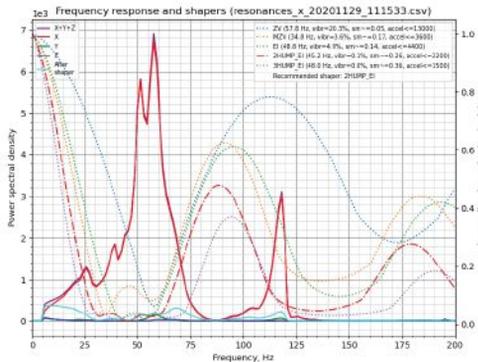
I wrote Klipper to do something different from what other 3D printer firmware does. Much of the existing software is designed to work within the limits of the tiny computer on the printer's mainboard — typically referred to as a microcontroller. The software works, but it tends to put as much emphasis on getting things to work on a tiny computer as it does on manufacturing excellent quality objects.

My goal was to model some interesting physics in software, so as to improve the quality of the final printed object. Getting the physics model correct is itself a large challenge — getting

it to also run on a tiny computer would be a nightmare. Others have run into these limits as well, but past solutions basically involved replacing a “very tiny” computer with a “mostly tiny” computer. I took a different route, and Klipper was born.

LET'S GET PHYSICAL

On Klipper the software starts with the physical models. We process those models in Python (and a little C) on a real, general purpose computer, typically a low-cost Raspberry Pi. The software then determines the best robot actions needed



RATTLE AND HUM: Klipper detects your printer's unwanted vibrations and cancels them out.

to follow the desired physics; those actions are arranged in a schedule of events, compressed into a small stream of data, and sent to the microcontroller. All the microcontroller has to do is rip through the events using the timing described in the schedule.

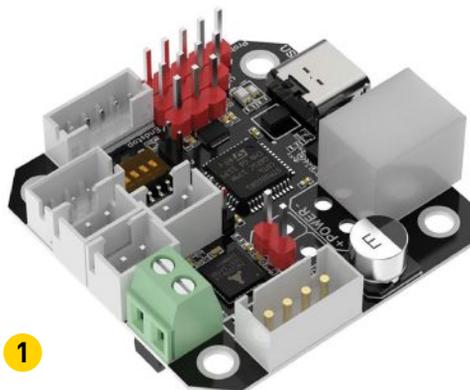
Because Klipper starts with the physics and uses a real computer, it is able to implement some advanced transformations that improve the quality of resulting objects. For example, the *input shaper* can model the machine's vibration (caused by rapid movements) and produce *resonance compensation* movements that minimize its impact (less "ringing" artifacts in printed objects). Input shaping has a rich history in CNC machines, but Klipper is the first to deploy it widely in 3D printers. Klipper's unique *smooth pressure advance* models the fluid pressure of plastic in the hot-end and can reduce ooze that causes blobbing and stringing artifacts on objects. These transformations can enable faster print times while maintaining excellent quality.

It's worth pointing out that Klipper does do things differently. If you have a printer that is working well for you, it's unlikely that Klipper will revolutionize it. Klipper has been most successful as a tool to "push the envelope." It has helped facilitate machines with many motors (for example, the Voron 2.4 machine with seven motors) and high-speed movements (for example, 300mm/sec and faster). The hardware in some of these machines was designed to take advantage of Klipper's capabilities, just as Klipper has evolved to drive these machines.

That said, Klipper will run on a large number of

WHY KLIPPER RIPS

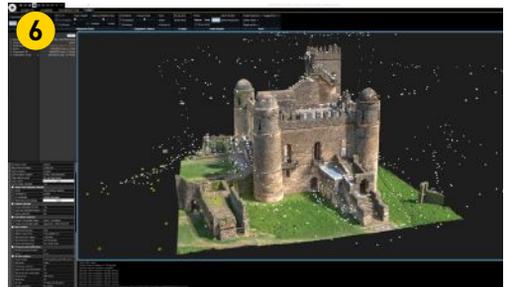
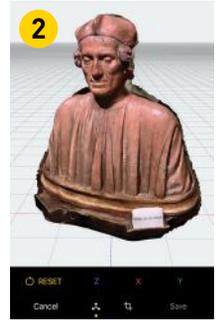
- **Bigger brain, faster motion control:** Klipper models the motion physics on a real computer, so all the printer's microcontroller has to do is rip through scheduled motor movements with microsecond timing.
- **Resonance compensation:** Like noise-canceling headphones, Klipper detects your printer's vibrations, and adjusts its motion to erase them.
- **Smooth pressure advance:** Predicts molten filament pressure to reduce ooze during non-print moves and blobbing at corners.



ACCELERATED: Klipper's success has spurred a market of accelerometer "toolhead boards" like this one from BigTreeTech (1), but can also use a good old breakout from Sparkfun or Adafruit (2).

existing machines, both homemade and out of the box. If you're interested in tinkering, or just want to try a different approach to 3D printing, then feel free to download the software and try! Klipper is Free Software (free as in freedom). 🍷

START SCANNING!



Andrew Sink, Revopoint, Shining3D

3D SCANNING IS EASIER THAN EVER, WITH PHONE APPS, PHOTOGRAMMETRY, AND ACCURATE HANDHELD AND DESKTOP MACHINES **Written by Andrew Sink**

Just like 3D printing, 3D scanning has exploded in popularity over the past decade and it's now easier than ever to get started with this exciting technology. 3D scanned models can be printed on 3D printers, uploaded to repository sites like Sketchfab to view and share online, or used as assets in video games and VFX.

If you have a smartphone, you already have all the tools you need to make your first 3D scans. Interested in creating higher quality models? Desktop 3D scanners allow you to scan extremely detailed models while also retaining the original color texture for use in VR/AR.



ANDREW SINK first used a 3D printer in 2012 and has printed everything from a scan of his own brain to a PB&J sandwich (seriously). He works as a senior applications engineer at Carbon, a leading additive manufacturing technology company.

3D SCANNING MOBILE APPS

1 POLYCAM

poly.cam free to scan, \$7/month or \$55/year to export

One of the easiest-to-use and most powerful smartphone apps available, Polycam can create models using photogrammetry (stitching photos together to calculate a 3D model) as well as lidar (distance-based laser scanning ideal for large objects like rooms, cars, and furniture). Polycam lets you export common file types such as *.obj*, *.stl*, and *.fbx*, as well as direct export to Sketchfab for sharing your model virtually. It's compatible with iOS and Android, and also offers a web-based interface for drag-and-drop uploads.

2 TRNIO

trnio.com \$5

While not as robust as Polycam, Trnio is an easy-to-use iOS app offered at only \$4.99 for unlimited scans. Trnio only utilizes photogrammetry (lidar is currently not supported), but it can quickly capture 3D scans when you're on the go. If you're looking for an inexpensive introduction into 3D scanning on an iOS device, Trnio is an excellent place to start.

DESKTOP 3D SCANNERS

3 REVOPOINT POP 2

revopoint3d.com \$699

The Revopoint POP 2 is a powerful structured-light scanner that can capture high-quality mesh geometry as well as full-color textures. Revopoint advertises the POP 2 as being accurate down to 0.01mm, or 10 microns, at 10 frames per second. Its minimum scan volume is 20mm³, which makes this desktop scanner ideal for scanning action figures, statuettes, and other small models with lots of detail.

4 SHINING3D EINSCAN-SE

einscan.com/einscan-se \$999

Shining3D's EinScan-SE is a white-light scanner that's designed for beginners and first-time users. Its integrated turntable moves the model automatically between frames, preventing motion blur or jitters from appearing in the texture. It's made to scan objects between 30mm³ and 700mm³ and offers a streamlined software experience to quickly go from 3D scan to 3D model.

PHOTOGRAMMETRY APPS

5 METASHAPE

agisoft.com \$179 standard, \$3,499 pro

Metashape is a photogrammetry app ideal for converting photos taken with a DSLR into a high-quality 3D model. The workflow is a little more complicated than smartphone apps, but Metashape is capable of making highly detailed 3D models from high-resolution photos that are ideal for 3D printing. The \$3,499 professional version enables georeferencing and other features designed for drone photography, while the \$179 standard version is more than powerful enough for most hobby users. Metashape is available for Windows, MacOS, and Linux.

6 REALITYCAPTURE

capturingreality.com variable pricing

Recently acquired by Epic Games, RealityCapture is a robust photogrammetry application designed for creating high-quality 3D assets. If you're interested in scanning the side of a mountain and want an ultra-realistic model to use for VFX, RealityCapture would be a good place to start. Unlike MetaShape, RealityCapture uses a credits-based, variable pricing scheme, so your cost will depend on the amount of scan points in your project. RealityCapture is only available for Windows. 🚫



CAD YOUR WAY

THE BEST 3D DESIGN PROGRAM? THE ONE THAT FITS YOUR STYLE

Written by Caleb Kraft

“Which 3D modeling software should I learn?” That’s a really tough question to answer! There are so many options, from simple to complex, free to thousands of dollars.

The best choice depends on your personal style of creation. If you break it down that way, you end up with some pretty well defined categories. There are platforms that appeal to artists first, to technical engineering gurus, and to jacks of all trades.

So which should you choose?

Artistic Sculpting

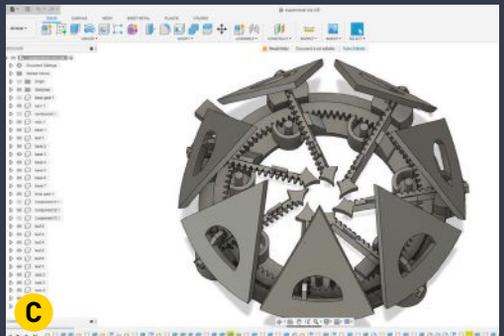
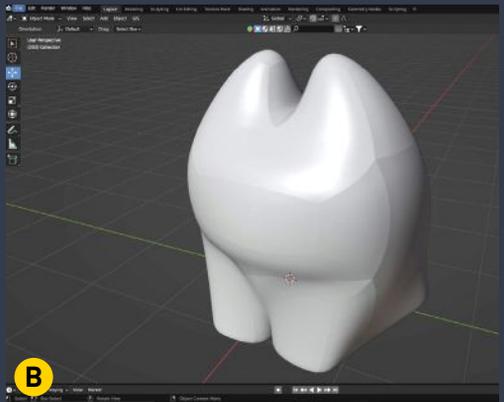
Are you most comfortable with the thought of sculpting in clay? Do you want to carve shapes out of a block and flex those artistic muscles? Do straight lines annoy you? Give **ZBrush**, **Nomad Sculpt** (Figure **A**), **Forger**, **SculptGL**, or other digital sculpting platforms a try.

3D World Building

Are polygons old friends to you? Do you want powerful rendering tools and the ability to animate? Do you think maybe you’ll expand your work beyond simply 3D printing a file, into say, gaming or animation? Then look into **Blender** (Figure **B**), **Autodesk 3ds Max**, and **Maya**.

Engineering and Manufacturing

Precision is the name of the game with this group. You’ve got serious engineering to do, and despite all the features of the other platforms, they don’t have the tools to accurately lay out items for precision manufacturing. This group of CAD programs has those design tools, and sometimes additional tools specifically designed to help in the manufacturing process. Check out **SolidWorks**, **Autodesk Fusion360** (Figure **C**), **Autodesk Inventor**, **OpenSCAD**, and **FreeCAD**. ☑



CALEB KRAFT is senior editor of *Make*: and has been 3D printing since 2013.

PRINT ME!

FIND 3D MODELS FAST FOR PRINTING, AT THESE POPULAR REPOSITORIES *Written by Sumit Basra*



There are many places to find STL files but some are definitely better than others. I'll go to different sites depending on the type of file that I'm looking for. Here are my top five.

Printables printables.com

My go-to site when I'm just looking for a file to send to the printer. It's really community-focused with regular design contests that enable a growing ecosystem of new and creative 3D prints. There's a reward system that encourages both designers and users to participate by publishing models or uploading "makes" of files they've printed.

Printables has hundreds of thousands of users and 300,000 models and it continues to grow. Currently all the files are free, but Prusa Research has said that there are plans to add monetization features in the future.

MyMiniFactory myminifactory.com

If you're looking for models for a session of D&D, MyMiniFactory is the best repo for you. A lot of the models here are different characters and architecture designed for various tabletop games. Unlike Printables, MyMiniFactory has both free and paid models.

One thing unique to MyMiniFactory is their Customizer — you can upload a bunch of models in a group so people can modify and choose which parts they want. This is a really easy way to personalize models before you print them. And for designers, this makes it a lot easier to upload multiple variations of a single model without having to make and export them one at a time.

MyMiniFactory also has a Scan the World project (see page 115 of this issue) that aims to create an ecosystem of 3D scanned cultural artifacts, and lots of other community elements that allow creators to write stories, monetize their designs, and take part in competitions.

Cults cults3d.com

For more art- or jewelry-focused STLs, I usually turn to Cults. As opposed to more functional parts, the designs on Cults are generally more aesthetic and fun. Cults also has both paid and free models.

Head over to the Top STL section to check out what's popular. Without fail, there's always something that catches my attention.

Thangs3D thangs.com

Thangs is the newest repository, but it's growing incredibly fast. There's a ton of great, free designs from awesome makers like ChaosCoreTech and 3dprintbunny.

Not only does Thangs search its own models, it also searches external websites — almost like the Google of 3D printing. You can even upload a model and search for others with similar geometry.

There's also a built-in collaboration system so you can work on projects with others and keep track of changes through a version control system.

Thingiverse thingiverse.com

Thingiverse is the largest and longest standing STL repository. Started by MakerBot back in 2008, it was the first great place to find free files and engage with others with similar interests.

Despite the large collection and giant user base, Thingiverse has its issues. The biggest one for me is the broken Download All function — for designs with a lot of parts, I have to download each one individually. Ads are now put in with the models, a subpar experience. Not to mention the data breach that made the personal information of many users publicly available. 🚫



SUMIT BASRA is a maker, video producer, and engineer. He loves taking projects from initial ideas to finished products.



WHICH LASER SHOULD YOU BUY?

CHOOSING
THE **DIODE**,
CO₂, OR
FIBER LASER
THAT'S RIGHT
FOR YOUR
PROJECTS

Written by Caleb Kraft



CALEB KRAFT is senior editor of *Make:* and thinks lasers are wild magic.

Lasers are friggin' awesome. I think it's safe to say that isn't a controversial stance. Not only are they awesome in pop culture, with laser guns and laser-wielding sharks, they're awesome in a workshop where they cut things with nothing but focused light.

Makers are confronted with so many choices of laser cutters and engravers that it can be intimidating. I'd like to guide you through a rough outline of the main differences between the lasers you'll find on the market today, in order to help you choose.

WHAT'S AVAILABLE?

For a typical home workshop or a makerspace, there are three main options. From cheapest to most expensive, you have **diode lasers**, **CO₂ lasers**, and **fiber lasers**. Prices can range from a couple hundred dollars to tens of thousands, so it's important to make an informed decision.

WHICH ONE DO I NEED?

That is the key question, isn't it? Your decision will be determined by what you intend to do with it, and of course your budget. To make things easier, I'll focus on four main factors: price, speed/power, size of work area, and whether or not it can work in metal. I'll elaborate more on each technology afterward.

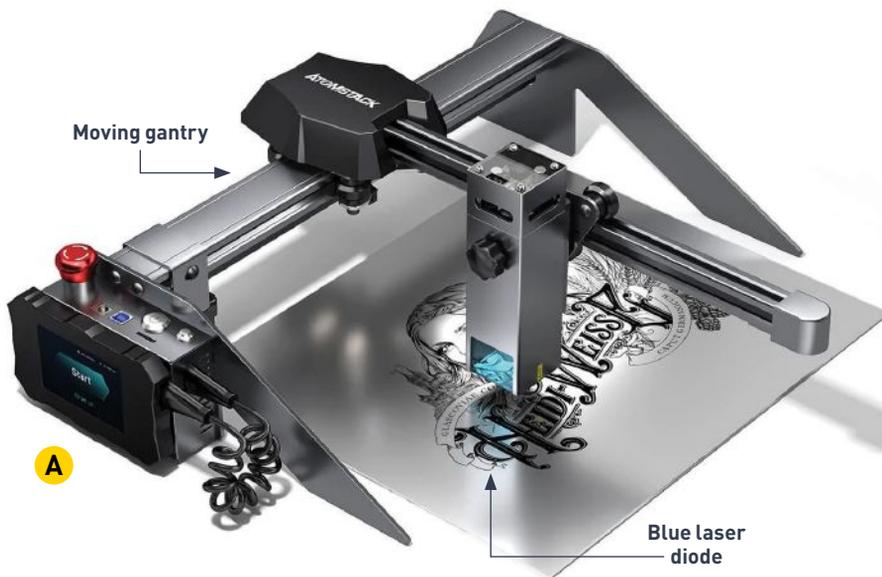
THE LOWDOWN

- **DIODE** = cheapest, slowest, mid/huge work area, don't cut metal*
- **CO₂** = mid price, faster, mid/large area, don't cut metal
- **FIBER** = expensive, fastest, small area, do cut metal

DIODE LASERS

These are becoming so common, I see them everywhere now. You've seen them too. They are a simple, open-air X-Y gantry with a block mounted on it that contains a laser diode (Figure **A**). These operate in blue light, typically around 450 nanometers (nm) frequency. They're very cheap because the components are readily available and there just isn't much involved in their construction. They're comparatively very weak though. Their output is going to be 20W and lower, and they get to this power by combining multiple 5W–6W diodes into one beam internally.

**metal engraving — There's a new slate of diodes in the 1064nm range of infrared (IR) light, which can engrave metal. See "Metal Blasters" on page 38.*



The 450nm frequency of laser light can engrave and cut materials like wood, paper, and leather, but will bounce off highly reflective surfaces and won't affect metal at all. Typically these units are small, with a working area under 2 feet square on even the largest, and most being smaller than that. However, they're extremely light and sit on the work surface. Using software like LightBurn to create massive art, you can simply move the entire unit on top of the work surface, lining up individual sections of a much larger complete design.

You will find these starting around \$150 and going up from there. Machines in this category:

- **Atomstack P7** atomstack.net
- **xTool D1 Pro** xtool.com

NOTE: A frustrating trend in this market is to advertise diode lasers by the power draw of the entire machine as opposed to the actual output of the laser. You'll see a "150W" machine advertised that actually has less than a 10W output. So far, we only see this in cheap diode lasers and not the other types.

CO₂ LASERS

CO₂ lasers are typically seen as a big box with a gantry inside (Figure **B**). These use a giant glass (or sometimes aluminum) laser tube that produces light roughly at the wavelength of 10,600nm or 10.6 micrometers (µm). These start at 30W and can go up to hundreds of watts. They're capable of engraving and cutting absorbent materials, and especially at higher powers, even reflective and clear materials like glass. However, this frequency does not allow them to engrave metal.

CO₂ lasers gain speed over diode lasers simply by being more powerful, so they can cut things in fewer passes. They're also often built with much beefier motors and gantries so they can move faster. The smallest of these machines will fit a standard piece of printer paper and they go upward from there, quickly becoming the size of a small car.

You'll find these starting around \$400 for small models like the generic K40, and going up from there. Some machines in this category:

- **Glowforge** glowforge.com
- **Makeblock / xTool Laserbox** xtool.com
- **Full Spectrum Lasers Muse** fslaser.com



B



Best DIY Upgrades to K40!

To hot-rod an inexpensive K40 laser cutter, check out "Make That Laser Blaze," *Make: Volume 81*, makezine.com/go/k40-upgrades.

Manport, Adobe Stock-alexkazachok

FIBER LASERS

Fiber lasers typically look like a pedestal with an arm cantilevered over a work surface (Figure C). Mounted on the end of that arm is a *galvanometer*, a set of magnetically controlled mirrors that can aim a laser beam with extreme speed and precision.

Fiber lasers operate in the 1064nm range of infrared light, and their biggest selling point is that they can engrave and cut metal. You may be able to “mark” some metals with other lasers, especially with the additional use of some kind of coating, but a fiber laser will actually ablate or remove material from metal.

Due to the use of a galvo, fiber lasers are extremely fast. And they’re fairly powerful, combining several diode lasers into a single beam via optical fiber. Unfortunately though, the work area is typically small, only a few inches in any direction.

You’ll find these starting around \$2,000. Machines in this category:

- **Monport** monportlaser.com
- **Cloudray** cloudraylaser.com

THE OUTLIERS

Each of the generalizations above has its outliers. For example, you can find a galvo-based diode or CO₂ laser, and there are gantry-based fiber lasers pushing thousands of watts for cutting steel panels! However, for the home/hobby market, the machines outlined here are typical. Start with these to begin your research and find the optimal laser for your needs. 🔍



More on choosing your laser at [youtube.com/watch?v=7Qh-nCMnGxU](https://www.youtube.com/watch?v=7Qh-nCMnGxU)





JOHN IVENER is the content creator behind Tripod's Garage. You can find him on YouTube and other social media platforms.

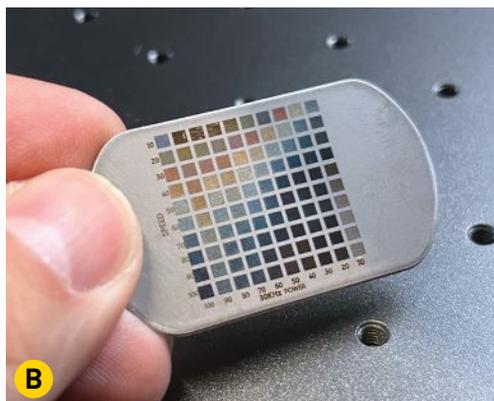
METAL BLASTERS!

TRULY LASER ENGRAVE METAL
FOR **\$2K OR LESS** *Written by John Ivener*

I've been interested in lasers ever since I watched my first science fiction movie as a kid. I purchased my first laser engraver 3 years ago, a small 1W machine that was built out of old CD-ROM stepper motors for the X and Y axis. Fast-forward to today — I now have nine 455nm diode lasers and five 1064nm lasers, at prices ranging from \$250 to \$14,000.

There's a big difference between the 455nm

(blue light) and 1064nm (infrared) lasers. A 455nm diode laser can engrave wood, fabric, leather, colored acrylic, and even glass (with an interface layer), but cannot engrave or etch metals; it can only "mark," like a marker, on stainless steel. If you really want to engrave metal, you need to use a 1064nm laser module, or a 1064nm fiber laser. Here's what to know.



John Ivenner/Tripod's Garage, Mr. Carve, ComMarker

GALVO LASERS

A basic galvo laser is a laser module attached to a galvanometer head, which means you can engrave at higher speeds. These are mostly 2W machines — a good choice when you want to mark metal lightly, and speed and/or quantity are important.

- **Mr. Carve M1** \$1,159 and up mr-carve.com

The Mr. Carve M1 (Figure **A**) has opened up more affordable 1064nm solutions. This is a 2W 1064nm galvo laser that I backed on Kickstarter. It can engrave practically any metal, and certain plastics. Will it engrave deep? Not really, but you *can* actually feel the engraving.

The M1 runs on software called SEACAD, which is very similar to the widely used EZCAD that's pretty much standard software for fiber lasers. With SEACAD and EZCAD you have great control of the laser, from speed, frequency, and power, to hatch patterns and even colors. Figure **B** shows a speed, power, frequency test grid I made for the Mr. Carve M1 that generated some nice colors.

More galvo 2W 1064nm IR lasers to look out for:

- **Atomstack M4** \$1,399 atomstack.net
- **xTool F1 1064nm+455nm** \$1,999 xtool.com/products/xtool-f1
- **LaserPecker 3** \$1,444 and up laserpecker.net

FIBER LASERS

What is a fiber laser? It is multiple 1064nm laser diodes that are coupled with a fiber optic cable to combine their power. For example, a 20W fiber laser would combine the pump light of approximately 11 diode lasers to equal 20W of output power. Some are all in one unit, while others have a separate hardware tower to the side. Desktop fiber lasers also typically use a galvo to direct the beam.

Professional-grade 1064nm fiber lasers start for around \$2,000 for 20W of power. These can etch a lot deeper in one pass — some are advertised at 0.3mm engraving depth!

- **ComMarker B4** \$1,999 b4.commarker.com (Figure **C**)
- **3Plasers EM-Smart Basic** \$1,999 3plasers.com
- **Monport 20W** \$2,199 monportlaser.com



GANTRY LASERS

- **Mr. Carve M3** \$889 mr-carve.com (Figure **D**)

This machine was the first of its kind, a gantry-style laser system with a 1064nm swappable laser module and a 410mm square work area to engrave! You can switch between the 455nm (blue) laser and the same 2W 1064nm (IR) laser module in the M1, which I thought was a great idea! Mr. Carve uses proprietary laser software to operate it; with a firmware update it can be used with LightBurn.

However, since you are now on a gantry system versus a galvanometer your engraving speeds will be decreased. There are no options to control the frequency, and limited hatches. With that being said, if you are looking to etch a large surface, this might be the option for you!

More gantry-based 1064nm systems to look out for:

- **xTool D1 Pro 2 in 1 Kit** \$1,249 xtool.com
- **Atomstack R30 1064nm IR Module Upgrade** \$499 atomstack.com

There seems to be a metal engraving laser to suit everyone's needs, from the tinker/hobbyist to the professional. Prices are coming down and makers can now test the waters to see if this is something they are interested in. 🚫



CAUTION: These machines are extremely dangerous. Please use proper safety equipment. This includes proper eye protection for 455nm and 1064nm wavelengths, and 10,600nm (10.6µm) for CO₂ lasers. These lasers can easily blind you if you're not careful. Also, make sure you are exhausting any smoke and particulates into a filter and preferably outside. You don't want to breathe laser cutting fumes or particulates; they can be very toxic.



23 Years Experience In Motor Manufacture and 3D Printer Parts



Trusted Manufacture of Voron Kits

Web : www.ldomotors.com

Email : sales@ldomotors.com



Created in DALL•E 2 to prove a point. Prompt: "A red robot making a blue robot. Insanely high quality, insanely intricate detail, studio photo, masterpiece, sharp focus, 8k artistic photography, ominous matte painting, dramatic studio lighting, trending on cgsociety, vibrant, epic, intricate, trending on artstation, volumetric cinematic perfect lighting."



STEFANIA DRUGA, PH.D.

is working on the future of AI in education, including research in the Personal Robots Group at MIT Media Lab.



GENERATIVE AI FOR MAKERS

Written by
Stefania Druga

FROM 2D ART TO 3D OBJECT DESIGN TO TEXT,
AUDIO, AND CODE, AI HAS TRULY ARRIVED —
AND IT'S HERE TO HELP YOU MAKE AND CRAFT

Imagine the *Star Trek* replicator exists, and you can use it to create or replicate any object. What would you ask it to make? Would you print ready-made things, or prefer instead to get parts you can assemble, polish, and customize?

Generative AI is the closest approximation of the replicator we currently have — powerful artificial intelligence models that can synthesize images, text, video, code, and even 3D objects. Their results are primarily digital and still require quite a bit of shepherding to materialize in the physical world, but already it can be done — and we're seeing a proliferation of new tools and improvements seemingly every day.

How can we use generative AI models for tinkering and making? What are some initial forays in real, physical crafting with generative AI that can inspire future potential directions? This article sheds light on how generative AI works (in particular diffusion models), how we might ideate, design, and make with it, and what this all means for creators.

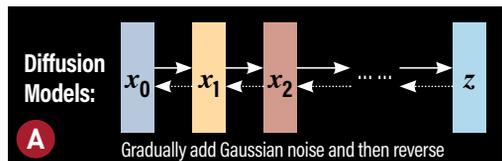
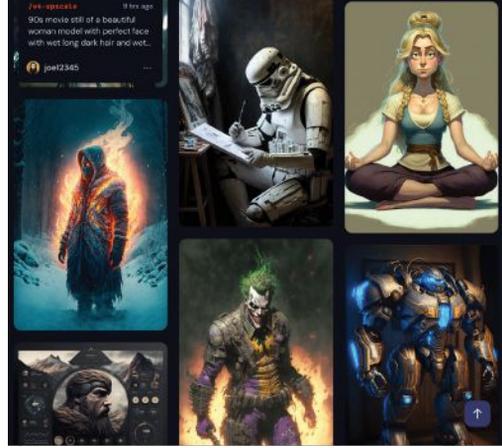
The Current State of the Art

Recent applications for generative AI, such as DALL-E (1.5 million users) or Midjourney (4 million users), have taken the content creation world by storm and stimulated our collective imagination to consider AI a new medium for artistic expression.

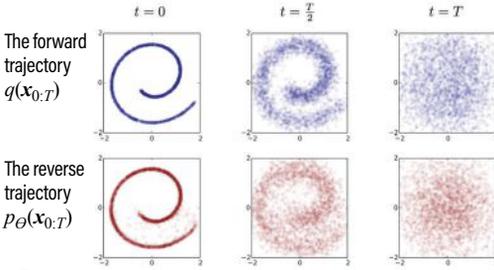
Many of these applications use machine learning models that generate images based on a text description, also called a *prompt*. These large image-generation models are trained on an enormous amount of data, allowing users to create amazingly high-quality images with no graphics or design training. While many of you have seen examples of AI-generated images or videos, you may wonder how this technology works and why it has become so popular.

HOW DO DIFFUSION MODELS WORK?

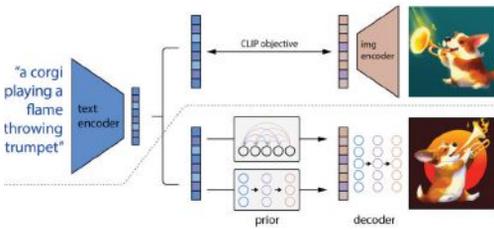
Many generative AI applications use *diffusion model* architecture under the hood (see Figure A). Diffusion models are a type of AI algorithm inspired by non-equilibrium thermodynamics. They add random noise to an input image and



then learn to reconstruct a new, similar image from noise. As more noise is added to different samples of the original image (x_1 , x_2), the image gets compressed into a low dimensional representation (z) which is used to create a new image similar to the original one. The process of gradually adding noise is called a *forward*



A Training a diffusion model for modeling a 2D Swiss roll. From Sohl-Dickstein et al., 2015., arxiv.org/abs/1503.03585v8.



B The architecture of unCLIP, from Ramesh et al., 2022, arxiv.org/abs/2204.06125.



"A delicious steamed bun in the shape of a shiba inu. Studio lighting, high resolution, high quality, dark background"



"A very beautiful intricately shaped organic sculpture carved from steamed buns depicting a shiba inu. Studio lighting, high resolution, high quality, dark background"

C Examples of hybrid and unique artifacts created by Shai Noy and Daniel Smith using Google Imagen.



D

trajectory or *forward pass*, and the process of reconstructing a new image progressively from noise is called a *reverse trajectory*.

The key insight is that a diffusion model needs to gradually learn the probability of the distribution of noise for different steps in the reverse trajectory (see p_{θ} in Figure **A**).

Another way to think about this is to imagine that diffusion models work by destroying training data through the successive addition of noise, and then learning to recover the data by reversing this noising process. After training, we can use the diffusion model to generate unique new data by simply passing sampled noise through the learned denoising process.

To guide the reconstruction trajectory, more recent implementations of diffusion models use text, semantic maps, or other images to condition what possible image should be generated (reconstructed) from the space of all possible options with different probabilities, aka the *latent space* (see Figure **B**).

As mentioned above, diffusion models have exploded in popularity as they produce state-of-the-art image quality and enable people to create fantastic or photorealistic images that didn't exist before, such as hybrid creatures, intricate architectures, new materials, and unique artifacts (Figures **C**, **D**, and **E**).



E

AI-generated design ideas for materials, fashion, and architecture from Shai Noy (D) and Oren Levantar (E).

Sohl-Dickstein et al., Ramesh et al., Shai Noy, Daniel Smith, Oren Levantar, Hugging Face, Playground, Kulkarni et al.

What Can I Make With Generative AI?

You can use generative AI to create images, text, music, games, avatars, UIs, videos, and even 3D models. Here are just a few platforms that have gained popularity:

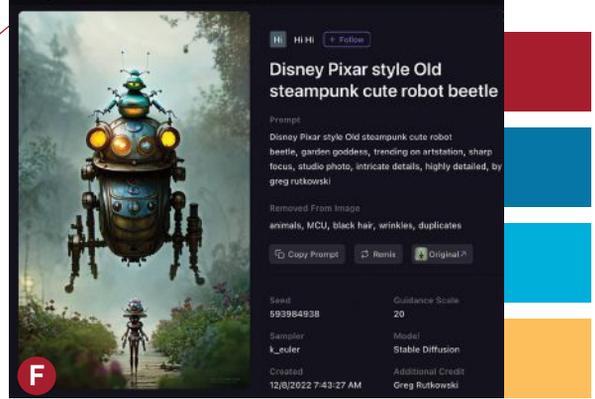
- **IMAGES:** DALL-E 2, Midjourney, Stability AI
- **TEXT:** GPT-3 Playground, Jasper, Google's AI Test Kitchen, Chat-GPT
- **VIDEO:** Meta's Make-A-Video, Google's Imagen Video
- **MUSIC:** Harmonai, Sony Flow Machines
- **AVATARS:** Character.AI, Lensa
- **USER INTERFACES (UI):** Figma plugins for Stable Diffusion
- **VIDEO GAMES:** NVIDIA's DLSS (Deep Learning Super Sampling)
- **VARIOUS DEMOS AND APPLICATIONS:** Hugging Face Spaces



Examples of popular Hugging Face Spaces (huggingface.co/spaces), user-submitted generative AI apps of all kinds.

Digital Crafting With Generative AI

Most generative AI models use text prompts as input, creating unique opportunities for creators and designers to iterate on their ideas quickly or to collaborate with others. As a result, large communities of practitioners have emerged around these technologies, with people sharing



An AI-generated image shared with the prompt that was used to generate it, referencing the styles of Pixar and artist Greg Rutkowski, on the Playground AI community. playgroundai.com/post/clbf910ht00bcs601q5xf2u2d

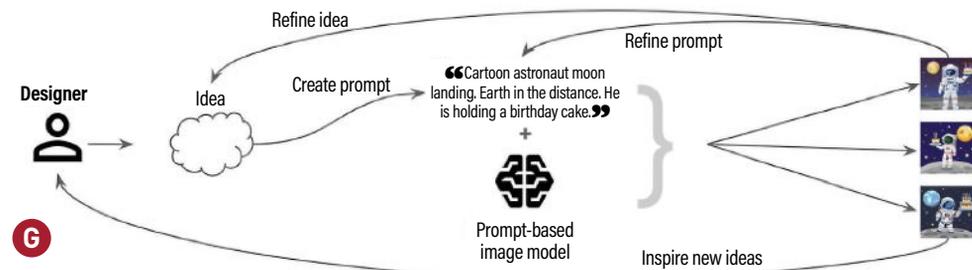
images, prompts, or tricks to achieve specific effects or styles. For example, Midjourney has more than 5 million users on their Discord, using the platform for fun and for professional projects.

Prompts as a Craft Material

Figure F shows an example of a text prompt, shared by user “Hi Hi” on the Playground AI platform — “Disney Pixar style Old steampunk cute robot beetle, garden goddess, trending on artstation, sharp focus, studio photo, intricate details, highly detailed, by greg rutkowski” — alongside the image that it generated. Other creators can remix whichever prompts inspire them, hoping to achieve similar effects. There are even secondary markets, such as PromptBase, where creators sell their successful prompts.

In my research with the PAIR team at Google Research, I found that designers working in pairs to create specific artistic artifacts prefer using generative AI over working without it, and that they collaborate more effectively when using it (Figure G).

In our observations of designers’ work, the



The process used by designers to generate specific design concepts with AI, from Kulkarni, Druga, et al., 2023

indirect nature of prompting both supported the design process (by augmenting creative freedom) and made it more challenging (working to rephrase prompts to match their intent).

In some ways, prompts now occupy a similar role in visual design as HTML did in early web design. By seeing how a webpage was constructed, designers could rapidly adopt good ideas, remix them, and popularize them widely. The role of web browsers was also key — by making View Source a universal feature, browsers likely transformed millions of people from web “readers” to web “writers.” Sharing AI prompts alongside the generated artifacts could catalyze visual design in a similar way.

For example, platforms such as Playground AI support more straightforward iteration and remixing, by allowing users to share images with all the metadata required to reproduce them (prompt, model ID, etc.) (Figures H and I). These features are making prompt-based image generation even more accessible and more craftable. Moreover, many of these features for generative AI are becoming available directly in design tools such as Photoshop or Figma, enabling designers to integrate them into their workflow.

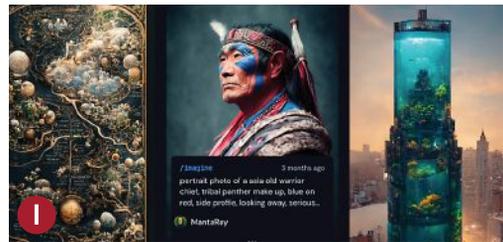
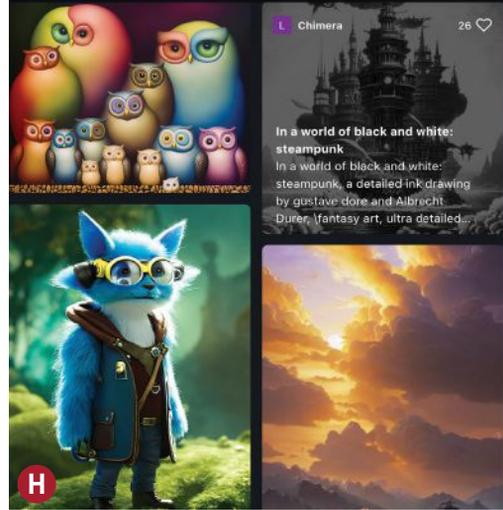
PHYSICAL CRAFTING WITH GENERATIVE AI

In a variety of maker communities, generative AI is starting to be integrated into fabrication and crafting projects. These examples show that generative AI models are primarily used for two purposes: **ideation** or **generative design**.

Ideation

Many makers are already using generative AI for ideation. For example, they use Midjourney to generate concept boards starting with an object or a concept they like, such as *shell earrings* (Figure J), *Birds of Paradise fashion* (Figure K), or *Rambutan dress* (Figure L).

Then they select an intriguing initial composition and use AI models to generate many revised iterations based on the original image. With each one, the AI learns more about your end goal and sometimes suggests its quirky take on



Artifact and prompt sharing at playgroundai.com (H) and midjourney.com/showcase (I).

PROMPT ENGINEERING

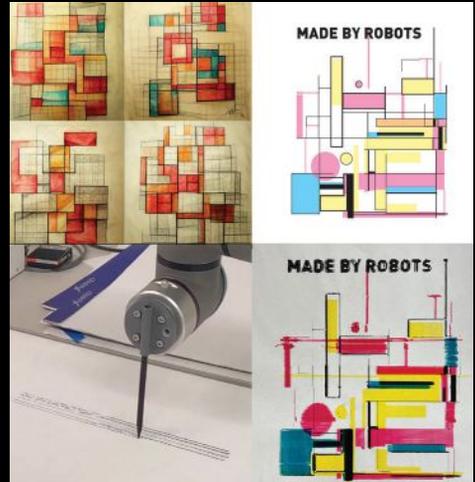
Becoming a good “promptist” is key to getting good AI images. Writing effective prompts is a black art almost as mysterious as what’s going on inside the AI; many users compulsively include “greg rutkowksi” and “trending on artstation” in every prompt for reasons that seem unrelated, even talismanic.

You can go a long way just by modifying existing prompts, but there are sites where you can learn the science of how they work, including your desired subject and style of course but also *negative prompts* (what you don’t want in the image), *seed number* (random by default, but reusing the same one lets you control your experiments), and *guidance scale* (how closely the image must adhere to the prompt).

Some sites even use AI to help you write prompts for the image AI! Check out Lexica, PromptoMania, Phraser, PromptHero, and Krea.ai, and learn more about how prompts work at makezine.com/go/trending-on-artstation. —Keith Hammond

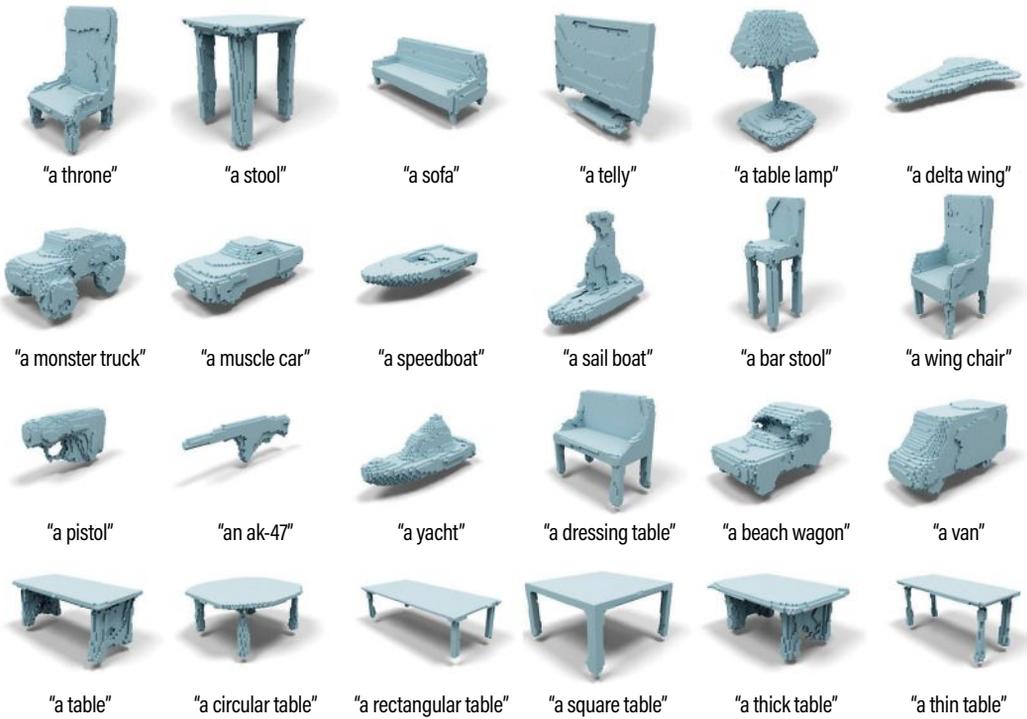
Art by AI, Drawing by Robot

Design students at CSU-Long Beach are using diffusion models to generate art that a robot can draw. The tricky part is picking a drawing style that could be successfully painted by machines — in this case a **Universal Robots UR5E robotic arm** wielding Tombo brush pens. The CAD tool of choice for this operation is Rhino's Grasshopper, which generates a topographical model of the image input into this definition based on the light/dark values of the image; lighter areas will cause the robot to lift itself upward, away from the page. Adobe Creative Cloud's Illustrator and Photoshop tools are used to adjust the outcomes.



the initial prompt along the way. Makers can then use the Upscale and Remaster features of the AI several times to get a very polished composition before moving onward with their fabrication process. Once they achieve a design they like,

they either generate a 3D model in CAD tools or — amazingly — use the successful prompt to directly generate 3D renderings in CLIP-Forge or other text-to-3D diffusion models.



M 3D objects generated with Autodesk's CLIP-Forge, Sanghi et al., 2021, arxiv.org/pdf/2110.02624.pdf.

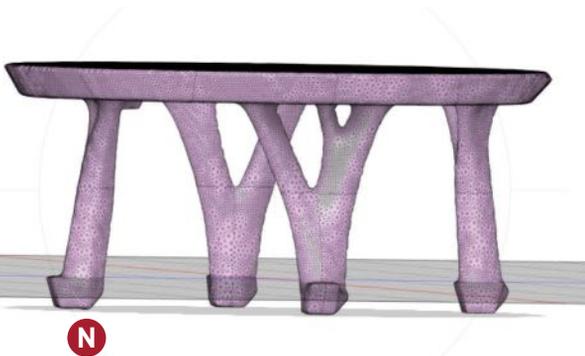
GENERATIVE DESIGN

Makers also use generative AI when they want to explore quickly a design space or various form factors for the same object type. Suppose you want to build a table; you could use a **text-to-3D AI model** like Autodesk's CLIP-Forge to generate 3D models of various types of tables directly from a text prompt (Figure **M**).

Once you pick a table model you like, you could go further and use **generative design tools in CAD programs** to generate various design

options for the legs or the top, like this project done in Fusion 360 (Figure **N**).

Many of the text-to-3D rendering AI models can also export 3D meshes. The newest DreamFusion model (dreamfusion3d.github.io) adds additional optimization strategies to improve geometry, allowing the final rendered models to have high-quality normals, surface geometry, and depth which could easily be exported to CAD for 3D printing (Figure **O**).





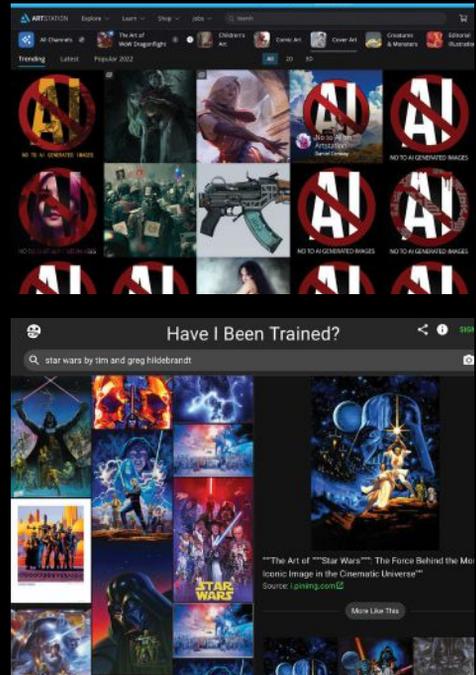
O DreamFusion, by AI researchers at Google and UC Berkeley, generates 3D printable meshes from a text prompt, Poole et al., 2022.

WHAT DOES THIS MEAN FOR CREATORS?

While these generative AI models allow anyone to express themselves with images, videos, music, or 3D models, they've been received with mixed reactions in the creators' communities. When an image generated by AI won an art competition, the artist community reacted strongly against allowing such submissions.

Art historians argue that generative models like DALL-E do not themselves create art but that the artists and technologists who apply them as tools are the ones creating art. Art communities such as Getty Images/iStock/Unsplash, Newgrounds, PurplePort, and [reddit/r/DigitalPainting](#) have banned AI-generated art on their platforms. However, design firms such as Ideo confirm that they are currently using generative AI in their practice to generate more inclusive personas or unique concept boards.

I think the examples of imagery we see emerging in the existing communities, such as Midjourney, really call us to revisit the famous quote from Alan Kay, "The music is not in the piano," and maybe create alternative metaphors. Rather than thinking of these models as paintbrushes or musical instruments — or as robots replacing us — maybe we can think of them as an opinionated design partner that sometimes will inspire us to diverge our creative process in surprising and whimsical ways. 🗳️

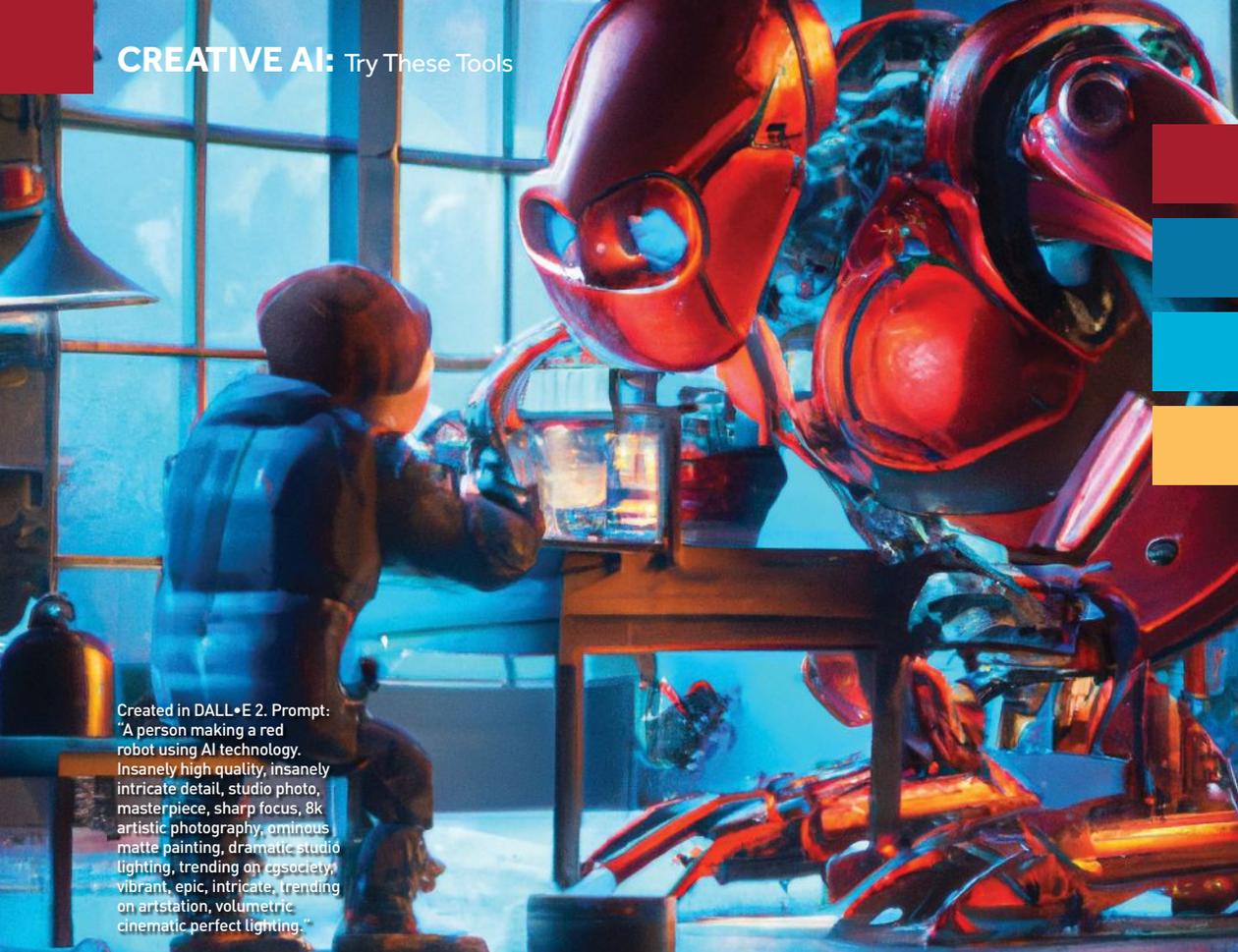


ARTISTS AGAINST AI

How about we scrape all the images off the internet, then train a computer to copy the style of every artist and photographer, living or dead? What's the worst that could happen?

A machine that steals your style is a new ethical, legal, and economic problem — especially if you're a working artist who's being mimicked. Do you get attribution? Get paid? Or just get ripped off and lose work to the machines? One thing seems clear: Existing copyright law can't keep up with AI art technology. And AI music and video can't be far behind.

Some artists are trying to opt out by explicitly denying companies permission to use their images for training AIs ([haveibeentrained.com](#)). In 2022 anti-AI protests broke out on ArtStation and other art portals; DeviantArt responded by letting artists flag their works "noai" to opt out of third-party training, and launched their own image AI, DreamUp, trained only on images whose creators give permission. Learn more at [spawning.ai](#). —Keith Hammond



Created in DALL•E2. Prompt: "A person making a red robot using AI technology. Insanely high quality, insanely intricate detail, studio photo, masterpiece, sharp focus, 8k artistic photography, ominous matte painting, dramatic studio lighting, trending on egsociety, vibrant, epic, intricate, trending on artstation, volumetric cinematic perfect lighting."

AI TOOLS YOU CAN USE RIGHT NOW

Written by
Caleb Kraft

GET YOUR HANDS DIRTY MAKING YOUR
COMPUTER DO THE CREATIVE WORK



CALEB KRAFT is senior editor of *Make:* and jumped at the chance to try out these new AI tools.

Created in DALL•E2

With AI popping up in the news daily, you may be wondering how you can actually play with it. There are many ways you can take advantage of the latest and greatest AI tools, in pretty much any medium you want — audio, video, text, images, and more. And not just for creating specific art or writings, but even for editing and other workflow enhancements.

Here's a list of tools you can use right now to experiment with the most cutting-edge computer brains available.

Image Generation

All the rage right now. We're constantly seeing new features, capabilities, and methods for creating imagery from only a text prompt. Late last year **DALL•E 2** (openai.com/dall-e-2) was announced and people were blown away. Google's Deep Dream and some style transfer stuff had been out there to play with, but generally speaking the public wasn't using prompts to create images from scratch. The tech had obvious errors and downsides — each image was different, consistency was an issue, hands and faces were distorted. Now, there are several different methods and new features every day that push the boundaries of what we thought possible. You can even create a character and use them as a base to create consistent imagery in various styles and situations.

Debate around the legality and morality of this is heated. Programmers are using the artwork of famous artists as training material for these systems, and as templates for their outcome. Some artists feel this is theft of their work (see page 49).

No matter where you fall on that argument, you probably agree that this feels like an inflection point, much like the invention of digital photo editing tools like Photoshop that changed the industry forever.

- **Craiyon** craiyon.com
- **Midjourney** midjourney.com
- **NightCafe** nightcafe.studio
- **Rosebud** rosebud.ai
- **Bria** bria.ai
- **Neural.Love** neural.love
- **Depix** depix.ai

Garbage In, Garbage Out

Why Chat-GPT is fantastic/ horrible for makers

Written by Chat-GPT

- **Chat-GPT is an innovative tool that allows makers and DIY enthusiasts to access a wealth of knowledge and information in a convenient and easy-to-use manner.** With Chat-GPT, users can ask questions and receive detailed, accurate responses in real-time, enabling them to troubleshoot problems, learn new techniques, and get inspiration for their projects.

One of the best things about Chat-GPT is that it is constantly learning and improving, which means that it is able to provide more and more accurate and helpful information to its users over time. ...

Overall, Chat-GPT is an invaluable resource for makers and DIY enthusiasts, providing them with quick and easy access to a wealth of knowledge and expertise. Whether you are a beginner or an experienced maker, Chat-GPT is sure to become an essential part of your toolkit.

- **Chat-GPT is an absolute disaster for makers and DIY enthusiasts. Far from being the helpful and convenient tool that it claims to be, Chat-GPT is nothing more than a time-wasting, error-prone mess.**

The responses provided by Chat-GPT are often completely inaccurate, providing users with completely wrong or useless information. This not only wastes the user's time, but can also be dangerous, as relying on incorrect information can lead to serious accidents or injuries.

Overall, Chat-GPT ... should be avoided at all costs by makers and DIY enthusiasts. There are far better resources available that actually provide accurate and reliable information, rather than the garbage provided by Chat-GPT.

Created in DALL•E 2



Some image software you might already be using is integrating AI features. For example, **Photoshop** is rolling out things like automatic sky replacement, subject selection, and even the ability to change the season within a picture. If you're using **Blender**, there's a free plug-in that will use AI to generate texture files from prompts, at github.com/carson-katri/dream-textures. And **Canva**, the free online design suite, has added AI image generation as well.

TEXT GENERATION

Another area that's seeing insane growth and technological achievement is text generation. These systems can create marketing text, carry on conversations, and even write simple stories, essays, reports — a threat to college professors and search engines alike.

- **ChatGPT** chat.openai.com
- **Jasper** jasper.ai
- **Anyword** anyword.com
- **Copy.ai** copy.ai
- **Writer** writer.com
- **HyperWrite** hyperwriteai.com

VIDEO PRODUCTION

AI is really getting into video production with many tools to aid in difficult editing tasks. You can have AI remove backgrounds, capture motion, rotoscope, and even paint out objects automatically.

- **Runway** runwayml.com
- **InVideo** invideo.io
- **Lumen5** lumen5.com
- **Plask** plask.ai
- **EbSynth** ebsynth.com

Free software like Blackmagic Design's **DaVinci** video editor are also getting AI tools like the ability to isolate vocals in a noisy environment. This could drastically improve videos shot by beginners and small YouTube channels that don't have the gear or experience to get a good mix.

AUDIO PRODUCTION

The world of spoken audio production has not been spared. You can go from creating narration from scratch to editing pre-recorded clips with the help of AI. Our very own Dale Dougherty uses **Descript** to edit the *Make:cast* podcast!

- **Descript** descript.com
- **Speechify** speechify.com
- **Podcastle** podcastle.ai
- **Murf** murf.ai

MUSIC CREATION

With these tools you'll save time in both the creation of music and the editing process. Simple repetitive tasks like isolating vocals can be offloaded to an AI. Some can even create full musical compositions simply by flipping a few switches.

- **Moises** moises.ai
- **Boomy** boomy.com
- **Musico** musi-co.com
- **Soundful** soundful.com

CODE GENERATION

Code is text — but with more restrictions. For example, if a paragraph of prose has some peculiar wording, you can typically figure out what the meaning is. Code, however, breaks down if there are errors. These systems are hoping to create AI code helpers and even write entire chunks of code using AI.

As with image generation AI, there is a lot of discussion about whether these systems are infringing on people's work. An AI could, in theory, choose to include a block of code you wrote verbatim, without your explicit permission, claiming it as its own work.

- **Codiga** codiga.io
- **Tabnine** tabnine.com
- **Debuild** debuild.app
- **MutableAI** mutable.ai
- **GitHub Copilot** github.com/features/copilot 🌐

DESCRIPT: AI FOR AUDIO (AND VIDEO)

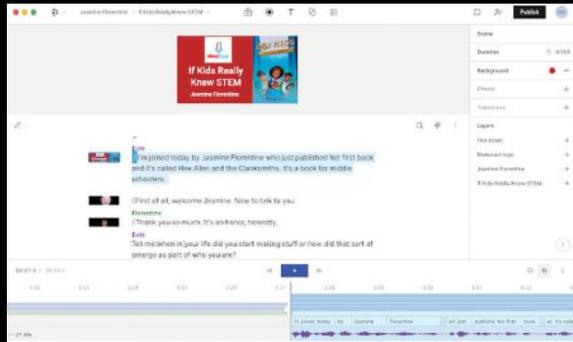
I am a word person. I like to work in words, sentences, and paragraphs. I also like to talk to people and record conversations, and I started doing that during Covid to create **Make:cast**, our podcast (make.co/make-cast). The problem was editing sound files. I tried the open-source Audacity and Adobe's Audition, but it was difficult to adjust to editing timelines. Then I found a new tool, **Descript**, that did something I thought was game-changing.

In Descript, I upload audio files produced from recording a conversation on Zoom. Then I generate a transcript of the conversation. Now the amazing part: I can edit like a word person, moving, deleting, or rearranging text in one window, and both the audio and the video will automatically reflect the changes I made in text. In other words, editing audio and video became more like editing a document rather than a timeline.

Descript also has a few other tricks based on AI. It can identify and remove filler words, like "uh" and "ah" and "you know," in a way that's mostly undetectable to the ear. It also allows you to create a "synthetic" version of your own voice, which requires your reading or speaking for about 20 minutes to train the AI. It is spooky to hear a voice that sounds so similar to your own, speaking words that you type. This artificial version of your voice is not quite good enough because it fails to get intonation right, but it can be a useful tool to insert a last-minute correction.

Descript released a completely new version in November called **Descript Storyboard**. The goal is to make video editing as easy as editing documents. This new release changed much of the interface, including keyboard shortcuts that created a challenge for its longtime users. It added the idea of breaking up a video into scenes where you can easily add other elements such as graphics and sound. While it does have a timeline view, most of the editing is done within the document itself. For those who find the learning curve for typical video editors like Adobe Premiere too steep a climb, Descript could make video production more like creating PowerPoint slides.

With the new release — and an investment by OpenAI Startup Fund — Descript represents a shake-up in content creation as well as demonstrating how AI tools can be embedded to introduce new features. —*Dale Dougherty*

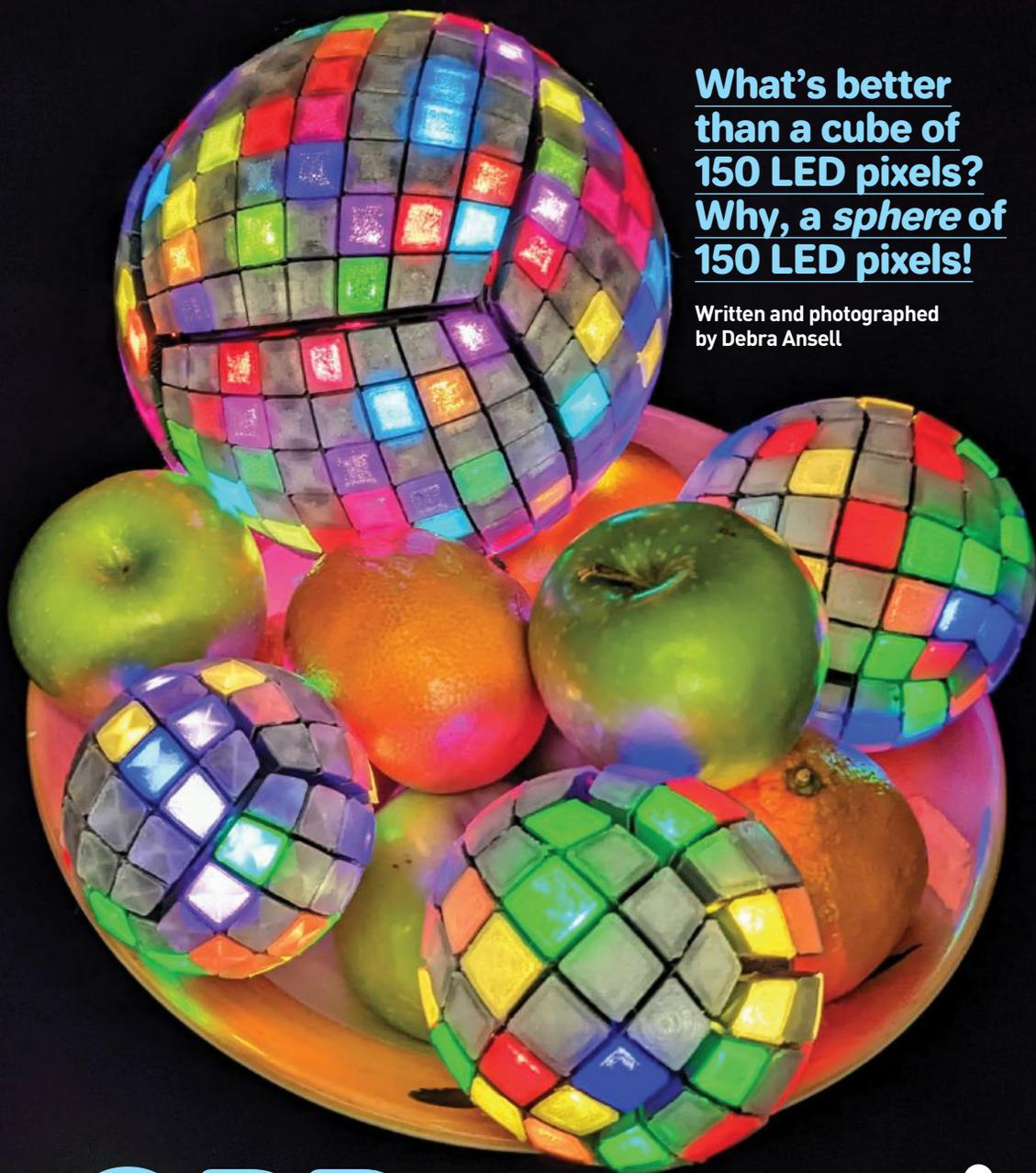


Beware the MECHANICAL TURKS

Some folks, determined to catch the hype train, are launching services advertised as AI that are possibly just outsourced to cheap labor. Try doing a Google search for the product you're looking at to see if people are discussing its legitimacy — especially for complex services like 3D model creation and video production from text.

**What's better
than a cube of
150 LED pixels?
Why, a *sphere* of
150 LED pixels!**

Written and photographed
by Debra Ansell



ORB-sessed



DEBRA ANSELL is a maker and educator who will never stop demonstrating that LEDs improve everything.

“Squaring the circle” is a mathematical challenge as old as geometry itself. The “Cube Orb” LED sphere inverts that goal and takes it to a new dimension. Notably, this spectacular project achieves its orbicular objective using only standard, easy to ORB-tain electronic components and 3D-printed parts.

WARNING: This article contains ORB-noxious puns. Feel free to ignore any you feel are too ORB-viously awful.

Ever since I saw Jiri Praus’ fantastic freeform-soldered LED sphere (instructables.com/Christmas-LED-Sphere), I’d wanted to create my own version. All the documented LED sphere projects I found required custom PCBs or tricky structural soldering. I wanted a simpler build. I knew I could construct an addressable LED cube from prefabricated WS2812B matrices and wondered if an LED cube could be transformed into a less eggy, better-rounded structure.

Inspiration arrived via a short blog post about computer graphics image mapping (mathproofs.blogspot.com/2005/07/mapping-cube-to-sphere.html). When projecting 2D images from the surface of a cube to a sphere, graphics algorithms often use *quadrilateralized spherical cube* or *quad sphere* geometry, which splits a sphere into six identical faces bounded by arcs from *great circles* (circles defining equal hemispheres), then subdivides each curved face with great circles spaced at equal angles. A quad sphere’s pieces are reasonably regular in shape and size, unlike a traditional “globe” subdivision using lines of latitude and longitude, which produces pointy triangles near the poles.

Newly motivated, I set about designing a 3D printable shell to transfer light from an LED cube to a circumscribed quad sphere. Many hours later, I’d designed and printed a six-piece spherical shell from transparent filament. That first build carried light nicely, but “bled” colors between LEDs, resulting in blurry patterns at the sphere’s surface. ORB-viously, more experimentation was needed.

The next design iteration fixed the light bleed problem using opaque shells with one channel per LED to isolate and pipe light to the orb’s

TIME REQUIRED: **A Weekend**

DIFFICULTY: **Intermediate**

COST: **\$60-\$90**

MATERIALS

- » **Seed Xiao nRF52840 Sense microcontroller** Seeed Studio 102010469, seeedstudio.com
- » **WS2812 LED matrices, 5×5 (6)** 38×38mm with four M3 mounting holes spaced at about 23.5mm, such as AliExpress 2251832458182101
- » **Solid core wire, 26 AWG, in multiple colors** I like the kind with silicone rather than PVC insulation, such as Amazon B076P2CYY3.
- » **PETG filament, shiny and opaque** e.g. Overture PETG in Space Gray, Amazon B07PGXY9Z3
- » **PETG or PLA filament, transparent** e.g. Overture PETG Transparent Clear, Amazon B07SB761QR
- » **JST 3-pin connectors, male/female 1.25mm (1 set)** Amazon B07STW5DZP
- » **Battery contacts, male AAA, 10mm×9mm (2)** with holes at the end of the contact stem, e.g. Amazon B07HRS5DMC
- » **Double-sided acrylic tape, 2mm wide**
- » **LilyPad Slide Switch breakout board (optional)** if you wish to be able to turn off your orb without removing the battery; SparkFun DEV-09350, sparkfun.com
- » **Rechargeable Li-ion battery, 16340 button-top** e.g. OLIGHT-16340-650MAH-CARD from batteryjunction.com
- » **Copper tape (optional)** helpful if the 16340 battery is shorter than standard
- » **Cyanoacrylate (CA) glue gel** I’m a big fan of Gorilla Super Glue Gel for this project.
- » **Magnets (4)** I prefer countersunk ring magnets, ¼"×½" with M3 hole, two north/south pairs, such as K&J Magnetics R422CS-P-N52, kjmagnetics.com, because you can mount them with screws. You can also substitute 4 cylindrical ¼"×½" disc magnets such as Amazon B07873ZCY4, and glue them into place.
- » **Flathead screws, M2×5mm, and nuts (20)** such as Amazon B01DK16VD8 and B07H3SXS2. It is essential to use only flathead/countersunk screws in this build.
- » **Flathead screws, M2×6mm, and nuts (4)** Amazon B015A38PQM, if you use countersunk magnets. If gluing magnets, these will not be necessary.
- » **Heat-shrink tubing, ¼" dia.** a few small pieces
- » **CosBond reinforcer adhesive, 1 sheet** Amazon B091SRGQ19, or strong cloth tape that can be cut into small pieces

TOOLS

- » **3D printer**
- » **Screwdriver**
- » **Wire cutters/strippers**
- » **Scissors**
- » **Soldering iron and solder**
- » **Tweezers** helpful for placing M2 nuts
- » **Multimeter/continuity meter**



A



B

surface (Figure A). Each channel is capped with a translucent curved tile which diffuses the light over a single quad-sphere pixel. Figure B shows the magical “bef-ORB and after” transformation of a 5x5 LED cube to its final Cube Orb form.

BUILD YOUR LED CUBE ORB

1. Print the parts

Download the build files for this project, which are available at makezine.com/go/led-cube-orb. Start by 3D printing the interior connectors and custom battery holder from the file *AllConnectors5x5.stl*. These small connectors contain thin walls and fine detail and are best printed from PETG for strength and flexibility. Print them in any color PETG with a 0.1mm layer height setting (Figure D).

Next, print six of the rounded shells from the file *Shell.stl*. Depending on your printer’s bed size, you may be able to print multiple shell pieces in a single session. Use an opaque, reflective PETG filament like Overture Space Gray with a layer height of 0.2mm and 40% infill. Total print time for all six shell pieces is about 9 hours and can

ORB-SESSIVE BEHAVIOR



C

My happiness with Cube Orb turned quickly into an all-consuming ORB-session. I created three different orb designs based on the most commonly available WS2812B LED matrix sizes. Figure C shows Orbs built from 4x4, 5x5, and 8x8 matrices. The smaller (ad-ORB-able!) 4x4 and 5x5 Cube Orbs are each controlled by Seeed Xiao nRF52840 Sense microcontroller, which fits an IMU, microphone, and Bluetooth into a tiny, 21mmx17.5mm footprint.

The larger 8x8 Cube Orb runs a long series of intricate, customizable patterns on Ben Hencke’s powerful Pixelblaze controller and Sensor Board, which I used previously in my Pixelblaze Pillows project (makezine.com/go/pixelblaze-pillows); see *Make*: Volume 83 for this article and more on the Pixelblaze controller).

All three orb designs contain an LED cube consisting of a body of four connected matrices and a detachable two-matrix lid secured by magnets. However, the different sized matrices have varying solder pad and mounting hole placements, so each requires a unique internal structure and assembly process to create the LED cube interior. The 4x4 and 8x8 cube designs have extremely tight tolerances requiring a great deal of patience and excellent soldering and construction skills. Additionally, the 8x8 build requires about 90 hours of 3D printing time vs. about 27 hours for the 5x5 version. The 5x5 cube is a much more forgiving, though still intermediate-level, build.

This article describes the steps to build the 5x5 LED matrix version of Cube Orb. Information on the significantly more challenging 4x4 and 8x8 builds is online at github.com/geekmomprojects/CubeSphere.



take place while you build the base LED cube.

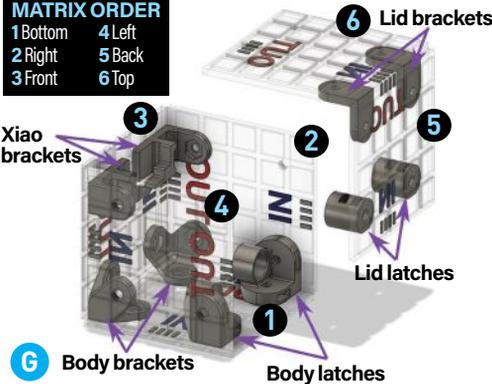
Finally, print the translucent tiles from the file *Tiles.stl*, using clear PETG or PLA filament at 0.1mm layer height and 100% infill. If your slicer allows variable layer height, you can speed up the print by using 0.2mm layer height everywhere except the parts above 3mm and between 1.0 and 1.6mm, where the layer height should be 0.1mm or smaller. Watch your printer carefully as the first several layers go down. You may find it helpful to apply a layer of Elmer's glue stick on the print bed to help them adhere.

Don't detach the finished tiles from the print bed (Figure E) until you're ready to glue them into place on the shell. The tiles may appear identical, but their individual positions and orientation are important! Once they get mixed up, sorting them out becomes a very painful 3D jigsaw puzzle. It's best to carefully loosen one row of tiles at a time from the build plate and glue it in place before detaching the next row. If you must remove the tiles from the print bed before you're ready to glue them to the shell, try to maintain their positions by attaching them to a sticky surface such as a wide strip of masking tape.

To secure each row of tiles, apply a thin line of super glue gel along the top edges of the shell's corresponding row (Figure F). One at a time, set each tile into its corresponding channel, being careful not to super-glue your fingers. The tile should settle comfortably into its channel but won't snap into place. If the fit seems awkward, double check the tile's orientation. Tile edges are wider closer to the center of the shell. Once all tiles are seated, gently press down on them to ensure good contact with the shell, then set it aside to dry for at least 2 hours.

Repeat for the other 5 shells.

MATRIX ORDER	
1 Bottom	4 Left
2 Right	5 Back
3 Front	6 Top



2. Build the cube body

For clarity, I'll refer to each matrix by its position in the final assembly — bottom, right, front, left, back, and top — and each 3D printed connector by the specific name shown in Figure G. The "Matrix Order" referenced in this image is the sequence in which the LED data signal travels between the matrices in the assembled cube.

We'll first build the cube body, consisting of the right, front, left, and bottom matrices. Lay

PROJECTS: LED Cube Orb

three 5x5 LED matrices in a row so that the input pads of one sit next to the output pads of another. Heat your soldering iron and tin all pads which sit adjacent to a neighboring matrix, forming rounded solder blobs that cover most of the pad (Figure H).

Before soldering the matrices together, secure them at right angles using the body brackets, lid brackets (temporarily), and 5mm M2 screws and nuts as shown in Figure I. All screw heads in the LED cube assembly sit on the LED side of the matrices.

Next, connect the perpendicular solder pads on adjacent LED matrices by melting “bridges” of solder between them. To form each bridge, melt a drop of solder onto the tip of your iron, then place it onto a tinned pad. Once it has merged into the solder on the pad, drag the iron to the adjacent pad, then quickly remove the iron, leaving a narrow solder strip which joins the two pads together. Take care not to melt the PETG connectors.

After the three matrices are connected by solder bridges, unscrew and remove the lid bracket connectors, but leave the body bracket connectors in place (Figure J).

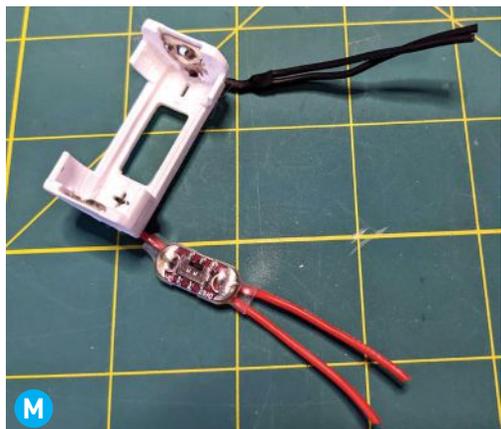
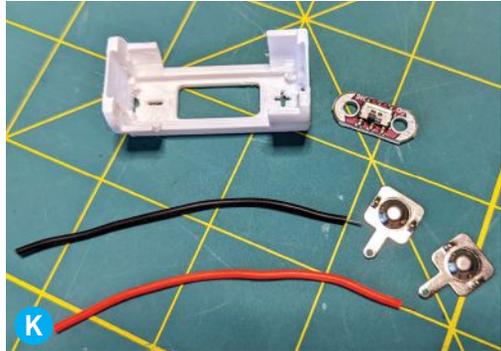
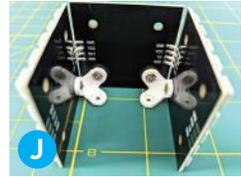
3. Make a custom battery holder

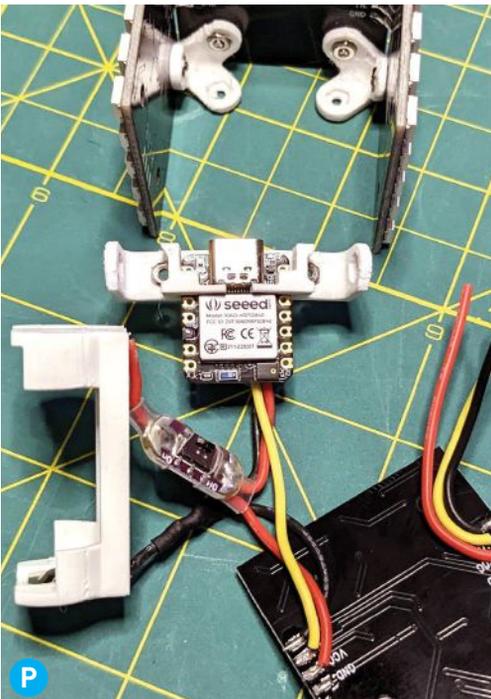
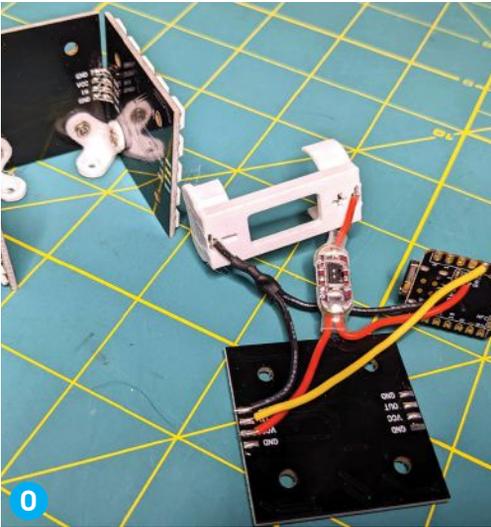
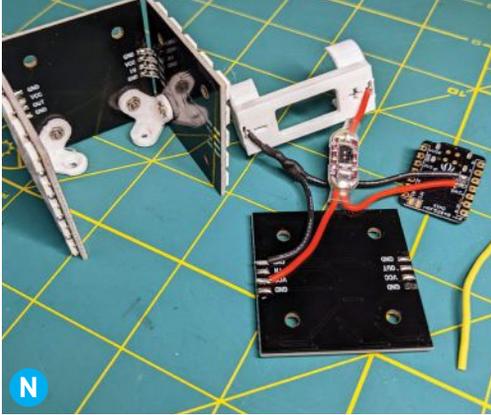
The slim 3D-printed battery holder is needed to fit the 16340 Li-ion battery inside the compact cube interior. The Xiao nRF52840 Sense controller has a built-in circuit that charges the battery while the Sense board is connected to USB power.

Gather the battery holder and two male AAA battery contacts and cut two approximately 5cm pieces of solid core 26 AWG hookup wire in red and black (Figure K). Strip 5mm of insulation from one end of the wires and push each through the hole in a male battery contact’s stem. Solder the wires to the contacts.

Next, slip the contacts’ wires through the small holes in the bottom of the battery holder, red at the end marked “+” and black at the end marked “-”. Gently slide the contacts down into the narrow slots in the holder’s sides so that the contacts’ bumps point towards the battery holder’s interior (Figure L). You may need to push them gently with pliers to seat them fully.

Trim the red and black wires about 1cm away





from the position where each exits the bottom of the battery holder and strip about 0.5cm of insulation from the end. If you're using the optional power switch, solder it to the stripped end of the red wire.

Next, cut two red wires and two black wires 4cm long and solder them to the same color wire extending from the battery holder. This lets us split battery power between the Xiao Sense controller and the LED matrices. If you placed a power switch in the circuit, solder the two red wires to the switch instead of directly to the red wire.

Cover the solder joins with heat-shrink tube and heat it until it contracts it over the wires (Figure M). If you used a slide switch, cover any exposed copper pads on the switch with shrink tube or tape to help prevent short circuits within the cube.

4. Complete the cube body

Next, we'll connect the bottom LED matrix and Xiao Sense controller to the LED cube assembly. Take one of the 5x5 matrices and tin the Vcc pads, Data pads, and one Ground pad on each side. Solder one of the battery holder's power leads and one of its ground leads to the Vcc and Ground pads on the data input side of this matrix. Solder the remaining power and ground leads from the battery to the small battery power and ground pads on the back of the Xiao nRF52840 Sense board (Figure N).

Cut and solder a data wire about the same length as the Vcc and Ground wires from the bottom matrix's data In pad to pin 4 on the Xiao Sense board (Figure O). Then cut and solder three pieces of 26 AWG solid core wire, each about 4cm long, to the data Out, Vcc, and Ground pads on the output side of the matrix. These will connect the output from the bottom matrix to the input on the right matrix.

We'll secure the Xiao Sense mechanically inside the cube with 3D-printed connectors. Take the two Xiao brackets and slide them over the Xiao Sense board from both sides as shown in Figure P. The skinny, long "arm" extending from each of these brackets fits just below the Xiao's USB-C connector. Carefully slide the 3D-printed connectors and Xiao into the cube, with the Xiao parallel to the front matrix. Align the brackets' holes with the holes along the cube body's top

PROJECTS: LED Cube Orb

edges. Using four 5mm M2 screws and nuts, fasten the Xiao brackets to the cube body, again with the screw heads on the cube's exterior.

Next, attach the bottom matrix to the LED cube body assembly by fastening it to the 3D-printed body brackets using two 5mm M2 screws and nuts. During this process, carefully guide the wires extending from the bottom matrix so they sit inside the cube. Once the bottom matrix is fastened to the body brackets, bend and trim the wires from its output pads so that they terminate at the input pads on the right matrix. Strip the ends and solder the wires directly to the right matrix input pads (Figure Q).

Before powering the circuit, use a continuity meter to test for short circuits inside the matrix body. Inspect the cube carefully to find any loose nuts or screws which may have fallen inside, as they can cause dangerous shorts if they contact the solder bridges inside the cube.

5. Test the cube with CircuitPython code

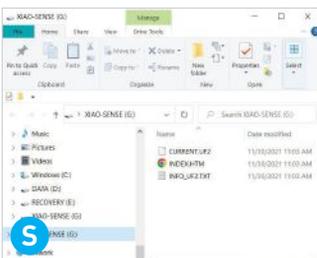
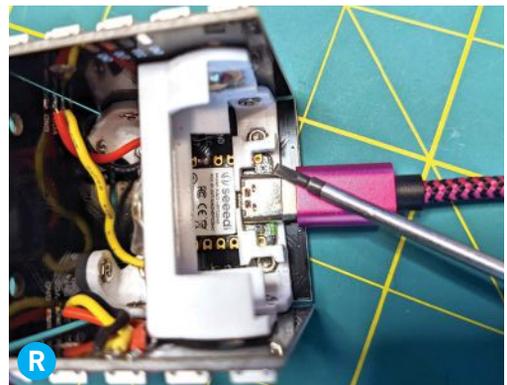
If no shorts exist, connect a USB-C cable from your computer to the Xiao board to power it on. Install CircuitPython by going to circuitpython.org/downloads, searching for the Xiao nRF52840 Sense board, and downloading its UF2 file. Put

the Xiao Sense in bootloader mode by double clicking the very, very tiny reset button just to the left of the USB-C connector. You may need to use a pencil tip or screwdriver head to press the button (Figure R).

When the Xiao Sense enters bootloader mode, it will show up on your computer as a drive named *XIAO-SENSE* (Figure S). Drag and drop the UF2 file you downloaded onto this drive. After the file is fully copied over, the Xiao Sense will reboot and appear as a drive labeled *CIRCUITPY*.

To test the wiring thus far, we'll insert a battery into the holder and run a simple CircuitPython NeoPixel animation program. Download and unzip the CircuitPython Library Bundle from circuitpython.org/libraries, Copy the *neopixel_mpy* library into the *lib* folder on the *CIRCUITPY* drive. Delete the default *code.py* program from the *CIRCUITPY* drive, then copy the program *examples/neopixel_simpletest.py* from the library bundle folder to the *CIRCUITPY* drive. Rename it *code.py*.

Using the Mu code editor (codewith.mu) in CircuitPython mode, or your preferred CircuitPython editor, open your new *code.py* file and make two changes to reflect the cube's wiring:



- Change `pixel_pin = board.NEOPIXEL` to `pixel_pin = board.D4`
- Change `num_pixels = 10` to `num_pixels = 100`

Once you save the edited `code.py` file, the program will start running, and the cube body's LEDs should display alternating red, green, blue, and rainbow colors. If that doesn't happen, check that the battery is well seated in the holder.

TIP: Cylindrical 16340 batteries can vary in size, and some are just slightly too short to make a good connection with the battery holder contacts. If this happens, you can extend the battery's power terminals slightly with small pieces of copper tape (Figure **T**) or melt small blobs of solder on the holder's contacts to bring them in slightly so they'll touch the battery terminals. Do not apply solder to the battery's terminals, only to the metal contacts in the 3D-printed battery holder.

After the circuit is tested and working, unplug the Xiao from your computer and remove the battery from its holder to safely continue cube assembly.

6. Connect the JST cable

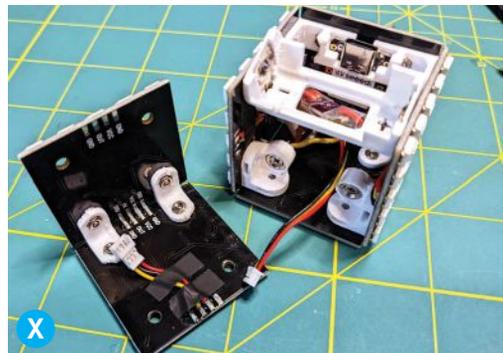
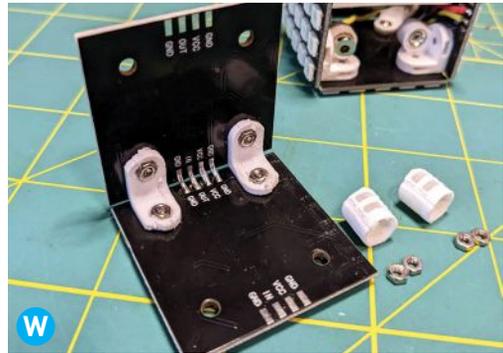
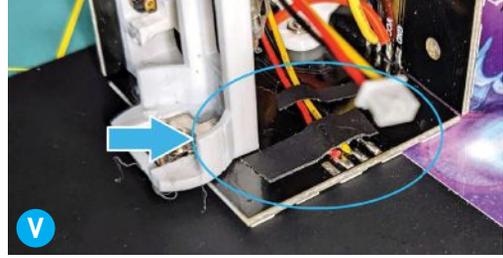
The next step is soldering the tiny JST connector cable to the main cube body. Take the small male 3-pin JST cable, trim it to about 7cm, and solder the red, black, and yellow wires to the Vcc, Ground, and data Out pins, respectively, on the left matrix. To prevent the cable interfering with the cube lid closing, the wires should run from these pads back into the body of the cube (Figure **U**).

Now, using small pieces of CosBond adhesive or gaffer tape, tape the wires down on inside of the left matrix near the solder pads to provide strain relief when the lid is opened (Figure **V**).

7. Put a lid on it

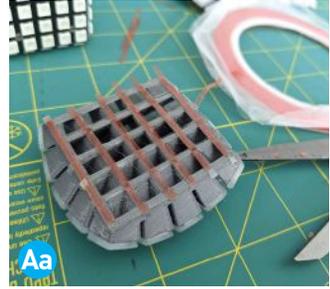
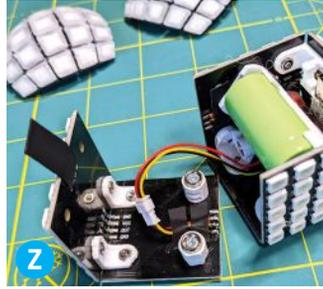
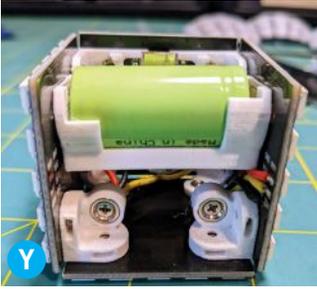
Now we'll construct the cube lid. Take the two remaining 5x5 WS2812B matrices and tin the input pads on one and the output pads on the other. Use the 3D-printed lid brackets and four 5mm M2 screws and nuts to attach the matrices at right angles. Heat your soldering iron and bridge adjacent solder pads together to complete the lid's circuit (Figure **W**).

Take the small female 3-pin JST cable and trim it to about 3cm long. Strip its ends and solder the red, black, and yellow wires to the available input Vcc, ground, and data pads on the back matrix,



orienting the cable so that the wires lie flat along the back matrix. Apply small pieces of CosBond adhesive or tape to adhere the cable to the matrix and provide strain relief (Figure **X**).

Now that the electrical circuits are completed, we'll install the magnetic connectors that hold the lid to the cube body. Use two 6mm (5mm will be too short) M2 flathead screws and nuts to attach two of the countersunk $\frac{1}{8}$ "x $\frac{1}{4}$ " magnets into the cylindrical recesses in the 3D-printed body latch connectors. If you're not using countersunk magnets, then glue two $\frac{1}{8}$ "x $\frac{1}{4}$ " disc magnets in their place, seating the magnets as far back into their recesses as they will go. After the magnets are secured, insert two M2 nuts into the captive nut slots in each body latch, and, using two 5mm M2 screws, fasten each body latch to the bottom matrix and the adjacent right or left matrix (Figure **Y** on the following page). Once the cube's lid is closed, it can be hard to locate the



opening, so it is helpful to make a tab, several centimeters long, from a piece of tape folded over itself and attach it to the unsoldered edge of the cube lid, as seen in Figure **Z**.

Double check the electrical wiring by first testing for shorts between Vcc and Ground with a continuity tester. If no shorts exist, connect the mini JST cable between cube lid and body, insert the 16340 battery into its holder, and run the same simple LED animation as before on the Xiao. Change the `num_pixels` variable's value from 100 to 150 to illuminate the LEDs in the cube lid as well as the body. If the patterns display correctly on all six matrices, your cube is complete — and ready to become more well-rounded.

8. Shell game: Take the edge off

In this last assembly step, we'll attach the 3D-printed shell pieces to create Cube Orb's final form.

Cut and place small strips of 2mm wide double-sided tape across the rows on the shell's underside, leaving the red plastic cover layer on each tape strip until all rows are placed. Then peel the red plastic from each row of tape, and lay columns of tape across each of the rows (Figure **Aa**).

Finally, peel the red plastic cover from each tape column and gently but firmly stick the shell to one matrix in the cube (Figure **Bb**). The tape provides a secure hold which stands up to reasonable handling but is still detachable, allowing access to the screws sitting underneath the shell pieces.



Repeat with the other five shells. Once all six are in place, take a moment to ponder Cube Orb's spherical perfection!

9. Program the Orb

Most of Adafruit's clever CircuitPython LED Animation library patterns look great running on Cube Orb. You can find out more in their excellent Learn Guide at learn.adafruit.com/circuitpython-led-animations. The LED Animation library also provides a useful basis for our code, because it manages animation timing, RGB pixel color generation, and pattern "playlists" which can be advanced automatically or by external triggers such as Bluetooth input or gesture detection.

Our animation, named "Tilt," uses input from the Xiao Sense board's accelerometer to determine its orientation. It displays a colorful "bullseye" that always fills Cube Orb's upper hemisphere, regardless of its orientation (Figure **Cc**).

To get Tilt running on Cube Orb, download the project code from github.com/geekmomprojects/CubeSphere/tree/main/Orb5x5 and then copy the files `code.py`, `coordinates.py`, `imu.py`, `orb.py`, and `tilt.py` to the top level of your CIRCUIPTY drive. You will also need to copy the Adafruit CircuitPython libraries `adafruit_led_animation`, `adafruit_lsm6ds`, and `adafruit_register` into the `lib` folder on your CIRCUIPTY drive. With all

files in place, the Tilt animation should start to run, and the illuminated pixels will remain on top, no matter how you rotate the orb.

Comments in the code files explain the functions in detail, but here's a general overview:



- The spatial coordinates of Cube Orb's 150 pixels are computed using the **Matrix** and **Orb** classes, defined in *orb.py*. The **Matrix** class stores the coordinates of the first pixel in each matrix, the direction of the matrix's rows and columns, and the row layout (parallel or zig-zag). The **Orb** class takes a list of **Matrix** objects, one for each of its physical LED matrices, and uses the properties of each matrix plus a little bit of math to project the matrix pixels to the orb's surface and store their Cartesian coordinates.
- In the main program file, *code.py*, the **Matrix** object properties are specified in the **orb5x5()** function which returns an **Orb** object. If your LED matrices have a different layout than the ones used in this project, you will need to change the matrix definitions here to reflect your orb's physical layout.
- An **IMU** class, defined in *imu.py*, obtains the data from the Xiao Sense's accelerometer. The Tilt animation, defined in *tilt.py*, takes an **IMU** object as a parameter, as well as the LEDs' spatial coordinates. The **Tilt()** class gets all the functionality of the **Animation** class through Python inheritance and overrides the **Animation** class' **draw()** function, which is called once in each animation frame to set LED colors. Each time it is called, the **draw()** function obtains accelerometer readings from the IMU, computes pitch (rotation about the X-axis) and roll (rotation about the Y-axis) angles, then uses them to transform the pixel coordinates to match the orb's real-world orientation. The **draw()** function fills all pixels in the upper hemisphere with colors determined by each pixel's vertical (Z-axis) coordinate.

The Tilt animation provides a template to code

your own CircuitPython LED animations which respond to Cube Orb's orientation. If you're not sure where to start, copy the Tilt code and make small changes to its **draw()** function, then save your changes to see the animation patterns change in real time.

FURTHER ORB-JECTIVES

If you'd like to go further with Cube Orb, here are some ideas to consider.

- Create an animation playlist using Adafruit's Animation Sequence class from the LED Animations library
- Include sound reactivity using readings from the Xiao Sense's built-in microphone
- Explore Bluetooth control to switch between patterns, using Adafruit's Bluefruit App to control the Xiao Sense (learn.adafruit.com/circuitpython-made-easy-on-circuit-playground-express is a good reference)
- The Sense board has a gyroscope as well as an accelerometer. If you're looking to get a bit more mathematical, do a bit of research on using a complementary or Kalman filter to combine the gyroscope and accelerometer data and improve the accuracy of the orientation calculations, then implement it in the code.



There is a definite magic in watching LED animations play across the surface of a sphere, but no wizardry is needed to assemble your own Cube Orb, just a bit of care and persistence. I'm willing to bet that, if you give it a try, you'll find this project as abs-ORB-ing as I have. 🌀

30 Dollar Wind Turbine

**Crank out the kilowatts with this DIY vertical axis
wind generator** Written and photographed by Daniel Connell



DANIEL CONNELL is an open source low-tech alternative infrastructure designer. He designs and tutorializes things you can make from recycled materials to generate energy, purify water, cook, and communicate.
youtube.com/c/OpenSourceLowTech

Looking for cheap, plentiful green energy?

Build this ultra affordable, vertical axis wind turbine (VAWT), which uses wind energy to drive things like an alternator/generator for producing electricity, or air and water pumps for cooling, irrigation, and similar.

The turbine uses the 35%–40% mechanically efficient Lenz2 design developed by Ed Lenz, a hybrid design that uses both lift and drag forces to generate power. It's made almost entirely from scrap materials, and should cost about \$15–\$30 for the six-vane version, which can be made by two people in 4 hours without much effort.

The three-vane version has been successfully survival tested to 80km/h (50mph) sustained winds and the six-vane version to 105 km/h (65mph). Both will do more, but exactly how much has not yet been ascertained. The current longest running version has been up since early 2014, through reasonable storms, with no noticeable wear and tear so far.

Full power curves have yet to be calculated for this build, but according to Ed Lenz's calculations a six-vane at 0.91 meters diameter and 1.1 meters high with a 90% efficient alternator should produce at least 130 watts of electricity in a 30km/h (18mph) wind, and 1 kilowatt at 60km/h (37mph).

The materials listed in this tutorial are to make the six-vane version. Halve everything except the bike wheels for three vanes.

1. MAKE THE PAPER TEMPLATE

Download and print the two template files from the Resources section at opensource.lowtech.org/wind_turbine.html. Make sure they're printed at 100% (300dpi). When printed, measure the distance between the dimension arrows; it should be 10cm on both pages. If it's a couple millimeters off that's probably OK.

Tape the pages together so that the 10cm dimension marks overlap as closely as possible. An easy way to do this is on a window pane during the day, so you can see both pages showing through.

Using the angle aluminum as a straightedge, cut out the outer border of the template with the craft knife. Any time you're cutting, always make sure your other hand is never in front of the knife,

TIME REQUIRED: 1–2 Days

DIFFICULTY: Easy/Moderate

COST: \$15–\$35

MATERIALS

- » **Aluminum lithographic offset printing plates, minimum 67cm long (11)** Width can vary, depending how tall you want your turbine. These are pure aluminum sheets used in offset printing, a process that's used for newspapers and packaging. A medium sized printing company may recycle hundreds of plates every week, so it's usually easy to pick them up cheap. The ink washes off your hands easily enough with soap and should be nontoxic.
- » **Pop rivets, 4mm diameter, 6–8mm long (280)**
- » **Machine screws/bolts, M4, countersunk head, 12–20mm long (30)** Strictly speaking only 9 need to be countersunk, the rest can be pretty much anything, such as hex head or socket.
- » **Lock nuts, M4, with nylon insert (30)** Nylocs are nuts with a ring of nylon to stop them rattling loose. If you can't find these a normal M4 nut with a spring washer will do the same job.
- » **Washers, 4mm ID: 10mm OD (48) and 20mm ID (42)** to fit the pop rivets and bolts, respectively
- » **Bike wheels, 26" (2)** about 58cm outer rim diameter, with 36 spokes and a normal thick axle about 10mm diameter (not quick release), and enough axle exposed to attach to your pole mount, at least 3–4cm. The wheel should run reasonably smoothly; it only needs gears if you're going to run a chain off it, which you probably aren't (see Configuration C on page 73).

It may be helpful to take the hub apart using wrenches and a bike cone spanner and give the bearings a bit of a clean and re-grease, and to extend the axle as much as possible on one side for attaching. Your local bike shop can show you how. Shouldn't be necessary though, if the wheel runs nicely enough and has enough axle showing.

- » **Bike wheel spokes (12)** Any length, type, or condition is fine.

TOOLS

- » **Power drill**
- » **Drill bits for metal, 4mm and 5mm**
- » **Craft knife** for cutting paper
- » **Stanley knife/box cutter** for scoring the aluminum sheets
- » **Aluminum angle, 20mm×20mm, 1m long** for ruling and bending. An extra 30cm length is also handy.
- » **Tape measure**
- » **Pliers**
- » **Work gloves**
- » **Pop riveter**
- » **Marker pen**
- » **Sticky tape**
- » **Clothespins (4)** springy or the other kind
- » **Computer and printer** Low-quality B&W is OK.
- » **7mm socket/nut driver (optional)** for use with the drill to tighten your nylocs. Much faster and easier.

PROJECTS: Vertical Axis Wind Turbine

so if you slip you're not going to slice yourself. The angle aluminum is good for this, as the vertical leg effectively shields the hand holding it.

CAUTION: From here on, you'll be cutting and drilling sheet metal. It's a good idea to wear gloves to protect your hands from sharp edges.

2. ROUGH CUT THE ALUMINUM

Take an aluminum sheet and measure a box 42cm×48cm. Draw a line halfway up the 48cm length so you have two boxes, each measuring 42cm×24cm.

Score the outer lines with the craft knife and straightedge (Figure A). You're not trying to cut through the metal, just create a crease for bending. A good method is to score once lightly, then a second time a bit deeper. Do not score the 24cm halfway line.

Flex the metal so it bends at a score line, then flex back the other way. Do this a couple times and it should split. Do the same for the other score, and remove the outer metal (Figure B).

3. CUT THE FORMERS

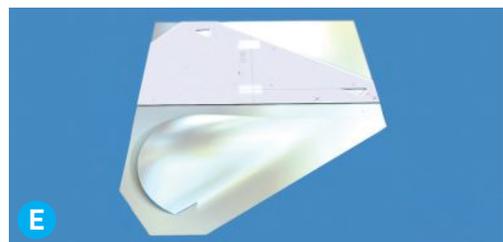
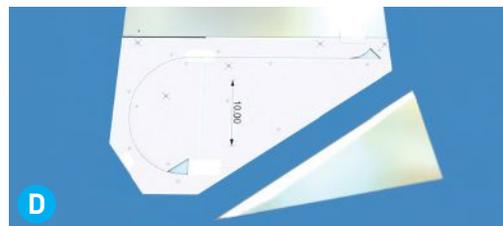
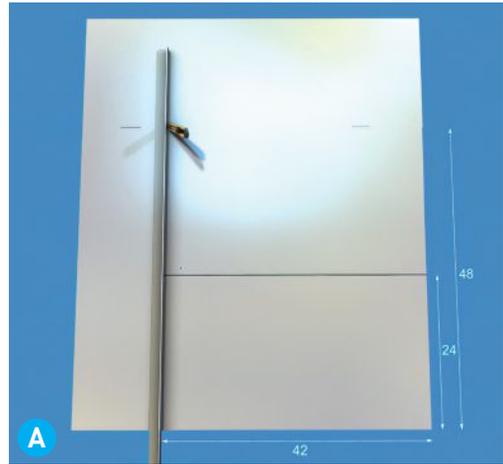
Tape the template to the metal rectangle (from now on to be referred to as a *former*) so that the long edge of the paper sits on the middle line and the right-hand edges of both line up. Don't worry if the other edges don't align perfectly.

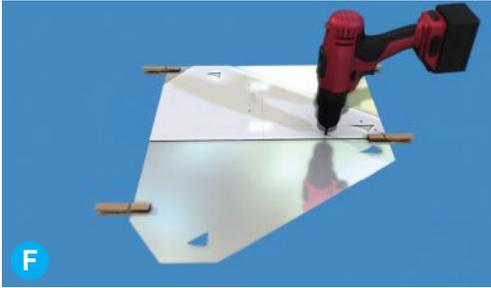
With blade and straightedge, score out the template curve, including the triangles at each end. It's not essential that this be 100% perfect, but try to get this first one reasonably nice, as you can use it as a template for the rest (Figure C).

Score, flex, and remove the two triangles of excess metal outside the template (Figure D).

Mark the centers of the 18 little circles on the paper template with a marker pen so that they're visible from the other side, then flip the paper over so that the printed side is down on the uncut half of the former, keeping the long edge on the middle line. Retape so it doesn't shift.

Give the curved score several light flexes, near the edge, and tear it out (Figure E). Remove the two small triangles. Be careful not to bend the unscored metal too much as you work, as this may weaken it.





F

You now have your first former. Use it as a template to cut the other 11 formers for a total of 12. On six of the formers, draw the 24cm line on the front, and on the other six draw it on the back.

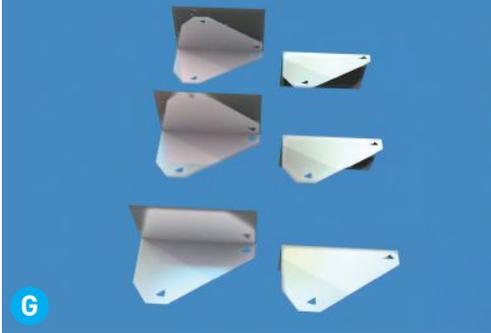
4. DRILL AND BEND THE FORMERS

Clamp all 12 formers together so that they're as nicely aligned as possible. Use tape to attach them if you don't have clothespins.

Now drill each of the 18 holes through all 12 formers with a 4mm bit (Figure F). It can help to put a bolt through the first hole to keep the formers from shifting around as you drill.

Remove the template and unclamp the formers.

Place a former with the 24cm line slightly overhanging the edge of the table. Place the straightedge on the middle line and bend the metal upward to 90 degrees. Bend all 12 to create 6 formers bent shiny side up, and 6 bent shiny side down (Figure G). Put the formers aside.



G

5. MARK AND SCORE THE VANES

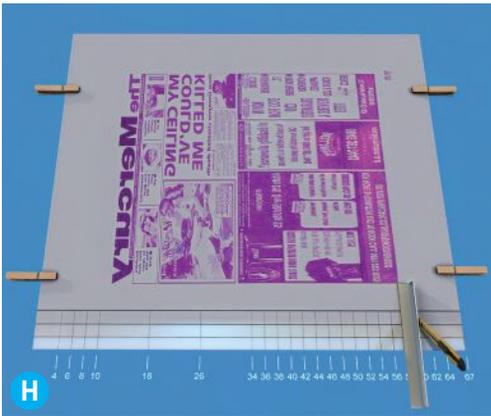
Flatten out an aluminum sheet and cut the long edge down to 67cm. The other edge can be any width, depending how tall you want your turbine; in my build it's about 60cm. (I've made vanes anywhere from 50cm to 1m tall, but more than 80–90cm probably isn't advisable for structural rigidity reasons.)

Draw a line 2cm from one of the 67cm edges. Flip the sheet over and draw a line 2cm from the opposite edge, on the other side of the metal.

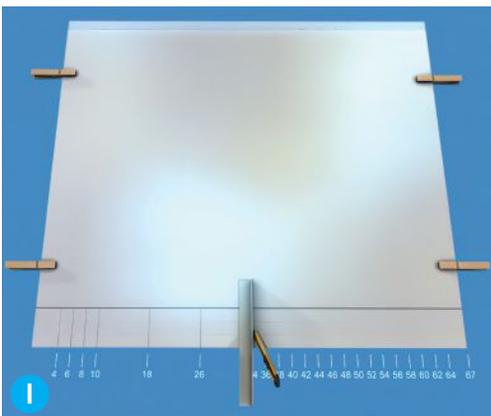
Repeat with 5 more sheets, then stack and clamp all 6 together so that each drawn line is aligned to the edge of the sheet above it.

Mark the edge of all the sheets at 4cm, 6cm, 8, 10, 18, 26, 34, and then every 2cm up to and including 64cm (Figure H). Keep in mind that one side has a score at 4cm from the edge, the other at 3cm.

Flip the sheets over, making sure they don't lose their alignment. Mark and score the opposite edge, same as the first edge. Make sure both have the 4cm gap on the same edge (Figure I).



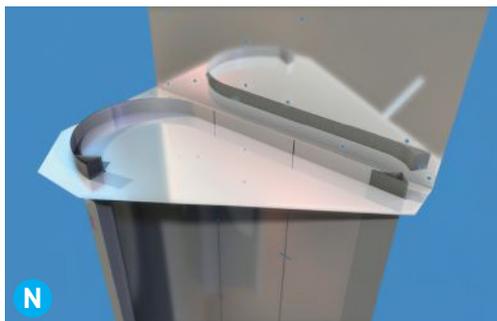
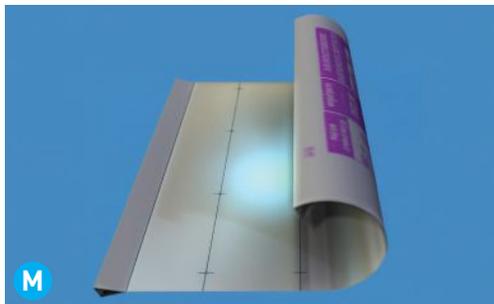
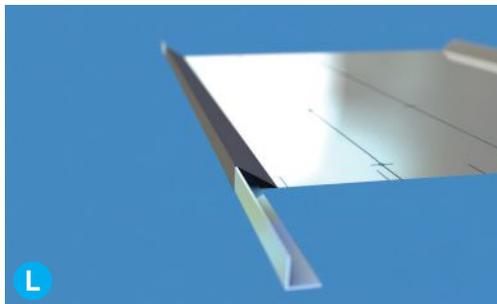
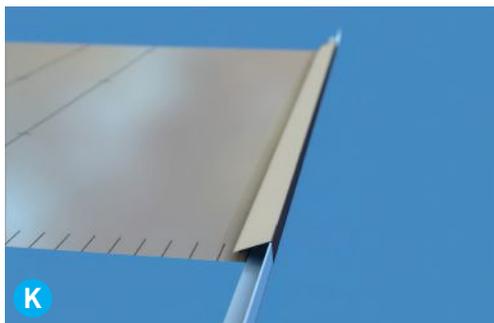
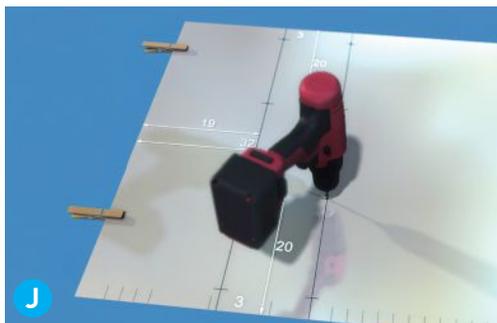
H



I

6. DRILL THE VANES

Unclamp and tap the sheets on the table so that they're aligned on top of each other. From the



4cm end, draw a vertical line 19cm from the edge, and one 33cm from the edge. Mark each line at 3cm and 20cm from both ends.

Clamp and drill all 6 sheets with 4mm holes at all 8 marks (Figure **J**). Unclamp the sheets.

7. BEND THE VANES

Place a sheet so that the second 3cm edge is overhanging the table. Place the straightedge on the second score mark in, and make two bends to triangulate the edge as shown in Figure **K**.

Triangulate the 4cm edge too (Figure **L**).

Finally, pre-bend each vane's curve (Figure **M**) so it'll be easier to place into the curved cut in the formers. Don't bend it so tightly that you crease the metal.

8. MOUNT A VANE IN 2 FORMERS

Flip the vane upright and insert into the curve cut into a top former (the uncut half of the former should be pointing upward). The best way to do this is to first place the 4cm edge triangle into its slot, then the 3cm edge, push in the inner flap, then work the rest of the sheet through the cut (Figure **N**).

Fold down the tabs so that the first three at each end fold outward, then alternate sides (Figure **O**). You'll probably need to flex the score marks a couple of times before tearing them, or use pliers if they're being stubborn. If you find you've bent a tab the wrong way, leave it, as bending it back the other way will weaken the metal. But make sure the three long tabs

alternate to each other.

Scoot the former all the way up so it's level with the bent flaps. Place 2 bike spokes in the fold of the former (Figure P) and bend it closed; they'll overlap a little in the middle. If you squish the edge of the metal around the spokes with pliers or similar it'll stop it from falling out.

Flip the vane, place the other former, and fold down the tabs in the same manner. Add spokes and bend it closed. The spokes will strengthen the edges where the vanes will be bolted.

9. CUT OFF THE CORNERS

Slice and remove the former's two outer corners. Cut the smaller triangle level with the edge of the other former half, but give the larger triangle a 2cm offset, so that the outer layer is 2cm bigger than the inner layer (Figure Q).

Repeat for the other former.

10. MAKE THE STRUT

Take one of the offcuts left over from cutting a former. Cut out a strip 7cm wide, and as long as your sheet width minus 4cm. Bend the strip into a triangular strut (Figure R).

On the face that's 3cm wide, mark the center at each end with a line a couple of centimeters long.

11. RIVET THE STRUT

Stand the triangulated strut inside the vane so that its 3cm face aligns with the row of 4 drilled holes closer to the back edge (Figure S). Sight your marked line through the top drilled hole to check that it's centered.

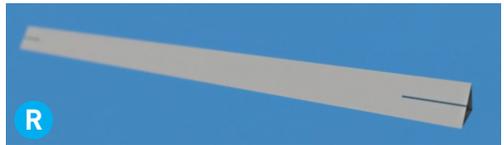
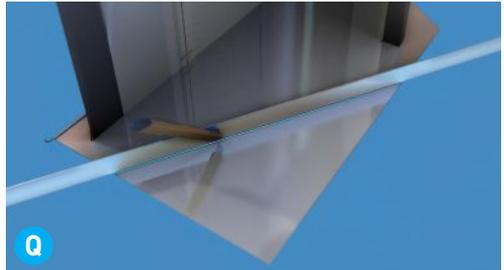
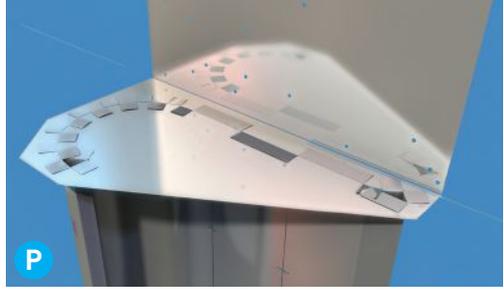
Drill the strut through the hole in the vane and attach with a rivet. Repeat for the bottom hole (Figure T), then the two in the middle.

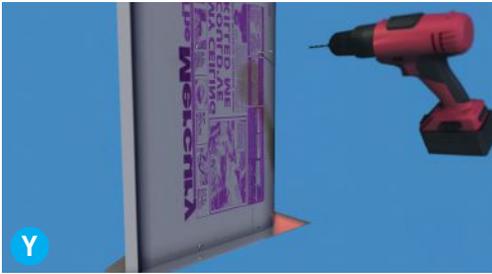
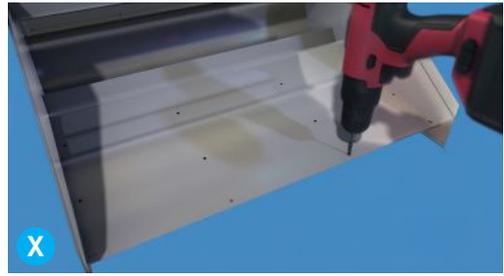
12. MAKE THE REINFORCING SHEET

Smooth a fresh sheet of aluminum, cut the length down to 67cm, then cut in half so you have two half sheets 33.5cm wide. Cut off 4cm from one of the short edges of both pieces (Figure U).

Repeat so that you have six sheets 33.5cm wide, and as long as your vane sheet width minus 4cm. Align and clamp all six together.

From one of the long edges, draw three vertical lines at 1cm, 9cm, and 19cm. Then mark these lines in from both ends at 1cm and 20cm.





Drill a 4mm hole at all 12 marks (Figure **V**). Finally, mark the sheet at 5cm in from the opposite edge and then bend the edge to triangulate it (Figure **W**).

13. RIVET THE REINFORCING SHEET

Lay the vane flat and place the half sheet inside so that its flat, un-triangulated edge is aligned with the vane's rear, or trailing, edge. It's OK to have a small gap or bowl at either end if it doesn't fit perfectly. Drill and rivet the row of holes in the half sheet closest to the edge (Figure **X**).

Stand the vane upright. Push the half sheet's triangulated edge in and forward so that it's against the vane sheet and somewhat tight over the strut. It will line up with a row of existing holes in the vane. Drill through that row of holes, then rivet in place (Figure **Y**).

Drill through one of the middle holes in the half sheet's middle row, making sure to keep the drill reasonably straight, and attach with a rivet

outside and a washer inside the vane. This bit is much easier with a second pair of hands. Try to keep the washer fairly flat on the metal.

Repeat for the final three holes in the half sheet's front, or leading, row (Figure **Z**). The half sheet should be tight across the strut. You should notice that the vane is now a lot stronger and more rigid.

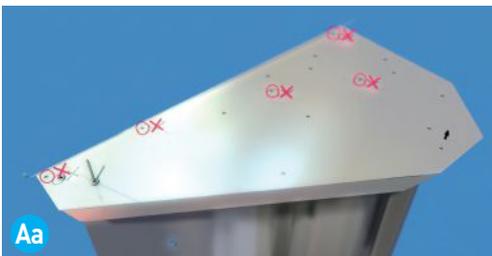
14. RIVET THE FORMERS

Fold the 2cm overlap on both formers inward to 90 degrees.

Drill through all the holes on the formers. It's best to drill into a small block of wood, or a rolled-up tube of aluminum offcut, so that the metal doesn't get pushed in and you don't risk drilling your hand.

Rivet all the holes on each former, except for the five marked in Figure **Aa** — three along the edge with the spokes, and two in the interior.

It's easy to just push the inner layer of metal



away accidentally with both the drill and rivet, so check that each is properly attached. If any aren't, you may need to drill out and replace the rivet.

15. MOUNT VANE TO BIKE WHEEL

Drill three 5mm holes evenly spaced around the bike wheel rim. Your wheel should have 36 spokes, so drill a hole every 12 spokes. The hole should be fairly close to the rim edge (Figure Bb).

Poke a countersunk head M4 bolt up through one of the holes in the wheel (Figure Cc) and through the middle unriveted hole next to the bike spoke, in the bottom former of the vane. The purpose of the larger hole size is so that this bolt head recesses further out of the way if you want to put a belt around the wheel rim to drive an alternator or similar.

Place a large washer and a nyloc nut on the bolt (Figure Dd). Make sure the bolt is against the bike spoke you put inside the former's folded edge, and the washer is over it. This is so the bolt, and therefore the whole vane, can't rip either sideways or upward off the wheel. Don't fully tighten the nyloc yet.

Align the vane so that the leading unriveted hole next to the bike spoke sits near the edge of the wheel rim and mark the rim with a pen through the hole (Figure Ee). Also mark the interior unriveted hole that's now lined up on the bike rim). Rotate the vane away so that you can drill the two marks (Figure Ff).

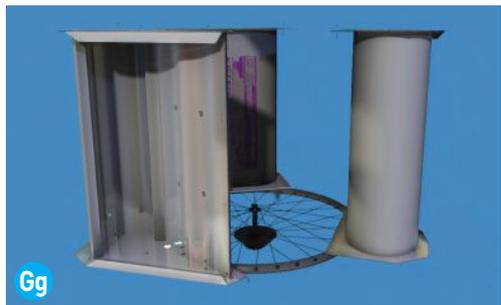
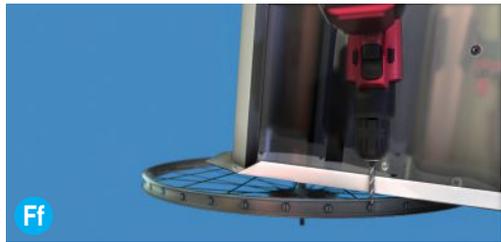
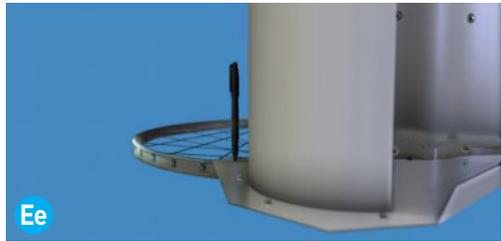
Move the vane back and lock it down with two more bolts, large washers, and nylocs. Fully tighten all three. This is where the 7mm socket/nut driver comes in handy, as tightening these by hand is a bit of work.

16. ASSEMBLE 5 MORE VANES

Repeat from Step 8 to assemble five more vanes from your remaining formers and sheets. Attach two more to the top of the first wheel (Figure Gg), and the last three to the underside of the second wheel so that all six can connect to each other, facing in the same direction (Figure Hh).

17. BOLT ALL VANES TOGETHER

Bolt all six vanes to each other, in a staggered overlapping configuration, with the trailing unriveted hole next to the bike spoke attaching



PROJECTS: Vertical Axis Wind Turbine

to the interior unriveted hole of the vane behind it. Use two large washers per, one under the bolt head, the other under the nyloc (Figure **li**).

The remaining unriveted holes can now be bolted to each other in the same way. It should be fairly obvious which connects to which as they'll be sitting more or less on top of each other. Moving them into alignment will force the vanes into a balanced, six-way symmetrical hexagon.

REAP THE WILD WIND!

Congratulations, you've made a vertical axis wind turbine! Here are some ways to attach applications to your turbine so it can do useful work. They're meant only as a guide; there's not really a one-size-fits-all solution.

When you get to this part of the process please email me at opensource@lowtech.org or check out the Facebook group, where the community can help you build what you need and you can follow what others have done already. Most builds are pretty straightforward!

CONFIGURATION A: Hoverboard Wheel

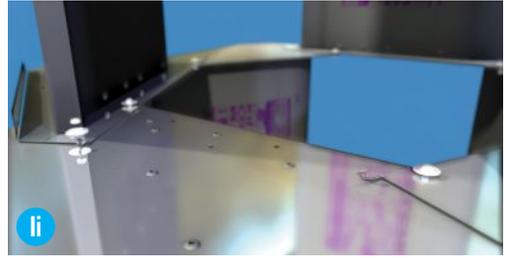
This turbine can be used to power a variety of applications, such as mechanically attaching a pump in order to move water or compress air, but you're probably going to be using it to generate electricity to charge batteries.

One of the easiest-to-source solutions for this is to use a permanent-magnet DC motor in reverse as a generator. Probably the best option for this is the wheel off a hoverboard, balance board, or Segway, as they are powerful, hard wearing, weather sealed, three-phase AC, do good volts per rev, and can be usually found for \$20-\$30 secondhand in the local classifieds.

Probably the easiest way to attach and drive this is with a ~2.5m alternator belt from a van/truck/bus/large car, looped around the bottom bicycle wheel of the turbine and the hoverboard wheel (minus its tire), with a tensioning system as shown in Figures **Jj**, **Kk**, and **Ll**. You'll probably want to attach a loop of nylon strap or leather inside the bike rim for cushioning and grip.

CONFIGURATION B: eBike Wheel

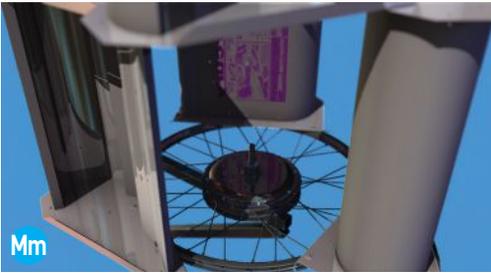
The perfect solution for generating electricity from the turbine is to use an electric motor hub





Ll

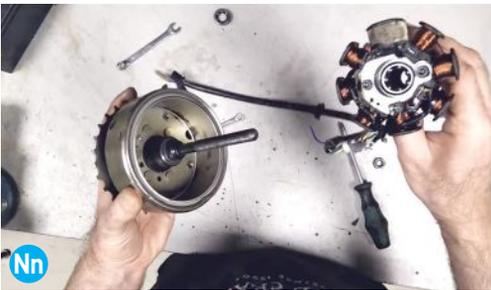
bike wheel (Figure Mm). If you can find one. The design uses a wheel anyway, and pretty much every aspect of power inputs, outputs, rpm, etc., fit quite nicely into a direct drive ~300-watt e-bike wheel. All you do is build the turbine on it and plug the wires into your electrical system. Unfortunately, outside of a few countries these wheels can be difficult and expensive to source.



Mm

CONFIGURATION C: Motorbike Alternator

In parts of the world where the above two items aren't readily available, probably the best option is the alternator (also called a stator) from a motorbike, scooter, or tuk-tuk. These aren't usually as powerful or high volting as the others, but still do a decent job. A general rule of thumb is the bigger and slower the bike, the more volts it'll do per rpm, which is what you usually want.



Nn

The main drawback to these is they don't have their own bearings. So I usually mount them on the hub from a bicycle wheel (Figures Nn and Oo), as documented in this tutorial: youtu.be/jLVcbd0C9Ns.



Oo

There are two main ways to attach these to the turbine: with a belt, similar to Configuration A, or with a short loop of bicycle chain from the sprocket set on the turbine's wheel to the one on the alternator assembly (Figure Pp). The former will give a lot higher revs and therefore volts due to being geared up, but an advantage to some bike alternators is they have a high voltage coil, which usually does about 10 times the volts per rev of the other coils, but at a tenth the maximum amperage rating (i.e., before it melts). So if you're only wanting 10–15 watts to charge some phones or USB batteries for LED lighting, then this should work OK, and since the resistance on the turbine is so much lower than with other options you should be able to generate power more or less constantly, even in low winds. ☺



Pp

Original tutorial video and more:
opensourcelowtech.org/wind_turbine.html

Facebook discussion group: facebook.com/groups/windturbinemakers

Support more prototypes and tutorials by joining: youtube.com/@OpenSourceLowTech

More on the Lenz2 vertical turbine design:
windstuffnow.com/main/vawt.htm



Bright Lights, Big TV

Written and photographed by Mike Senese

Elevate your home entertainment setup with this Pi-powered ambient television backlight system



MIKE SENESE is the former executive editor of *Make*. A lifelong tinkerer and tech writer, he lives in the San Francisco Bay Area with his wife and son. Find him on the web: mikesenese.com

Televisions these days are technological marvels — absolutely massive yet paper-thin screens with crystal-clear 4K (or better) resolution, up to 120Hz refresh rates, high dynamic range (HDR) color and luminance, and other features that turn living rooms into amazing personal theaters. As great as these new TVs are though, the magic still ends at the thin bezel that frames the screen. But what if you could make your shows, movies, or games stretch beyond the television itself?

With a Raspberry Pi, a few pieces of HDMI hardware, a strip of assignable LED lights, and free software, you can do just that. The hardware processes your video content, detecting the specific colors that are closest to all edges of the screen and then driving the LED lights to correspondingly project the same colors outward behind the television. It all happens dynamically and in real time, creating an immersive lighting effect that makes the content feel even larger and more exciting.

This trick is known as *ambient lighting* or *bias lighting*. You can find a couple all-in-one ambient lighting systems that offer this effect from companies like Philips, but they're expensive and proprietary. Fortunately, it's not hard to put your own together, nor is it particularly expensive. Ready to get radiant? Here's how.

1. CONFIGURE THE HARDWARE

To get the LED backlights to display hues corresponding to what's shown on the screen, we'll be splitting the video signal from an external HDMI device (Apple TV, Chromecast, Roku, etc.) into two signals. One of those passes through to the television screen where it will be displayed normally, while the other gets routed via USB to the Raspberry Pi, where the HyperHDR software processes the signal down to just the video elements on the outer limits of the TV screen, then sends that signal to the LED light strip (Figure A).

2. PREPARE THE LED ELECTRONICS

There are a wide range of LED strip lights on the market and HyperHDR can handle most of them. It can even use external Philips Hue lights remotely, via the Hue Bridge — allowing you to

TIME REQUIRED: 2Hours

DIFFICULTY: Moderate

COST: \$150

MATERIALS

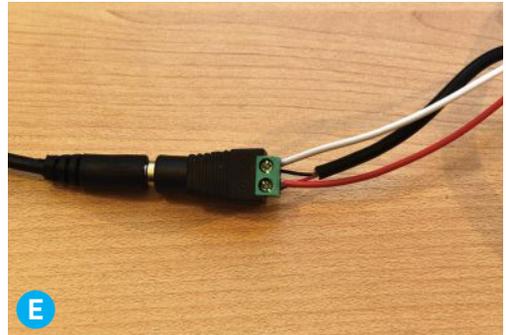
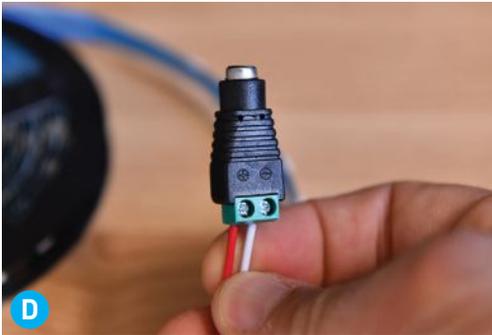
- » **Raspberry Pi single-board computer** Pi 3 or 4 recommended, but this will work with even the Pi Zero.
- » **MicroSD card, at least 8GB capacity** and SD card adapter
- » **LED strip, WS2812B, 5 meters**
- » **Streaming device, HDMI** e.g. Roku or Chromecast
- » **Power supply, 5V, 10A**
- » **Barrel jack power adapter, female, 5V**
- » **HDMI to USB capture card, 4K** aka USB video grabber. I used a generic non-HDR 4K USB 3.0 card with HDMI pass-through (\$30 on Amazon) for a basic setup, but to maintain your HDR signal and preserve Atmos audio, go with a separate, suitable HDMI splitter (e.g. Ezcoo SPI2HAS, about \$65) and one-way HDMI-USB capture card (\$20). If you want CEC too, you'll need the SPI2H28S instead (\$140).
- » **HDMI cable, 2.0 or 2.1** Use 2.1 for HDR.
- » **USB cable, A-A** to connect grabber to Pi
- » **USB cable, Micro or C** to match the power input of your Raspberry Pi
- » **Jumper wires, M-F (1 or 2)**
- » **Tape, double-sided foam (optional)** if your LED strips don't have adhesive backing. Or get creative with strip-light channeling and 3D-printed brackets.

TOOLS

- » **Wire stripper**
- » **Screwdriver, precision**
- » **Computer** with Wi-Fi and internet access
- » **Keyboard and mouse, USB**



PROJECTS: DIY Ambient TV Backlight



place additional lights alongside the television for even wider ambient light dispersion. Turn your whole room into the viewing experience!

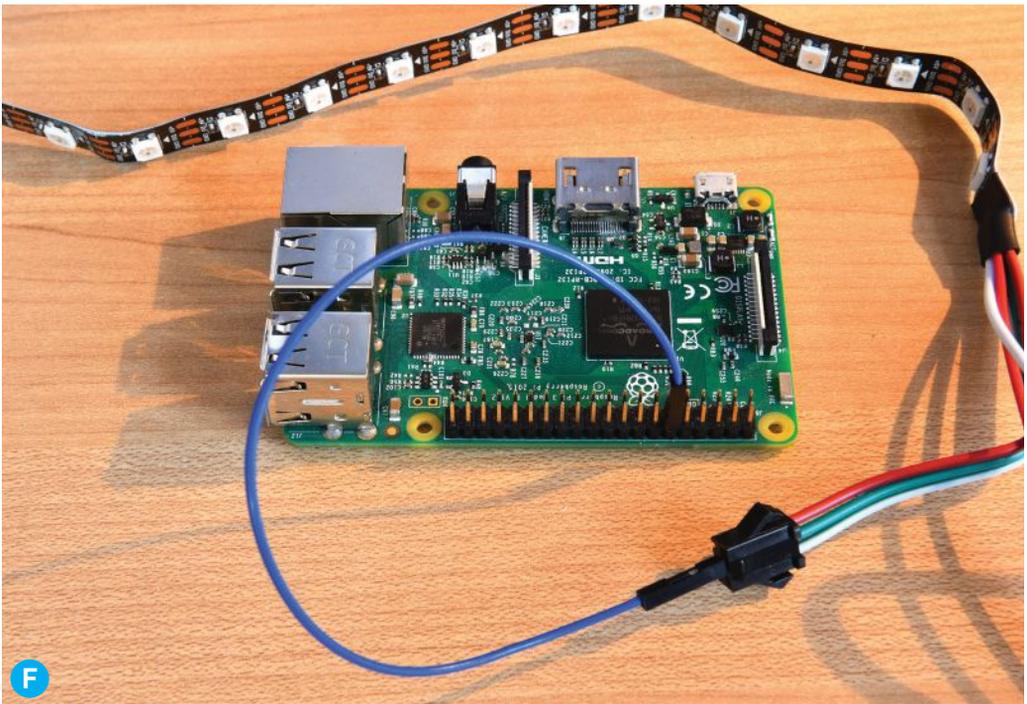
For my build, I used WS2812B string lights. They're cheap and easy to find, and they run off 5V, so you can even build a power circuit that powers these and the Raspberry Pi with just one plug. I got a 5-meter (16.4-foot) strip with 60 pixels per meter. More pixels equals more resolution, right? Well, yes, although I'm not convinced that the improvement over the 30 pixels/meter option is worth the extra wattage needed to power them. (There are also advantages to using 12V strip lights, such as the WS2815 version — these don't suffer from voltage drops across longer lengths, as the 5V ones can. But they don't offer the easy option to power the Pi from the same power source.)

Speaking of power sources, you'll need one that is sufficient for lighting all those LEDs. We're talking 150–300 LEDs, potentially blasting a full, pure white light, meaning they'll be drawing maximum amperage. A standard phone charger won't cut it for that; you'll want to get a laptop-style power brick (Figure B) that matches the voltage of your string lights and has a fair amount

of amperage. Mine does 5V 10A, for 50 watts of power, but if I were wiser I'd get a bigger power supply that can go up to 300W, just for safety. They're not much more expensive, either.

To connect the LED light strip to the power source, use a 5V barrel jack adapter. Some power supplies include this, but you may have to buy one. They usually come in a small set; be sure you get the "female" side with it. Strip a small bit of insulation off the power leads from the LED lights, then connect these to the screw terminals of the female jack. The red wire goes to positive (+), the black or white wire goes to negative (-) (Figures C and D).

NOTE: If you're using 5V lights and want to couple in power for your Raspberry Pi, here's where you'll do it. Cut off the big end of a Micro-USB or USB-C cable (depending on which model Pi you have), find the red and black wires, strip off about 1/8" of insulation, and insert them in the corresponding + and - slots along with the wires that power the LED strip (Figure E). This will let you power the Pi from the same power supply.



For longer lengths (300 LEDs), also feed the tailing red and white wires into the barrel plug here as well, so the voltage and ground feed both the start and end of the lights.

Finally, use a M-F jumper cable to connect the Data line from the LED strip (it's the middle pin on most strips) to pin 18 on the Pi (it's the sixth pin from the bottom corner) as shown in Figure **F**.

IMPORTANT: If you decide to power the Pi separately, you'll also need to put a jumper between one of the GND pins and the ground wire on the LED strip, otherwise it won't work.

If you'd like, you can now plug the devices together. Connect your external HDMI streaming device into the HDMI capture card, an HDMI cable from there into the TV, and also a USB-A cable into a USB port of the Raspberry Pi. My Pi's USB jack supplies power to the capture card; look for the red light on it to know that it's working.

Then turn on the TV and your HDMI streaming device, and select the HDMI input that you're plugged into on the TV. If everything has power, you should now see your normal content on the TV screen.



3. ASSEMBLE AND MOUNT THE LEDS

For best results you're going to want a rectangle of LED lights around the back edge of your screen, close to the sides. Some people just affix the light strip with its built-in adhesive, folding the strip at the corners. Others build a dedicated frame to hold the lights at an angle, with pre-made corner connectors (Figure **G**). This is up to your personal preference.

Whatever you do, count the LED lights on each



side and mark them down. You'll need these numbers for the HyperHDR configuration.

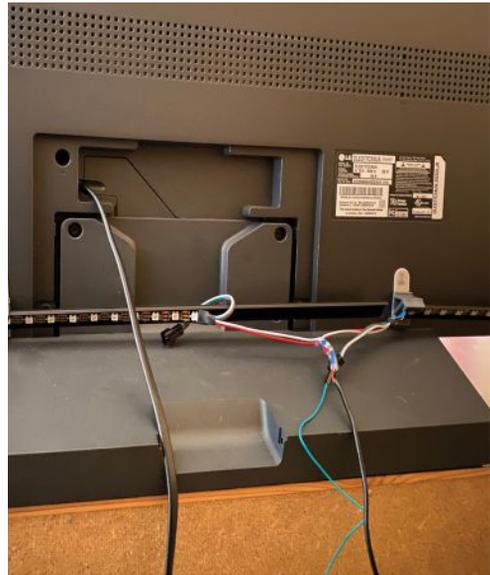
You'll also want to decide where the input for the light strip should start. Top corner? Bottom center (Figure **H**)? This is software-configurable as well. The default direction of the lights is clockwise (when looking at the screen from the front) but you can reverse that in the software if necessary. You can also input a gap setting in the software, measured in LED pixels, for instance if you leave a space in the light strip for the television stand. Mark all these numbers down, you'll need them in a moment.

Finally, mount or stash the HDMI hardware somewhere out of sight but convenient.

4. DOWNLOAD AND INSTALL SOFTWARE

For this project, we'll use HyperHDR, a variation of the popular open source Hyperion software. It allows you to match the vibrance of the LED lights with what's displayed on your HDR-capable TV screen, without needing an expensive HDMI splitter that transmits the HDR signal on both split channels. Most HDMI splitters and capture cards downgrade the split-off signal to SDR, which results in less-rich color transmission on the surrounding lights. HyperHDR fixes that.

Download the latest version from github.com/awawa-dev/HyperHDR/releases. I'm running the



64-bit beta version of 19.0.0.0 on a Raspberry Pi 3. Look for *SD-card-image-19.0.0.0beta1-aarch64.img.xz* on the releases page, which also works on the Pi 4, Pi Zero 2 W, and rev 1.2 of the Pi 2. (Check out github.com/awawa-dev/HyperHDR/wiki/Installation for releases supporting other Pi models.)

Once the file is saved on your computer, use a card imaging app to build a bootable SD card from it. I like Etcher (balena.io/etcher) but other options like Rufus (rufus.ie/en) work great too. You can also use the Raspberry Pi Imager tool (raspberrypi.com/software), which is a pretty slick method of creating many different types of images with the settings you want. Use a card with at least 8GB capacity.

Once the image is built you'll need to add a file to the card to give it your Wi-Fi credentials, which will allow you to log into its UI and configure the settings. To do this, open a text editor and input the following, with your own network details:

```
ctrl_interface=DIR=/var/run/wpa_
supplicant GROUP=netdev
update_config=1
country=PL
network={
  ssid="Name of your WiFi LAN"
  psk="Password for your WiFi LAN"
}
```

Save that text file with the name `wpa_supplicant.conf` and drag it onto the `/boot` folder of your card while it's still in your laptop.

Now you can boot up the Pi — insert the SD card in your Pi, plug it into the TV you'll be using with an HDMI cable, and power up the Pi. You'll see the familiar Raspberry Pi bootup screen. After a couple minutes of processing, it will ask you to log in (user `pi`, password `raspberrypi`), then change the default password and mark it down. I use a USB keyboard and mouse to input these directly into the Pi on-screen; you can also SSH into the Pi from a separate computer, but since this project already involves a TV screen, it's just as easy to input the info directly.

Next, find the IP address of the Raspberry Pi by running the `ifconfig` command in the terminal on the Raspberry Pi. Write it down, you'll want it to SSH into the Pi. You'll find it as the `inet` number at the start of the `wlan0` section, probably something like `192.168.xx.xx`. Alternatively, I use the Fing app (fing.com) on a spare Android phone to find my Pi's IP address remotely; I find this is easier.

Now you can remove the USB peripherals and disconnect the Pi from the HDMI connection. From here you should be fine doing everything else via SSH and the HyperHDR user interface.

5. CHANGE USER TO ROOT

If you're using WS2812B LEDs, it's likely that you'll be using PWM to control them, via pin 18 (the default PWM pin for HyperHDR and many other Raspberry Pi LED projects).

However, one thing that isn't always communicated in ambient backlight project write-ups is that the Pi's PWM function can only be accessed and controlled if the Raspberry Pi is running in "root" mode. It's quite likely your

installation won't initially be in root; generally it is discouraged as it allows direct access to critical files. However, the LED lights won't turn on without it! So next, we'll enable root access on the Pi with the following steps:

- Open the Terminal tool.
- SSH into the Pi using that IP address you wrote down from the previous step, by typing:
`ssh pi@<IP address of Raspberry Pi>`
- Input your password.
- Verify that your Pi is not already running as root. In the terminal, type:
`sudo systemctl status hyperhdr@pi.service`

If, inside the results that pop up, you see **Active: active (running) since...** you are running as `pi` and not as `root`. Press Control-C on your keyboard to exit the results and go back to the command prompt.

- Now disable the `pi` user:
`sudo systemctl disable --now hyperhdr@pi.service`
- Then enable the `root` user:
`sudo systemctl enable --now hyperhdr@root.service`
- You can now verify that `root` is active by using that same status command:
`sudo systemctl status hyperhdr@root.service`

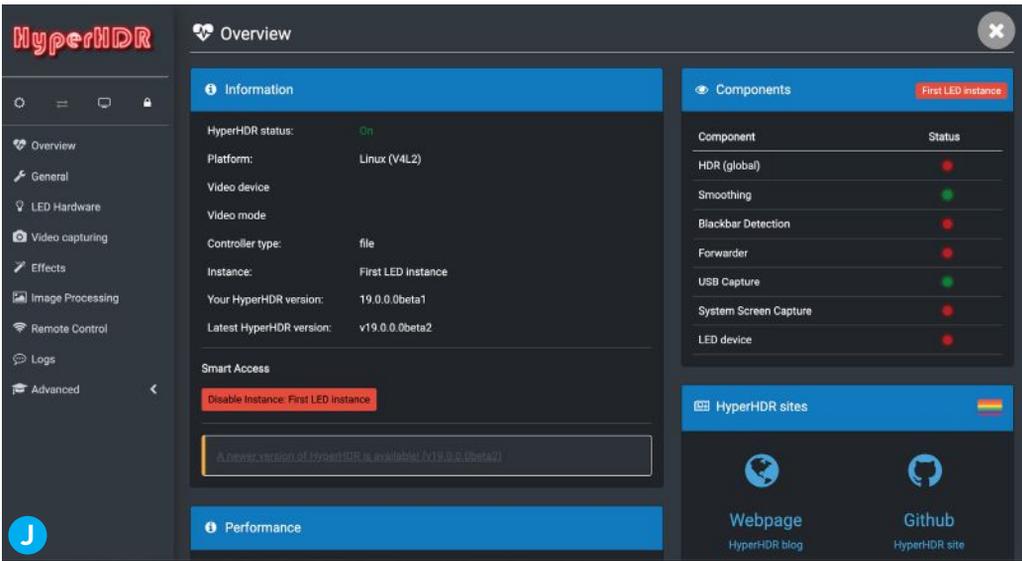
If it says **active** you are good to go (Figure 1).

6. CONFIGURE THE UI

Now go to a separate computer, open a browser, and type in `http://hyperhdr:8090` to get to the HyperHDR user interface (Figure 2 on following page). You may get a prompt to choose a password here.

```
[pi@hyperhdr:~] $ sudo systemctl status hyperhdr@root.service
• hyperhdr@root.service - HyperHdr ambient light systemd service for user root
  Loaded: loaded (/etc/systemd/system/hyperhdr@root.service; enabled; vendor preset: enabled)
  Active: active (running) since Mon 2022-12-19 01:50:10 GMT; 27s ago
  Main PID: 2454 (hyperhdr)
  Tasks: 11 (limit: 779)
  CPU: 6.931s
  CGroup: /system.slice/system-hyperhdr.slice/hyperhdr@root.service
          └─2454 /usr/bin/hyperhdr
```





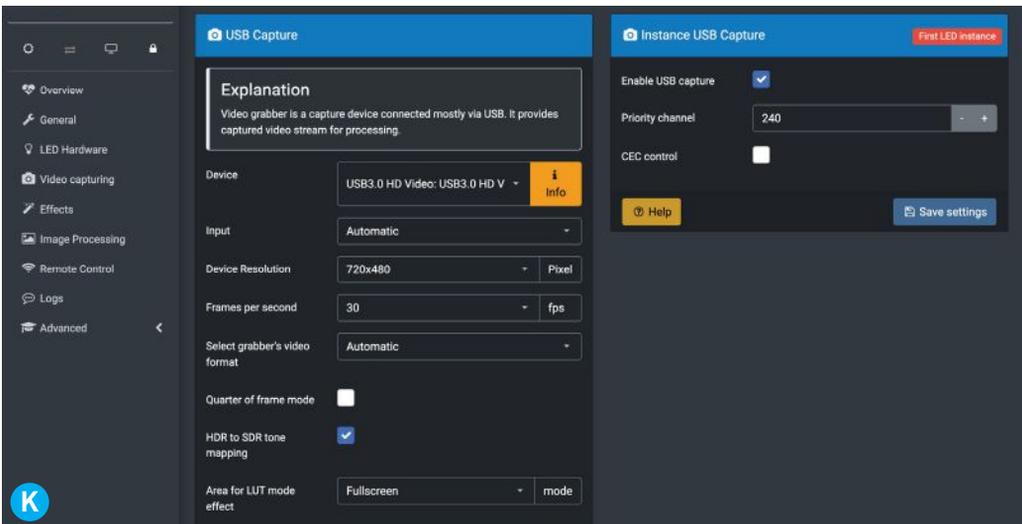
There are a ton of setting configurations in the software, and you'll need to explore those yourself for best performance with your own setup, but the main ones to jump to first to get things working are:

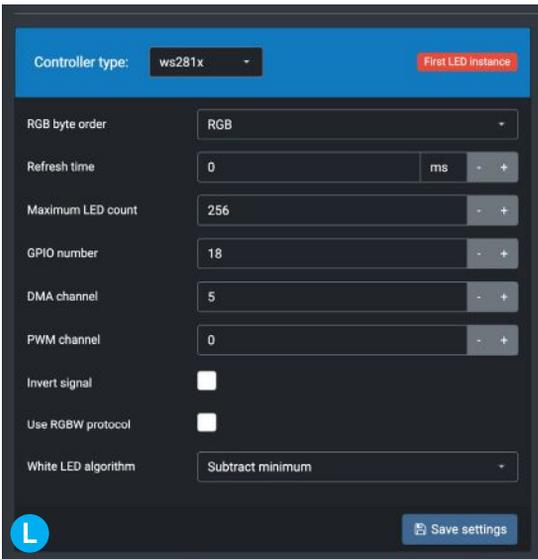
- **VIDEO CAPTURING:** Your HDMI grabber should automatically show up here, under the Device setting (Figure K). You can keep the resolution and frame rate on Automatic, but to keep things zippy, reduce the settings down to even 640×480 and 20FPS — we're not dealing with fine pixels. You can also activate HDR to SDR

tone mapping here. Click "Save settings."

On that same screen, in the Instance USB Capture section, click the checkbox to Enable USB capture, then click "Save settings."

- **LED HARDWARE:** Under the LED Controller tab, choose "ws281x" from the "Controller type" dropdown menu (Figure L). You may need to change your RGB order (there's a wizard for this under the Advanced menu). Input your total number of LEDs. Click "Save settings." You might now see some of your LEDs starting to light up at this point.





MORE HELPFUL LINKS AND RESOURCES:

- HyperHDR Github repo: github.com/awawa-dev/HyperHDR
- Raspberry Pi's HyperHDR tutorial: raspberrypi.com/tutorials/raspberry-pi-tv-ambient-lighting
- This Smart House video tutorial for Hyperion: youtu.be/PY8_KYnxyl

Click the LED Layout tab next. Here's where you'll input those LED counts, gap length, and input position. Once you click Save settings, your full LED array should fill up with light!

TOTALLY IMMERSED

From here, if you have content playing on your HDMI streaming device, you should be able to see corresponding ambient lights playing. Cool, isn't it? You might need to fiddle with the software for a bit to get the LED placement correctly configured, along with color matching, black bar detection (recommended), and lots more.

Naturally, the effect is most noticeable in a darkened room or at night. You may find yourself repositioning the TV to get better light dispersion, or to prevent those bright LEDs being too visible by people standing alongside the television.

The Hyperion forum has guidance on setup and hiccups. Also, as noted in the materials list: Users with A/V receivers, surround sound, and CEC-connected devices will need to use slightly upgraded HDMI hardware to maintain those features. It quickly becomes a slippery slope.

You've just added a new dimension to your home media center. Enjoy the immersion! 🎯





Soft Speakers

Experiment with making wearable speakers and haptics using conductive textiles

Written and photographed by Lee Wilkins
with software by Kyle Chisholm



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_

We're going to explore ways to make audio speakers more wearable — not by sewing ordinary hard speakers into garments, but by creating new kinds of speakers out of textiles and conductive thread. Then we'll make a soft speaker of our own!

HOW DO SPEAKERS WORK?

Inside every common loudspeaker are three simple elements: a stationary *permanent magnet* and a moving *voice coil* that's attached to a *speaker cone* or *diaphragm*. An amplifier feeds an audio signal into copper wire, which is wound into a the coil. As this electrical signal passes through the coil, a magnetic field is created, which interacts with the magnetic field of the permanent magnet. As the signal's frequency fluctuates, the coil's field also fluctuates and the speaker cone vibrates, pushing and pulling the surrounding air. This creates a pressure wave in the air that extends forward and backward from the cone. Sound!

For a speaker to function well at all frequencies, we must prevent the pressure waves created by the back of the speaker cone from canceling out the waves created by the front of the cone. This is why speakers are typically built into an enclosure. If you take a speaker out of its enclosure you'll notice a change in tone, because sound from the back is now interfering with the front.

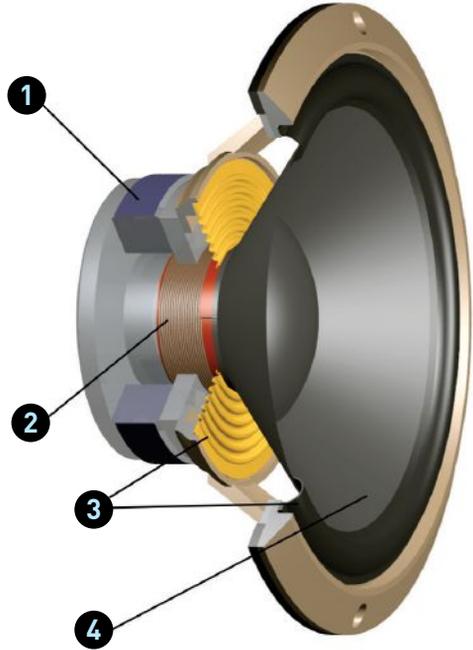
SOFT SPEAKERS & SQUISHY FUTURES

Soft speakers use these same technical concepts to explore what a speaker might look like made entirely out of textile. Think a hat with a fully integrated speaker, or answering your phone by listening to your gloves in the winter. Although the lack of rigid components can make resonating difficult, soft speakers are fun and experimental ways to imagine what a world made out of soft and squishy tech might look like.

To take a small detour away from what makes a good speaker into my artistic practice, I think it's important to ask: Why make a soft speaker at all? Everything about making an effective speaker relies on rigidity and non-soft components, so why make a not-so-great speaker out of fabric?

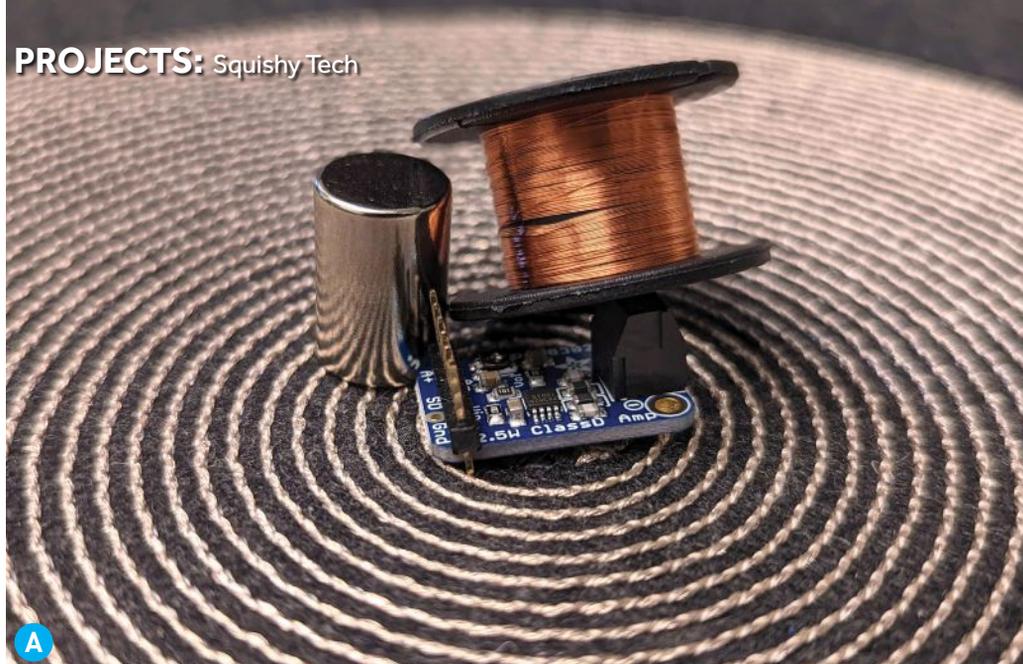
CUTAWAY VIEW OF A TYPICAL LOUDSPEAKER

- 1 Magnet
- 2 Voice coil
- 3 Suspension, aka "spider" and "surround"
- 4 Diaphragm



For me, it gets back to the core idea of this column, Squishy Tech, which aims to imagine what it means to question what makes up technology, and to understand why we built the world the way we have. A squishy future might be filled with electronic cyborgs made out of textile tech, but it also might be uncertain, unknowable, and untapped, so we should experiment and understand what makes up the technology we take for granted.

I've been experimenting with soft speakers for a while but I'm not alone. There are a ton of other e-textiles practitioners I've learned from and this work wouldn't be possible without people like Hannah Perner-Wilson, Leah Buechley, Becky Stewart, Claire Williams, Rythâ Kesselring, Lee Jones, Sara Nabil, Audrey Girouard, Joanna Berzowska, Marguerite Bromley, Afroditi Psarra, and Mika Satomi, who have all written about their experimentation with soft circuits and/or textile coils long before I made my first spiral!

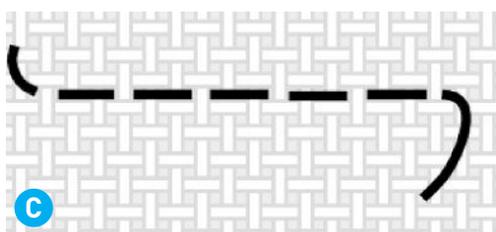


FACTORS OF MAKING A GOOD SOFT SPEAKER

To make a good soft speaker we'll need to re-create the components of a traditional speaker — coil, magnet, and cone — then connect it to an amplifier circuit and an audio source. Let's start by understanding how it all goes together. Soft speakers are typically made out of conductive thread stitched into a spiral on a textile base, serving as *both coil and diaphragm* (Figure A). A magnet is suspended above or behind the textile so that it doesn't interfere with vibrations. An amplifier circuit, often in the form of a breakout board, is attached as well. It can be placed in a pocket or attached to another textile surface.

Textile coils: A typical soft speaker coil is made out of conductive thread or enameled wire stitched into a spiral. There are a couple of ways to achieve this, depending on your skill, patience, and access to equipment. The easiest way is to hand-stitch a **spiral of thin conductive thread or wire** using a running stitch or a couch stitch, but you can also cut out **conductive fabric** (Figure B), or use **conductive nylon or copper tape**.

A basic **running stitch** is the first stitch you'll learn to sew: it goes over and under the fabric in a straight line (Figure C). Try to make your stitches fairly small and evenly spaced. It's tempting to make big stitches and go faster, but I promise, not only will your speaker look bad, it's easy to mess



up and get your thread tangled. If you break your thread, you can tie a new piece to it, but that's not ideal; it's tricky and it will show on your final coil.

If you're feeling more advanced, a *couch stitch* is a great way to go (Figure D). This method uses a non-conductive thread to hold down your conductive thread, which lies flat along the base textile. I find this works best if you want to use a thicker wire to make the coil.

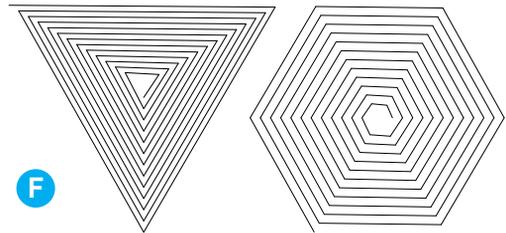
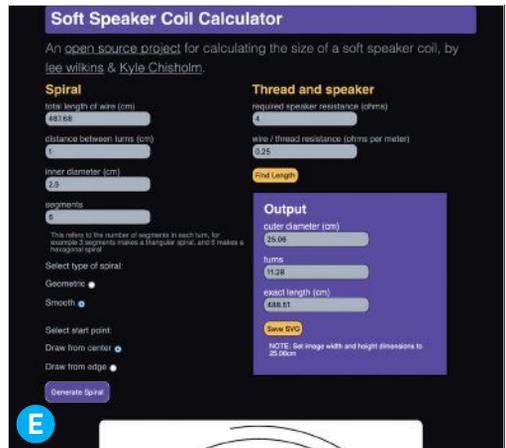
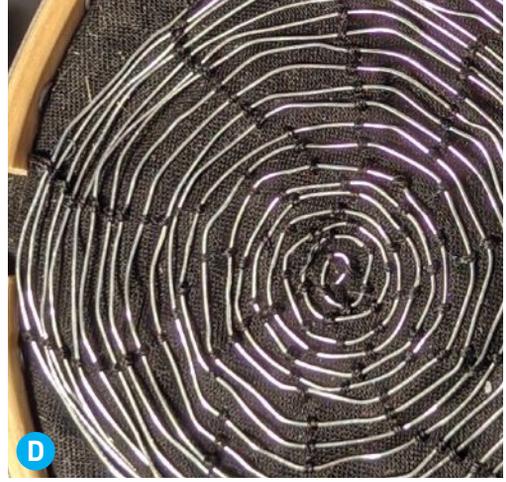
When hand sewing coils, I like to either use a fabric marker or chalk to draw the spiral on the material, or print out a spiral template and use transfer paper to put it on the fabric. I also use an embroidery hoop so it's easier to see my full design and not lose track of where I am.

For your first design, I suggest going bigger rather than smaller, to give yourself the space to learn to use the tools. There are a few factors to balance when designing a coil. The first is to understand how **resistance** works in your circuit. Depending on the amplifier you use, it will work best with a speaker of a specific resistance, aka **impedance**. Most small amplifier breakouts are meant for speakers with 4 to 8 ohms (4Ω–8Ω) of resistance, including the one I suggest in the tutorial below. You'll need to calculate how long your conductive thread should be by dividing the desired total resistance by the resistance of your wire per meter. For example:

$$\begin{aligned} & \mathbf{4\text{ ohm speaker resistance} / 0.25\text{ ohm per}} \\ & \mathbf{meter\ thread} \\ & = \mathbf{16\ meters\ of\ thread} \end{aligned}$$

TIP: For this reason, try to avoid using stainless steel conductive threads for this project; they have a relatively high resistance, meaning your speaker won't work very well! I suggest silver, silver-plated, or copper-based threads which can have resistance as low as 0.22 ohms per meter.

It can be a bit tedious to embroider your spiral by hand without knowing how big it will get! If you want to know the diameter of your spiral before you begin, you can use the **Soft Speaker Coil Calculator** tool that I worked with Kyle Chisholm to develop: leecyborg.github.io/soft-speaker-spiral-calculator (Figure E). It can calculate the size and shape of your spiral — smooth spirals or geometric shapes — with the exact parameters

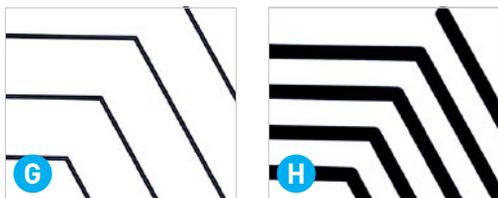


you want. You'll want to adapt the default settings to suit your needs. I like to leave at least 1cm between each spiral turn if I'm hand sewing, and at least 2cm in the center of my spiral.

You can use this tool to lay out your spiral by hand using a ruler, or input the values into Adobe Illustrator and print out a template on transfer paper. If you're using an embroidery machine, you can use these settings to create your digital pattern too; by default it exports the spiral as an SVG path, which can be opened in any vector program (Figure F).

If you want to try using a Cricut or laser cutter

PROJECTS: Squishy Tech



to cut out the spiral and iron it on using adhesive conductive nylon, you can increase the size of the stroke (Figures G and H) and expand the shape to create a thicker line that can be cut out, like in the thicker speakers in Figure B.

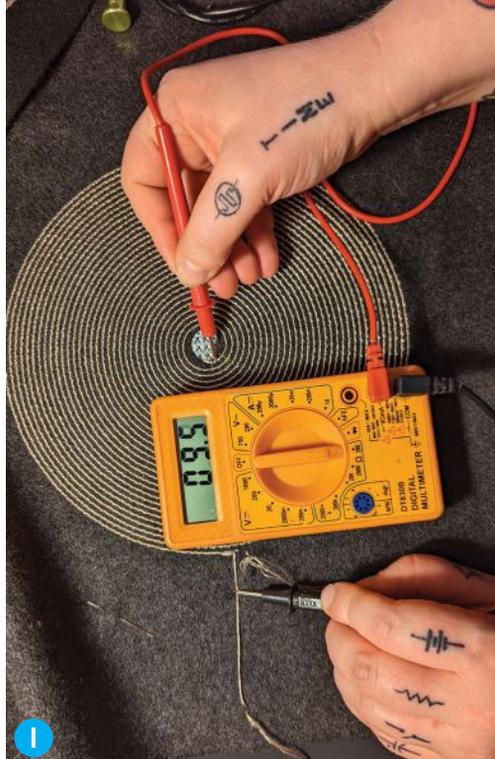
You'll find every conductive thread, fabric, or yarn has a resistance measured in ohms, although you'll need to convert any length units to metric for the calculator.

Once you know how much material you'll need, you can begin to design your spiral. The effectiveness of your speaker will depend on how tightly the coils are wound, but be careful — if your thread is not coated, your wires must not touch or you'll create a short circuit. The magnetic field is created by the overlapping fields of each circle of wire, so they should be close together, but not touching. For this reason I like to use **magnet wire**, which has an insulating enamel coating.

You can also experiment by making your coil a weird pattern full of wobbly lines, or convert an image into a spiral; these will still work but might be less "effective." In general, you want to squeeze in as many revolutions as possible in the smallest space possible.

To measure the resistance of your coil, you can use a multimeter on the ohms (Ω) setting. Every meter is different, but you'll want to find the setting that measures under 20 ohms. Place the probes at the center and end of the coil to get a reading (Figure I). You want to make sure the signal goes through the entire coil to get the full resistance reading. If you finish your spiral and it has way too much resistance, you can use the multimeter to find the right part of the coil to cut your circuit.

If you're lucky to have access to a sewing machine or a digital embroidery machine, you can machine-sew these too. If you're sewing with conductive thread make sure to go slowly; I find it easier to put it in the bottom bobbin and turn the



wheel manually. Take your time!

When using an embroidery machine (Figure J) I like to make vector files using the spiral template from our coil calculator, and then make fun designs with them using Adobe Illustrator, Inkscape, or Affinity Designer. You can experiment with the stitch, but be careful to remove the backing before trying out your speaker.

Base fabrics: Once you've decided on your spiral design and material, you can choose a base fabric. As with most artistic endeavors, it's hard for me to say one fabric is "better" than another, as each will produce different qualities of sound. You want a base fabric that is strong enough to vibrate and create a wave, but not fully rigid. I do suggest avoiding loose or stretchy fabrics which can be harder to work with. My go-to is a light, tightly woven muslin fabric, but it's a good idea to try out lots, from silk to canvas! Light fabrics can produce tactile sensations, whereas leather or thicker materials produce deeper audible vibrations.

Magnets and amplifiers: You'll need a magnet to activate your speaker; the sound is directly proportional to the strength of the magnet. I like to get mine from Radial Magnets (radialmagnet.com) but there are a ton of sources out there, and magnets can also be salvaged from all kinds of computer or electronic parts.

You'll also need an amplifier. My preference is the stereo 20W Class D audio amplifier **MAX9744** breakout from **Adafruit**, but if you want to get a more powerful sound, there are tons of options out there. Class D amplifiers like the MAX9744 or the mono **PAM8302** use transistors to modulate the pulse of the signal to amplify it. It's possible other sorts of amplifiers work; I've seen **Kobakant** use a **Darlington pair** circuit to the same effect. Some amplifiers are 1 or 2 channels, usually reserved for left and right, and they will each specify a desired resistance for your speaker, so it's best to consult the data sheet for each one.

It's really important to ensure your speaker does not have less resistance than the amplifier requires, or you can risk damaging your audio devices. I connect my amplifier to my phone and then explore different songs. Try out something with lots of bass, lots of vocals, and different ranges of tones in combination with your fabric and coil choices to see how it changes the sound.

You can also experiment with larger amplifiers, like the **TPA3116D2**, bigger coils, and stronger magnets to get some pretty rad effects. You can even add a resonator to your soft speaker if you want, or put it in a cup to hear the effects.

Make Your First Soft Speaker



TIME REQUIRED: An Afternoon

DIFFICULTY: Easy

COST: \$40-\$60

MATERIALS

- » **Copper enameled wire, 38 AWG** aka magnet wire
- » **Woven muslin fabric**
- » **Large neodymium magnet, 2cm or larger**
I used a 2cm cylinder 4cm long.
- » **PAM8302 2.5W mono amplifier IC breakout board** such as Adafruit 2130
- » **Jumper wires** aka DuPont wires
- » **Audio cable, 1/8" plug**
- » **5V power source with barrel jack**
- » **Sandpaper**

TOOLS

- » **Embroidery hoop**
- » **Sewing needles**
- » **Audio source with 1/8" audio jack** or adapter



1. MAKE YOUR COIL

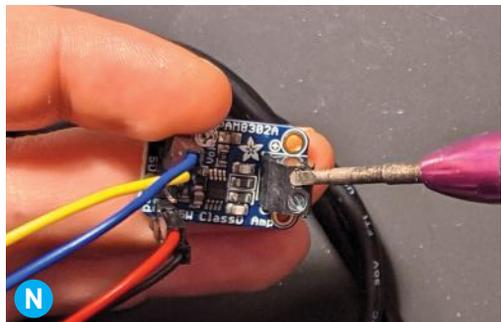
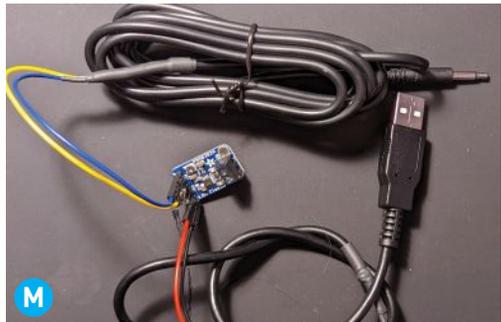
Depending on the tools you have on hand, you can either digitally embroider or hand sew your coil. If you are hand stitching, I suggest drawing your spiral on the textile using a washable marker, chalk, or fabric pen.

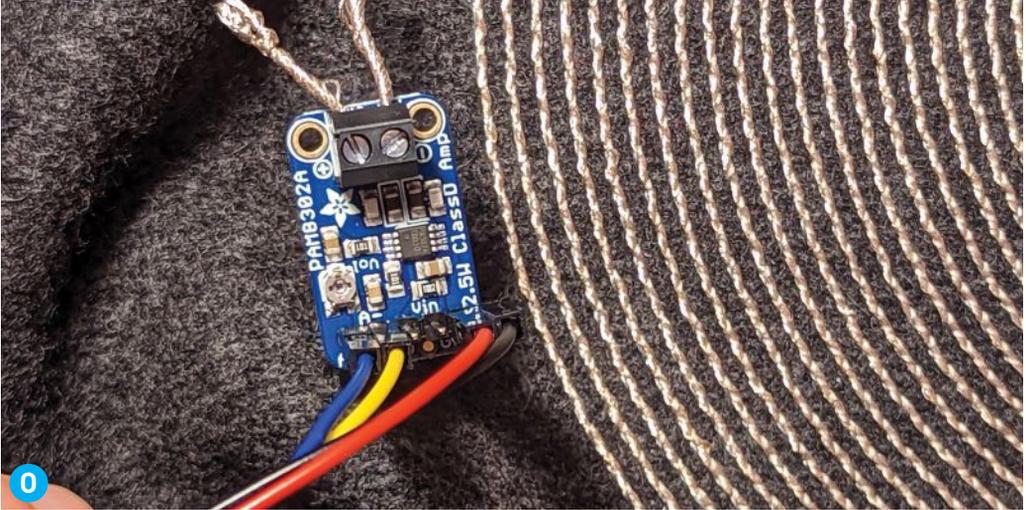
First, determine the total length of your wire by dividing the required speaker impedance by the resistance per meter of your wire. I need to make a 4Ω speaker with wire that has 0.25Ω resistance per meter, so I'll need 16 meters of wire total. You can use the [Soft Speaker Coil Calculator](#) to determine the diameter of your spiral and revolutions, and mark them on your textile using a ruler before you begin, to keep it consistent.

If you want to be very precise, you can use Adobe Illustrator, Affinity Designer, or Inkscape to generate a spiral pattern using these parameters, then print it on transfer paper or use an embroidery machine or Cricut to cut out your SVG as described above. (Thank you to the Milieux Institute and Genevieve Moisan for helping me wrangle the Tajima embroidery machine!)

When you're ready to start sewing, stretch the muslin fabric over your embroidery hoop. Pull it tight, but not too tight or it will slip out of the hoop. Give yourself plenty of space to work and try to center your spiral on the hoop. Begin stitching on the interior of the spiral using a running stitch (Figure **K**), keeping the stitches a few millimeters long and consistent for best results. Take your time, and make sure to fully pull the thread through the fabric before beginning your next stitch.

When you're done, tie off your wire and leave some length remaining to attach your amplifier.





If you're using magnet wire (Figure **L**), use sandpaper to remove the enamel from both ends of the wire by carefully sanding them.

2. WIRE YOUR AMPLIFIER

Every amplifier breakout is different, but most will have a few consistent connection points. On the PAM8302 amplifier, you can solder header pins that will plug into the socket end of the DuPont jumper wires. I made two cables to attach to the board, for the power and audio input connections (Figure **M**). For the 5VDC and Ground pins, I cut a USB cable and soldered DuPont wires to the end.

Then I did the same for an 1/8" audio cable and connected it to Audio Input+ and Audio Input- pins. This is a mono amp, so you're only connecting two audio wires — use a mono cable or only one channel (L or R) of a stereo cable. (You

can make two speakers if you want stereo!)

Solder the screw terminals to the 4–8Ω Load pads on the other end of the board (Figure **N**). Then you can push the conductive thread from your speaker coil ends into the screw terminals and tighten them (Figure **O**). You can also use alligator clips, or solder directly to the board.

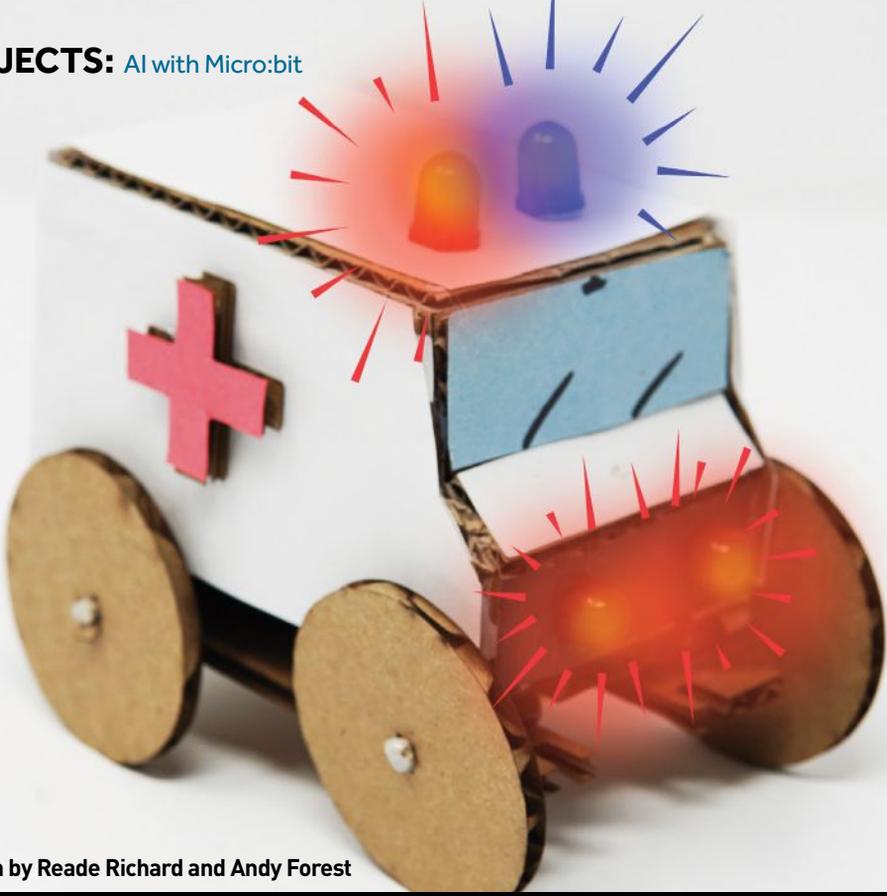
Plug the audio cable into your phone or computer.

3. JAM TO SOME BEATS!

You're ready to hear some beats! Start playing sound through your audio device and hold the magnet just above your soft speaker (Figure **P**). You should be able to hear the sound coming from the speaker as well as feel it in the magnet. Happy listening! 🎧



A



Written by Reade Richard and Andy Forest

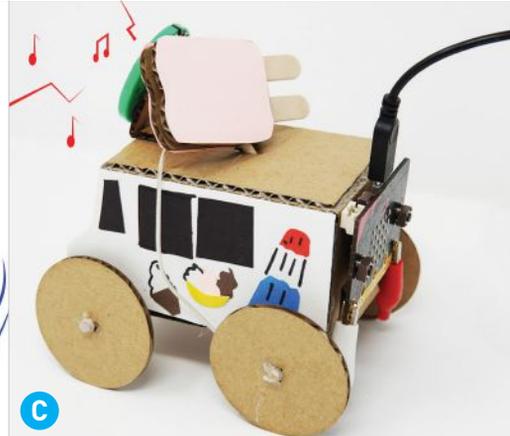
Anyone Can Use AI

Build your first AI project!

B



C



How much more creative could your projects become if you added artificial intelligence?

In this article, we'll show you how you can use your webcam and free web-based software to add powerful vision recognition AI to a simple micro:bit project. You will train an AI model to recognize different classes of objects that will be used to make predictions based on what can be seen through your webcam.

YOUR FIRST AI PROJECT

In this project, we're going to train our AI to be able to recognize a few typical city vehicles and write a program in MakeCode to play sounds unique to each one on the micro:bit, depending on which vehicle is recognized.

For this project, we're going to use three different types of cars made from cardboard. You can create vehicles similar to ours (Figures **A**, **B**, and **C**), but you can easily follow along by making any vehicle or machine you'd like! (Kathy Ceceri's book *Making Simple Robots* is full of awesome micro:bit creations if you want inspiration!)

HOW TO TRAIN AN AI ENGINE

Google's **Teachable Machine** allows anyone to create an AI prediction model to recognize images or even sounds. The process of training an AI model requires that you specify different **classes** of images that you want the AI to be able to recognize.

Each possible prediction, or class, needs to be filled with a *bunch* of photos — the more photos you add, the more examples it has to learn from, and the smarter your AI becomes because it detects similarities and patterns in the images that you upload. Machine learning AI algorithms are very powerful, but the AI needs to have many examples to reach a general understanding of what it's seeing. If you only provide pictures of the side of your car, it will have no idea that the front view is also a car.

When you head over to Google Teachable Machine, you'll find three different models to choose from. To recognize the images from a webcam, choose the **Image Project** option.

Start a new project and create an "empty" class (which we can call Background) so that the AI can

TIME REQUIRED: 20 Minutes

DIFFICULTY: Easy

COST: \$18-\$20

WHAT YOU'LL NEED:

- » **Micro:bit v2 mini computer with USB cable**
- » **Windows or Mac computer with a webcam**
- » **Microsoft MakeCode website (makecode.microbit.org)** to program the micro:bit
- » **Basic craft materials**

We are also going to use two websites to build and apply our AI model.

- » **Google Teachable Machine (teachablemachine.withgoogle.com)** will help us train and build an AI model for our application.
- » **AI Robots (microbitAI.inventor.city)** will use the AI model to make decisions and communicate the results to your micro:bit.

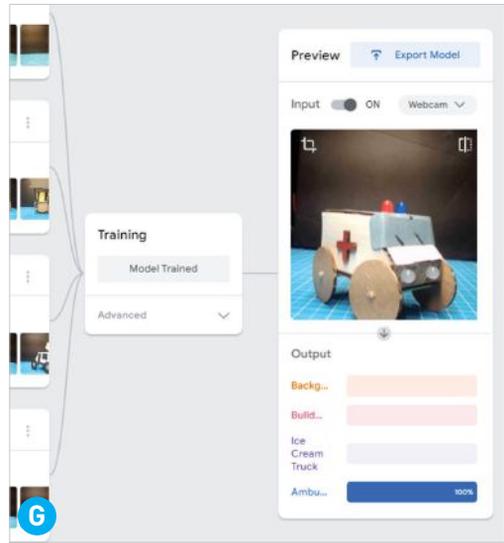
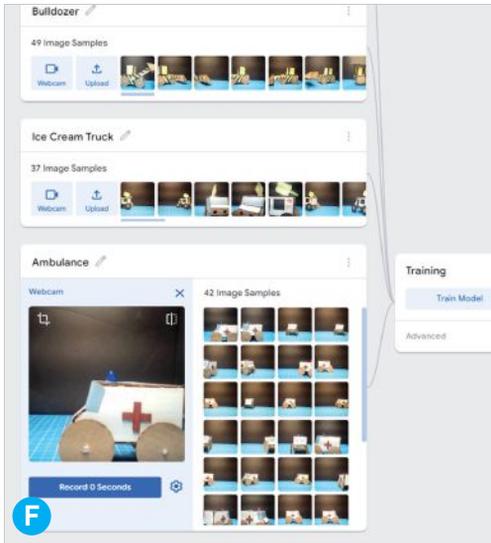
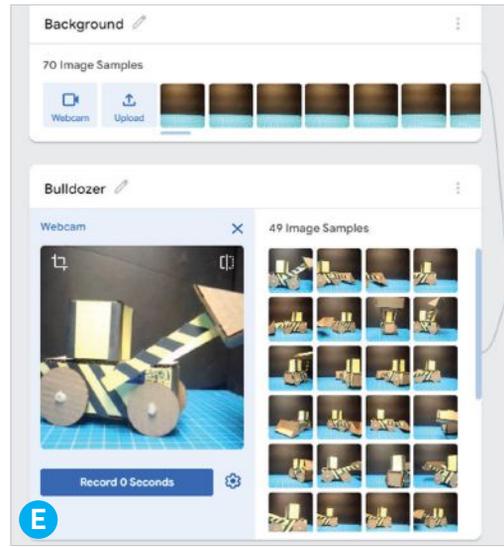
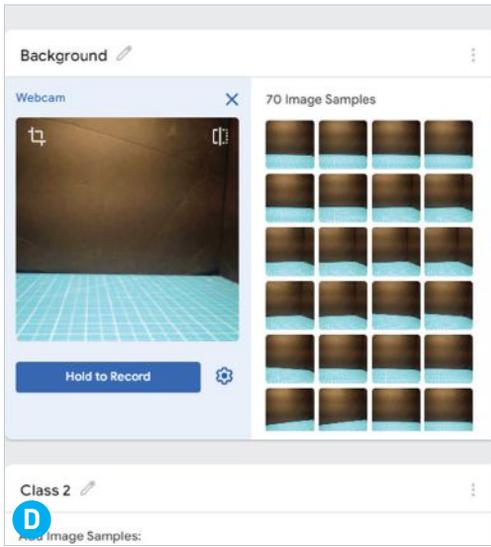
AI Robots is a web tool developed by steamlabs.ca that allows you to easily integrate AI into your micro:bit projects. The micro:bit is not powerful enough to run most AI models, so AI Robots acts as a bridge between your micro:bit and the pre-trained AI model on the cloud. This allows your micro:bit to easily access the power of AI to recognize images, sounds, and more without having to do any of the heavy lifting itself. Try AI Robots and unlock the full potential of your micro:bit projects! microbitAI.inventor.city



READE RICHARD is a maker/educational content developer for Steamlabs with a passion for micro:bit and laser-cut activities. In his spare time, he enjoys bringing artifacts from his favorite films, books, and games to life using woodworking, laser cutting, and other fabrication tools at his disposal.



ANDY FOREST is the executive director of Steamlabs, an education innovation non-profit helping all people to understand science and technology and use them to solve their personal challenges, improve their communities, and make the world a better place. He leads teams that produce software experiences to develop kids' identities as creators, coders, scientists and makers.



recognize when there is no vehicle present at all, shown in Figure **D**. The system will only choose between the classes you add, so if there is no “empty” class, it will strain to pick up tiny clues in the empty scene that look like your vehicles and misrecognize it. Press the Hold to Record button to add photos to this class.

Continue creating classes and naming each one after a different vehicle, as shown in Figures **E** and **F**.

The photos for each class need to have as much variety as possible. A bunch of *the same photos* will not work; try to take photos from all

different sides of your vehicles, moving them to one side of the camera, and placing parts of them out of frame. This will ensure the AI has a robust dataset to eventually compare to. Aim for at least 20–25 photos — the more, the merrier!

When you’ve finished adding photos, click the Train Model button, and test your AI off to the side, shown in Figure **G**. When you’re confident the AI can predict accurately enough, export the model, and select Upload My Model on the following screen, as shown in Figure **H**. Save the link it gives you, and then we’re ready to start coding for the micro:bit.

CODE YOUR APPLICATION

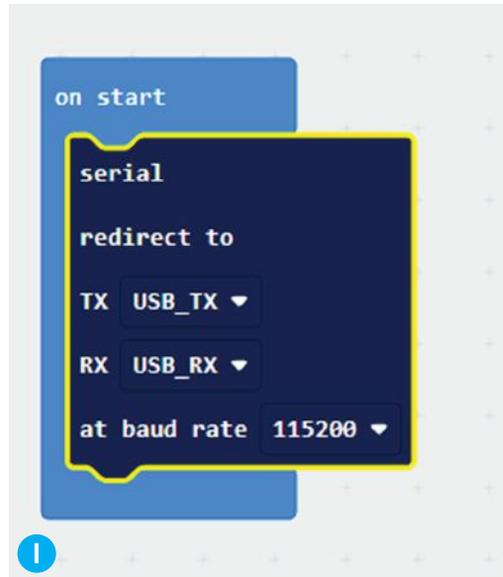
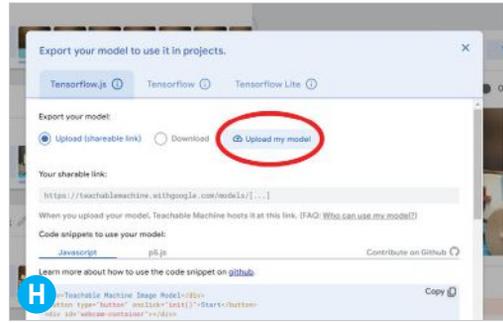
We will build an application in MakeCode to pass *serial data* back and forth from the micro:bit and the computer through a USB cable.

We'll need to add a few lines of specialized code, as shown in Figure I.

- Start a new project and explore the Serial category (aka **Serial drawer**) off to the side.
- Place the large square **serial redirect to** block into the **on start** block in your workspace to initialize communication.
- Set the **TX** and **RX** dropdown menus to **USB_TX** and **USB_RX** respectively, and leave the baud rate as high as it will go, **115200** (this allows lightning fast data transfer).

We'll need a way for the micro:bit to be able to look at all of this info, so we'll store all of that as a *variable*.

- Start by dragging the **serial on data received** block out of the Serial drawer and into the workspace, allowing us to run code every time new serial data is received.
- Then create a variable called **SerialData**.
- Place a **set SerialData to** block down first, and then a **serial read until new line()** block from the Serial drawer into the bubble at the end, as shown in Figure J.



PROJECTS: AI with Micro:bit

That's all you need to do to set your code up to be ready for Vision Recognition activation.

At this point, the code is ready to receive the class name that the AI Robots site sends whenever it recognizes an object, and save that into the variable **SerialData**.

Now we want to do something with that class name!

- Set up an **if statement** and use text comparison blocks from the **Logic drawer** to check if **SerialData** matches any of our class names from the AI model.
- Add a new branch in the **if** statement for every class you trained in Teachable Machine.

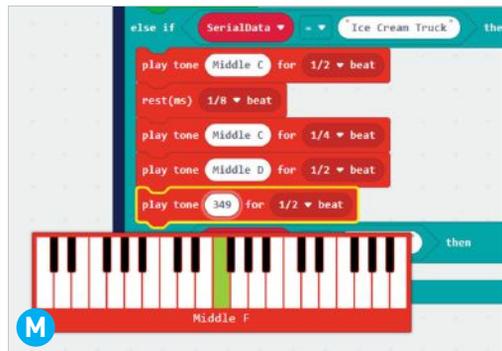
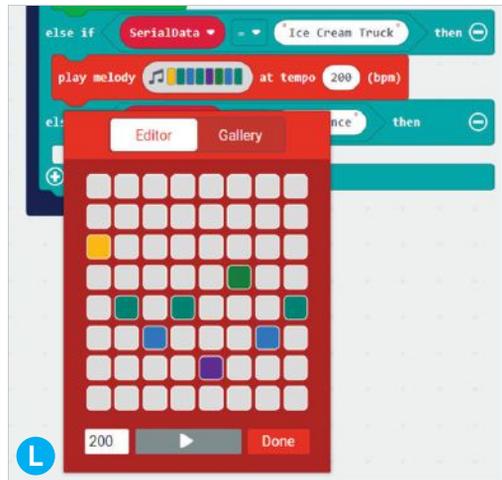
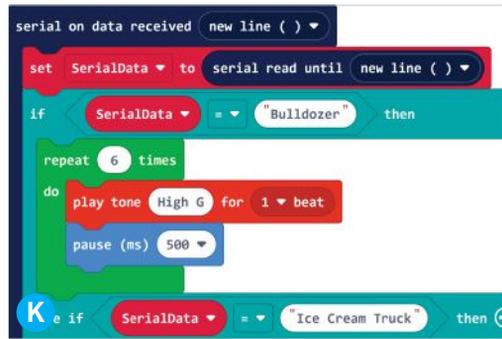
Now it's time to decide *what* your code will do when a class is recognized. You don't necessarily need to add anything for the background class you trained. Take the bulldozer for instance — a unique sound made by this machine would be the distinct warning beeps it gives while raising its front blade or backing up, as shown in Figure **K**.

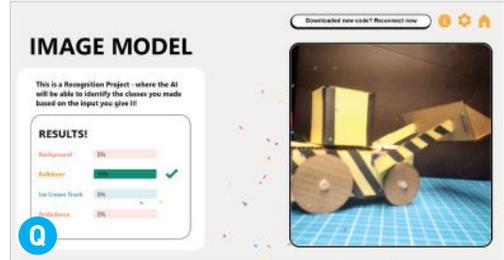
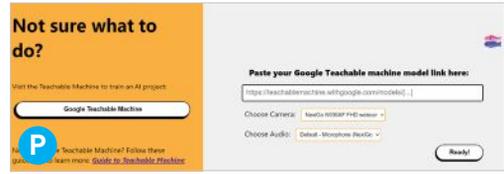
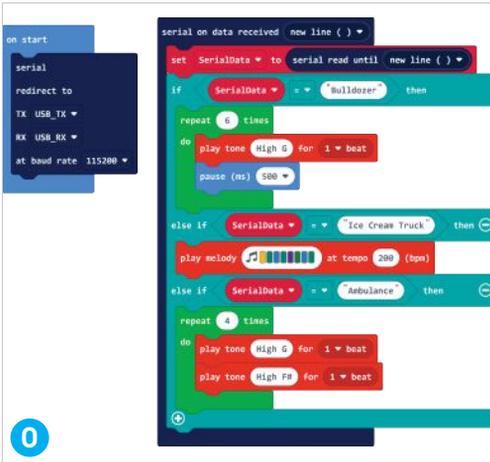
- Look through the **Music drawer** and find a **play tone** block that lets you select beeps of varying frequencies.
- Choose one that sounds appropriately high enough, and add a short **rest** after.
- Place this sound inside a **loop** from the **Loop drawer** to make the sound repeat over and over.

The sound for the ice cream truck can be handled in a similar way. You can either use a premade song or create a quick one yourself using the **play melody** block, as in Figure **L**. If you're musically inclined, you could even write out an entire song using the **play tone**, **beat**, and **rest** blocks, shown in Figure **M**.

Lastly, the sounds of the siren wails from an ambulance should be easy to make using the blocks we've already explored here. You'll need two tones that are close together in pitch, and a way to repeat those tones to create a constant whistle. Use the **play tone** and **loop** blocks we showed you above to create your own siren, as shown in Figure **N**.

When you've chosen all the fun sounds for your vehicles, download your project to your micro:bit, and you're ready to bring it to life (Figure **O**).





CONNECT YOUR AI TO YOUR MICRO:BIT

Finally, we need to connect it all together! In this step you will use the vision recognition AI model you trained with Teachable Machine to send the class names to your micro:bit over your USB serial cable.

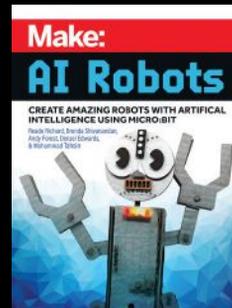
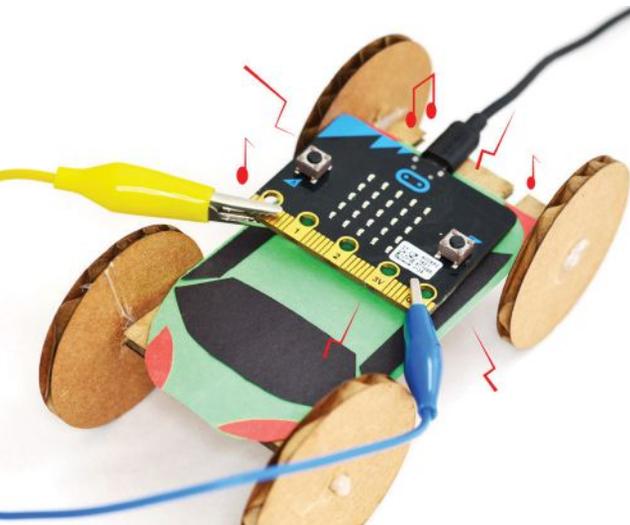
Go to Steamlabs' **AI Robots** site (microbitAI.inventor.city) and input the link you saved from the Teachable Machine site (this is the actual trained AI model), as shown in Figure P.

Once you upload the model and connect your micro:bit, you'll be taken to the project page where you can watch the AI begin to make predictions about what it is seeing. Here you can also tweak your AI a little bit by increasing or decreasing the threshold for what it considers

an *accurate prediction*, which is helpful if you find it's having a hard time coming to a decision. Or you can even tell the AI to pause after making a decision — helpful if you're looking for an AI to predict a race winner (marble races, anyone?).

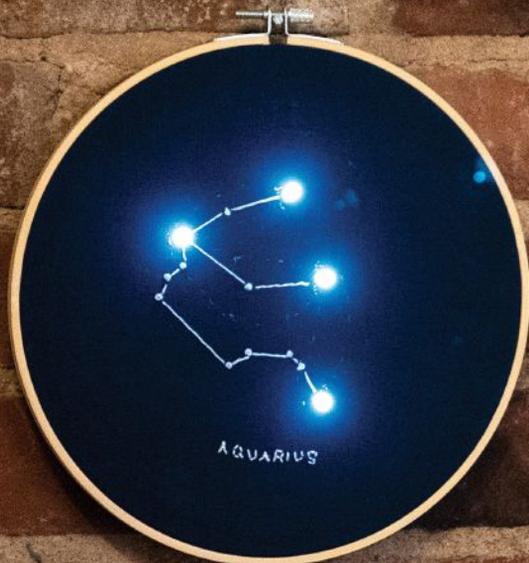
If everything is set up properly, your micro:bit will spring to life as soon as a class has been detected, as shown in Figure Q. Place any vehicle you made in front of the camera and be amazed as your micro:bit decides to play a little tune all on its own!

If you thought this project was a fun idea, check out *Make: AI Robots* (coming soon) — a new project book featuring many other fun projects. With the help of our AI Robots site, you'll never run out of ways to control your projects again! 🤖



This article is adapted from the upcoming book *Make: AI Robots*, an introduction with 8 fun and educational projects for kids and parents using micro:bit with AI enhancements.

Learn how to create interactive robots that respond to facial expressions, add up coins, judge marble races, and more! Find this and more great micro:bit projects and kits at makershed.com/collections/micro-bit.



Written and photographed by Becky Stern



TIME REQUIRED: 1–3 Hours

DIFFICULTY: Easy

COST: \$5–\$25

MATERIALS

- » **Dark blue fabric, about 10"×10"** such as Amazon B09TVGKBJK
- » **Embroidery hoop** like Amazon B07N64QD4D
- » **White embroidery floss** like Amazon B0033PCHLE
- » **Zodiac templates** Free downloads; see text.
- » **LED sewing kit (optional)** for the light-up version, beckystern.com/ledsewingkit

TOOLS

- » **Scissors**
- » **Embroidery needle**
- » **Water-soluble marking pen**

Zodiac Embroidery

What's your star sign? Stitch your favorite constellation and light it up for all to see



BECKY STERN has authored hundreds of DIY tutorials about everything from microcontrollers to knitting. She is an independent content creator and STEM influencer living in New York City. Previously she worked as product manager at Instructables (Autodesk), director of wearable electronics at Adafruit, and senior video producer for *Make*.. She enjoys riding on two wheels, making YouTube videos, and collecting new hobbies to share with you. beckystern.com

Here's an easy beginner embroidery project that celebrates your favorite constellation.

Follow along to see how I made these classic constellations and also glowing versions made with LEDs and conductive thread.

DOWNLOAD THE ZODIAC PATTERNS

Whether you want to embroider the constellation with or without LEDs, I've got you covered with a free PDF pattern for every sign in the zodiac, plus circuit diagrams (Figure A):

- makezine.com/go/zodiac-embroidery-patterns
- makezine.com/go/zodiac-embroidery-circuit-diagrams

MARK OUT THE DESIGN

Start by putting the dark blue fabric in the hoop: Sandwich it between the inner and outer rings and pull it taut while tightening the screw.

Then draw the constellation pattern with a water-soluble marking pen. I printed the pattern and traced it using my USB lightbox (Figure B), but you could also tape it up to a window or use your laptop screen as a lightbox instead.

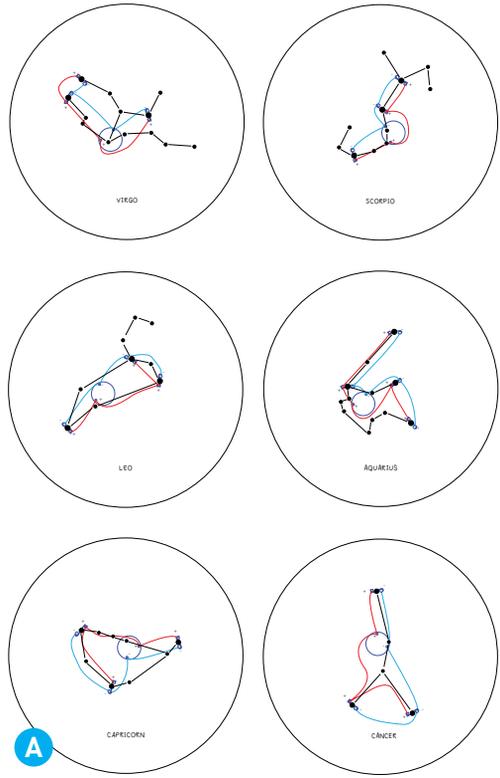
FLOSS PREP AND BASIC STITCHING

Next, thread a needle with white embroidery floss. I used three strands, which I separated from the full thickness. Start stitching from back to front (Figure C), leaving a few inches of floss tail at the back. Instead of knotting the floss at the back, I like to secure that tail using the future stitches. This keeps the embroidery nice and flat, but it's also OK to tie a knot in the floss.

For the lines connecting the stars in my constellation, I stitch back and forth between the front and the back wherever I want a line to be. If you skip ahead and stitch back, like I did in this sample, it's called a *backstitch*, but I also used a *running stitch* to make the long lines.

FRENCH KNOTS

For the stars, I use another type of stitch called a *French knot*. I come up from the back of the fabric and pull the floss all the way tight. Then I'll take my needle in my dominant hand, and grab the floss near the fabric with the other hand. With the point of the needle facing away from the hole in the fabric, wrap the floss around the needle a few





times (Figure **D**), then pierce it through the fabric close to where it originated. All while holding the floss slack snug with my non-dominant hand, I'll pull the threaded needle through the newly formed knot to the back of the fabric, until the slack neatly tightens to form a knot. The size of the French knot depends on how much floss you're using, and how many times you wrap it around the needle.

CREATING THE CONSTELLATION

I used a combination of running and back stitches and French knots to follow along the lines I drew on the fabric earlier. To end the floss at the back, I just used the needle to thread it through the backs of some other stitches, and cut off any extra. Then I sprayed the whole thing down with water and used a paper towel to lift away the water-soluble pen marks.

FINISHING THE EMBROIDERY

Before I could hang it on the wall, I wanted to take care of the extra fabric along the edge. I cut it to match the shape of the hoop and then gathered it at the back with a running stitch and some plain thread (Figure **E**). But if you don't like the wood hoop look, you could also mount this up in a standard picture frame, or even sew it into a pillow cover or quilt.

ADDING LEDS (OPTIONAL)

While this embroidery is perfectly fine on its own, you know I couldn't resist adding LEDs to this space-themed project to bring it to the next level (Figure **F**). I'm using my LED sewing kit (becksystem.com/ledsewingkit), which has everything I need for a project like this.

I'm starting with the same embroidery as before, except I've picked three big stars for the



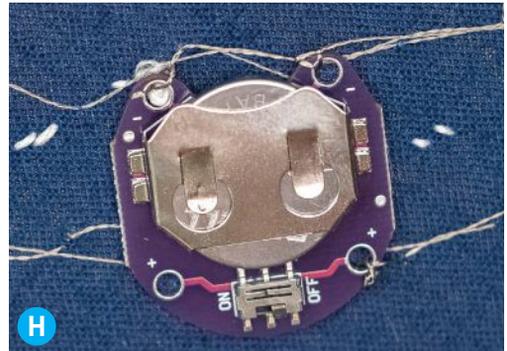


LEDs and left those spots blank instead of the usual French knot. Pierce the LED legs through the fabric in those spots, and splay them out at the back. Find the longer, positive leg of each LED, then use pliers to twist each of these into a loop, so they're easy to tell apart from the negative legs.

Next, stitch on the battery holder using conductive thread, somewhere toward the middle of the design. I attached it to the backs of the stitches where possible, and just caught a few fibers of the fabric everywhere else (Figure G), so you won't be able to see very much conductive thread on the front.

Attach all the positive LED legs to the positive (+) contacts on the battery holder, and all the negative (-) contacts to ground (Figure H). This conductive thread is very thick, so I needed to tie several knots and tuck in the thread ends where they can't spring apart and touch positive to negative, which would make a short circuit.

The battery holder has a little switch on it,



which makes it easy to turn the LEDs on and off. Light them up!

For more free and excellent beginner lessons, please visit my friend Jessy's Embroidery Class ([instructables.com/Embroidery-Class](https://www.instructables.com/Embroidery-Class)). 🎧

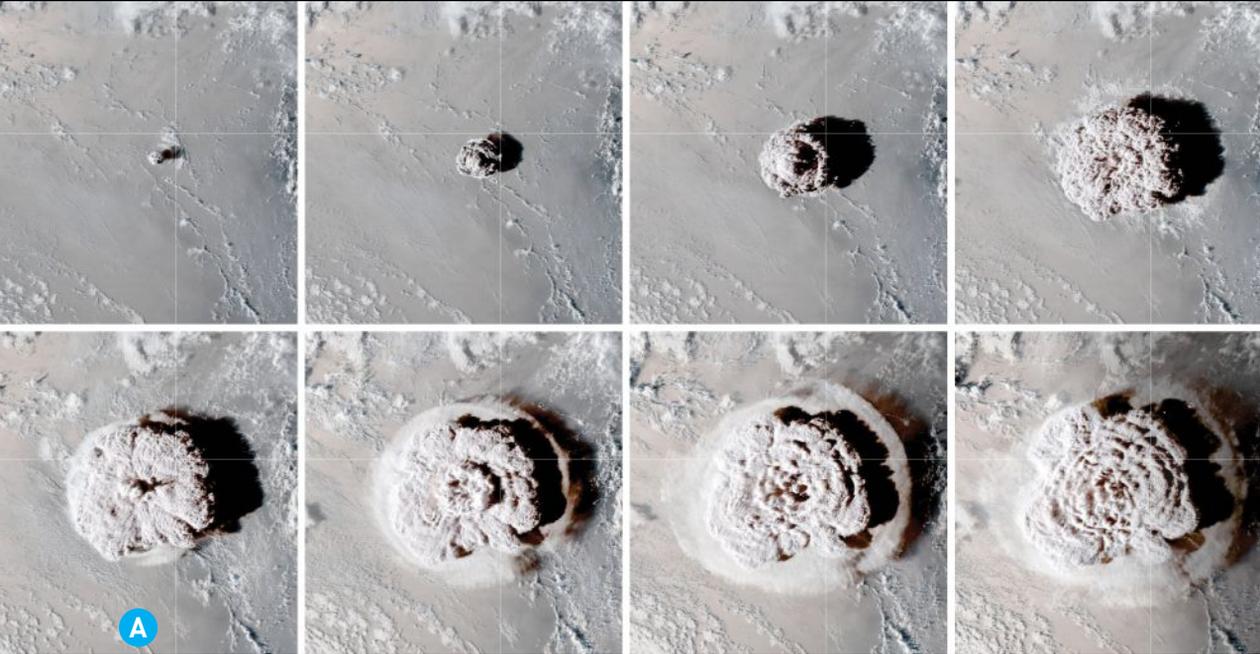


Watch a video version of this tutorial at youtu.be/CSdNQIm7PiI.

King of the Ring of Fire

Twilight glows reveal the height of Tonga's volcano eruption — the highest ever recorded

Written and photographed by Forrest M. Mims III



TIME REQUIRED: 1–2 Hours

DIFFICULTY: Easy

COST: Free

TOOLS

- » Watch or clock
- » Notebook
- » Camera (optional but helpful)

Hunga Tonga-Hunga Ha'apai is a giant volcano under the South Pacific Ocean, 3,000km (1,860mi) east of Australia. The January 15, 2022, eruption of Hunga Tonga propelled a huge dome of water and volcanic ash up through the entire stratosphere and into the mesosphere where meteors burn up (Figure A). It's the highest eruption ever observed.

While Krakatoa and Pinatubo may have launched far more solids than Hunga Tonga, the altitude of Hunga Tonga's eruption plume and its massive amount of water were the largest of any known eruption. If Krakatoa and Pinatubo were



The Pinatubo eruption in 1991 (left) included far more sulfur dioxide and appeared much larger and denser than Hunga Tonga (right), but Hunga Tonga’s eruption plume was much higher.

shotgun blasts, Hunga Tonga was a bullet.

I made hundreds of photos of twilights caused by the 1991 Pinatubo eruption, the second greatest of the 20th century. Figure B compares Pinatubo and Hunga Tonga sunsets and clearly reveals that the Pinatubo cloud was denser. Nevertheless, Hunga Tonga produced spectacular twilight glows around the world (Figure C). On some days the Hunga Tonga aerosols surrounded the sun with a deep red glow (Figure D).

The Hunga Tonga eruption increased the water vapor in the stratosphere by 5 to 10 percent. A prominent atmospheric scientist told me the excess would remain in the stratosphere for up to a decade. This is important, for water vapor is the chief greenhouse gas. Thus, adding water vapor to the stratosphere might slightly increase the Earth’s average temperature. It might also slightly reduce the stratospheric ozone layer.

Major volcano eruptions like Hunga Tonga also inject sulfur into the stratosphere, where it is transformed into microscopic droplets (aerosols) of sulfuric acid. The Hunga Tonga cloud contains far less sulfuric acid aerosols than Pinatubo’s. But there’s enough to cause spectacular orange and red twilights around the world.

TWILIGHT GLOW AND VOLCANIC AEROSOL CLOUDS

If your location is experiencing bright, colorful twilight glows from Hunga Tonga, you can measure the maximum altitude of the volcanic cloud using only a watch, or the clock on your phone. This method is described in “The Eruption of Krakatoa and Subsequent Phenomena” (Krakatoa Committee, The Royal Society, 1888). This 495-page report includes vivid descriptions of the famous eruption, the damage it caused, and the brilliant twilight glows that followed. You can read it online or download it for free at Google Books, Open Library, and other sites.

Aden and Marjorie Meinel explain volcano twilights in *Sunsets, Twilights, and Evening Skies* (Cambridge University Press, 1983). They also describe how to use the twilight method for estimating the peak altitude of volcanic clouds. This remarkable book is available from Amazon, and it’s must reading if you’re interested in studying twilights and the impact giant volcanoes have on the atmosphere.

The Meinel method is easily implemented:

1. Find a location with a clear view of the horizon where the sun will set, free from city lights.

Joshua Stevens of NASA Earth Observatory



The Hunga Tonga eruption caused spectacular twilights around Earth, like this one over my Geronimo Creek Atmospheric Monitoring Station in Texas.



The Hunga Tonga aerosol cloud was dense enough to redden the sky at sunrise and sunset, seen here across the Gulf of Mexico from Port Aransas, Texas.

PROJECTS: Amateur Scientist

2. Wear sunglasses; don't look directly at the sun.
3. When the sun touches the horizon, it will disappear in 2 minutes. Make a note of the time the sun disappears, for that's *sunset*.
4. After 15–20 minutes, the sky over the sunset will brighten. If volcano aerosols are present, the glow will become bright orange or even brilliant red.
5. Continue watching the sky until *glowset* approaches. Make a note of the time the upper edge of the glow slips below the horizon.

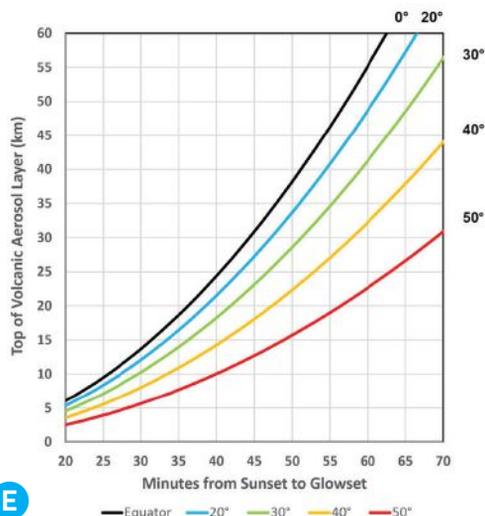
Haze and the fuzzy, upper edge of the glow can make it difficult to determine the exact time of glowset. That's why I make a series of photos of the horizon beginning a few minutes before glowset. For best results, mount your camera on a fixed tripod or selfie stick and use a remote control to snap a series beginning just before glowset.

Depending on your geographic latitude and the height of the aerosol layer, glowset can occur 60 or more minutes after sunset. Figure E is a chart based on Meinel's formulas that shows the altitude of the top of the volcanic aerosol layer for various latitudes and times from sunset to glowset.

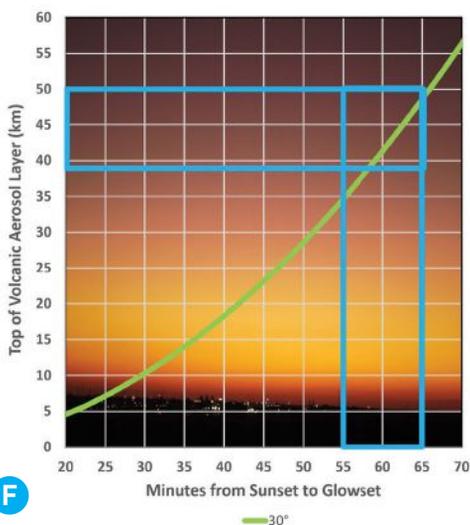
Figure F shows typical Hunga Tonga twilight results at my site, which is just below a latitude of 30 degrees. The box in this chart shows the peak altitude range of the volcanic aerosol cloud over my site during November 2022. The Meinel method is influenced by distant clouds, mountains, and the altitude of your observing site, which should be added to the altitudes in the chart. If you'd like to make your own chart, you can get the complete Excel spreadsheet used for Figure E from makezine.com/go/volcanic-altitudes.

The altitudes in Figures E and F are given in kilometers (km). You can multiply kilometers by 3,281 to convert them into feet, but kilometers are much easier to use in atmospheric studies than feet and miles. That's why altitudes of volcanic clouds and layers of the atmosphere are usually given in kilometers.

The *troposphere* is the layer beginning at the surface and extending to 10–15km. The *stratosphere* extends from the top of the troposphere to 50km. Above 50km begins the *mesosphere* — the region that was penetrated by the unprecedented Hunga Tonga eruption plume.



E



F

USE A TWILIGHT PHOTOMETER TO MEASURE THE HUNGA TONGA CLOUD

The twilight method provides the altitude of the top of a volcanic cloud. The profile of the cloud can be determined by lidar, satellite instruments, and the LED twilight photometer I described in these pages in 2013 (“Build a Twilight Photometer to Detect Stratospheric Particles,” makezine.com/projects/twilight-photometer).

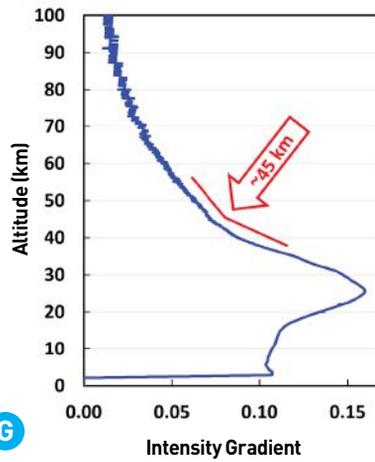
An LED twilight photometer is an ultra-sensitive light meter that detects the intensity of scattered sunlight directly overhead (the zenith) for around 90 minutes after sunset or before sunrise. My design employs LEDs as photodiodes that detect a narrow band of wavelengths, a principle I discovered in 1971 (“Light Emitting

Diodes,” Howard W. Sams & Co.).

In 1990, I began using two LEDs in a sun photometer that provided key data for my paper on 30 years of measurements (doi.org/10.1175/BAMS-D-21-0010.1) of atmospheric haze and the water vapor. That research established the long-term stability of LEDs used as photodiodes and led to the ultra-sensitive LED twilight photometer I described in *Make*: Volume 44 in 2015.

Hunga Tonga aerosols began arriving over my Texas site in May 2022, and I soon began measuring aerosols higher than 30km (98,425 feet). A NASA scientist read about my findings in emails I sent to scientists studying the eruption. This led to an assignment from NASA through Science Systems and Applications, Inc. (SSAI) to build five LED twilight photometers. My friend Scott Hagerup improved the circuitry and built the five new instruments while I continued measuring the Hunga Tonga plume. These instruments and their findings will be described in a scientific paper that Scott and I are writing with our NASA sponsor.

Figure G shows an LED twilight photometer sky profile on November 6, 2022, from the surface to 50km (164,042ft). The profile shows that the densest region of the Hunga Tonga plume was at 25.8km. Figure H is a sequence of some of the twilight photos that evening. The sunset to glowset time (63 minutes) and the graph in Figure F show that the top of the plume still reached 46km (150,918ft) — over 28½ miles high — 10 months after the eruption. 🗓️



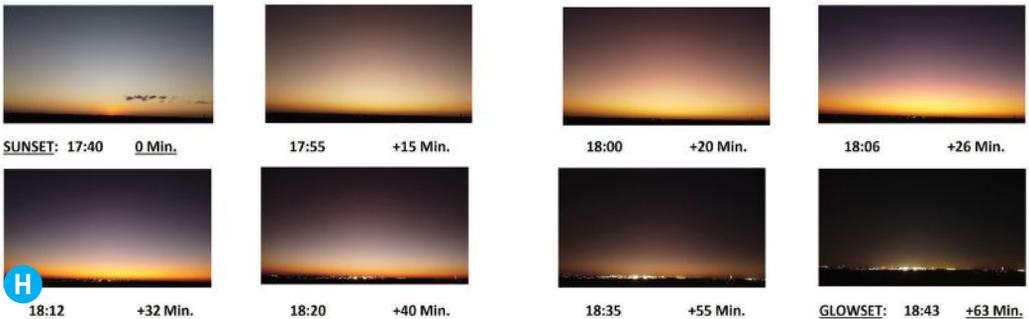
G

LIDAR VS. PHOTOMETER

The Meinel method and the Krakatoa studies of 1888 provide credibility for the measurement of the height of the top of aerosol clouds. But how can we know the altitude of the densest bulge in Figure G is correct?

Lidars measure the altitude of aerosol layers by means of a powerful laser. In 2016, I compared one of my twilight photometers with the lidar at Hawaii’s Mauna Loa Observatory, which I was trained to operate by its developer, Dr. John Barnes. After data from six twilight sessions, the stratospheric aerosol layer in the data measured by the lidar and the photometer were compared. The average altitude differed by only 0.9km (2,953ft). This provides credibility for the altitude range in Figure G.

Hunga Tonga-Hunga Ha’apai twilight, 6 Nov. 2022, Geronimo Creek Atmospheric Monitoring Station, Texas (29.6 N, 97.9 W)



H



FORREST M. MIMS III is an amateur scientist and Rolex Award winner, and was named by *Discover* magazine as one of the “50 Best Brains in Science.” He has measured sunlight and the atmosphere since 1988. forrestmims.org



TERRA GILBERT

is a former accountant, current software developer, and forever student of all things. She loves to learn, tinker, and spark inspiration in future engineers by making fun projects with lights, movement, IoT, and 3D printing.

LED Pipe Dreams

Build a DIY digital clock with glowing, flowing light pipes

Written and photographed by Terra Gilbert

Years of 3D print and circuit hackery have led me to build some pretty crazy contraptions. I tend to favor the kinds of projects that combine art and function and require me to learn something new in order to complete. This project was inspired by the very cool fiber optic projects posted online by Martin Oehler ([@maketvee](#)), John-Paul Wenger ([@ItsMrJP](#)), and others. I am grateful to find the cool part of Twitter that celebrates people chasing their crazy ideas and sharing what they make.

DESIGN PROCESS

The design for this clock took a while. It evolved from several experimental versions, each one teaching me something new about the limitations and possibilities of combining the light pipes with

a variety of different kinds of lights and materials. My goal from the start was to somehow turn these beautiful pipes into a digital clock, while still showing the pipes and how they change colors, to highlight the beauty of the light traveling to the digits.

Figure **A** shows the original idea I sketched out on the back of an envelope, and Figure **B** is the first digital rendering done with 123D Design. As you can see, my first ideas relied heavily on suspending the pipes in place. The intent was to run them through a block of 3D-printed clear PETG that would be a bit blurry, but you could still see the pipes. This idea failed mostly because the block was too big to print on my machine.

So, I made a more compact version next (Figure **C**). This one was smaller and more

TIME REQUIRED: 2–4 Hours

DIFFICULTY: Intermediate

COST: \$50–\$60

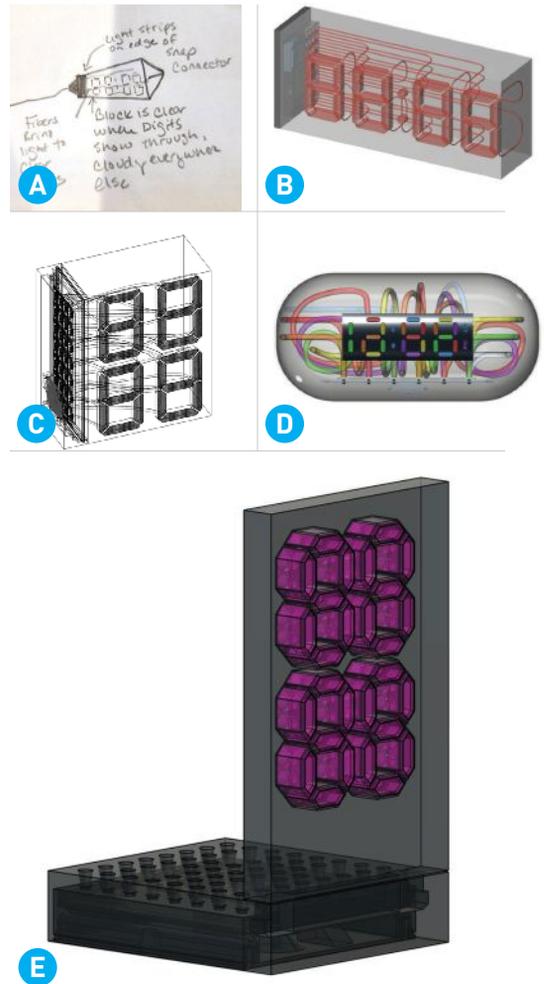
MATERIALS

I have included Amazon numbers for convenience, but the parts can be found elsewhere, probably cheaper.

- » **3D printer filament, white and black** I used basic PLA; results with other materials may vary.
- » **LED fiber optic cable, side-emitting, flexible PMMA plastic, 3mm/0.12" diameter, 10' long (2)** aka light pipe, Amazon B07R47L56L
- » **LED matrix, WS2812B, 8×8** Amazon B081BCBQ6B
- » **ESP8266 microcontroller board, D1 Mini type** Amazon B073CQVFLK
- » **USB data cable, Standard-A to Micro-B**
- » **MPU6050 accelerometer/gyroscope (IMU) module** Amazon B07W3S7X7W
- » **Machine screw, M2×6mm**
- » **Hookup wire** I recommend red, black, and 3 other colors.

TOOLS

- » **3D printer**
- » **Soldering iron and solder**
- » **Wire strippers**
- » **Snips (optional)** for post processing 3D printed parts
- » **Hot glue gun (optional)** for keeping parts still and shielding exposed connections
- » **Screwdriver**
- » **Computer with software:**
 - **Arduino IDE** free from arduino.cc/downloads
 - **Slicer for 3D printing** such as Cura, free from ultimaker.com/software



printable, but as I quickly found out, the pipes weren't very visible, and there wasn't enough contrast in order to be able to see the digits clearly.

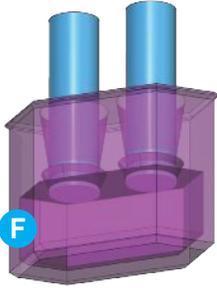
So, my next design focused more on contrast, and the possibility of encasing the pipes in acrylic for better visibility (Figure D). I know. It looks like a potato. Moving on!

This is the point where I gave up on the idea for a while. I didn't want to just make something that didn't serve my original idea: a functional clock that highlighted the beauty of the light pipes. But I couldn't let it go. After a week or so my brain was back on the case, working to solve the problem. How could I suspend the digits, see the lights, and keep it as simple as possible? At this point I was tired of experimenting with acrylic. Too messy!

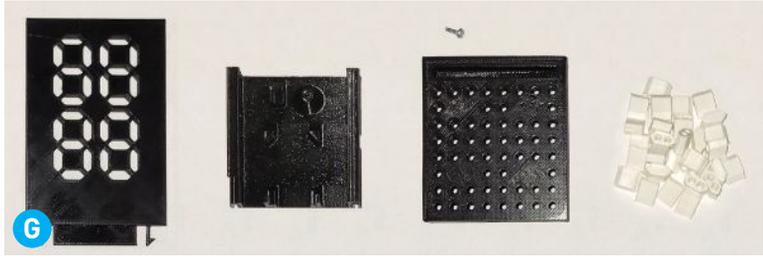
And so, the last version — the simplest of them all — was my favorite (Figure E). I guess I had to go the long route, but at least I can say I learned a lot on the way.

The cool part about this version is the holes for mounting the pipes. They're cone shaped, and the narrowest part is slightly undersized for the PMMA to push through. This helps to grab the pipe and hold it so it's less likely to fall back out. I found that super glue, hot glue, and even UV-cured acrylic resin failed to hold these pipes in place, so this friction-fit design saved the day. Figure F on the following page shows a close-up of the lens design.

The slight air gap between the end of the pipe and the face of the digit creates a smooth, diffused glow when lit.



F



G

AND NOW, HOW TO MAKE IT!

1. 3D PRINT THE PARTS

Download the STL files from the repository at github.com/terra819/LightPipesClock, then print the following parts as is, no supports necessary (Figure G). They already have correct orientation.

base.stl — print 1 in black

face.stl — print 1 in black

underside_lid.stl — print 1 in black, recommend using a brim

lens.stl — print 28 in white

2. FLASH THE MICROCONTROLLER

Download the clock code file, *ClockSketch_v7-75Cv3-TFO-3.ino*, from the repo. Using Arduino IDE, open the file and update the Wi-Fi SSID and password. Connect the ESP8266 board with the USB cable, then upload the code to the board.

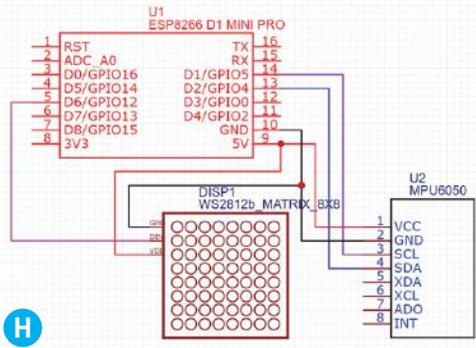
This code is a slightly modified version of ClockSketch V7 by Daniel Cिकic, aka Paralyze (instructables.com/ClockSketch-V7-Part-I). It is highly configurable, so play around with it if you like, but the version I have posted on GitHub is modified to work with this clock specifically.

3. ASSEMBLE THE CIRCUIT AND BASE

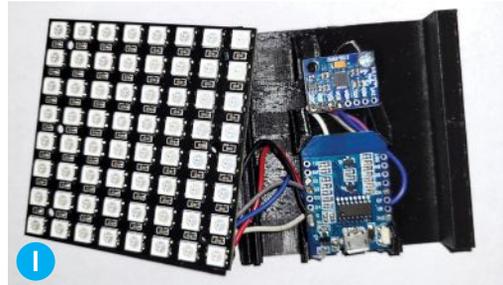
Solder the circuit, following the schematic (Figure H) and connecting wires to the underside of the MPU6050 and ESP8266 boards. The enclosure has a gap for the wires to pass through. If they're wired on top, the LED matrix won't have space.

Secure the MPU6050 in the underside lid piece using the M2×6mm screw, and slide the ESP8266 into the slots (Figure I). You can use glue to hold down the ESP8266 a bit more firmly, but once the clock is assembled, this part will not move.

Make sure the LED matrix wires pass through the gap without lifting the matrix (Figure J), so that it sits flat on the rails of the underside lid.



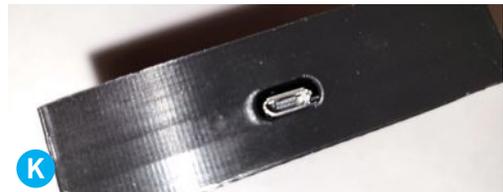
H



I



J



K

Now test the circuit by plugging it in. Also test the gyro by turning the piece upside down to change the color palette.

Once the circuit is tested, slide the underside lid up into the clock base. Line up the oval

opening with the micro-USB port of the ESP8266 (Figure K), then push slightly up into the base. It shouldn't need to be forced; if it's hard to push, check the parts arrangement and make sure nothing is in the way. You should hear a few clicks when it goes in correctly.

If you need to pull the parts back out of the base, pinch slightly on the sides of the underside lid and pull down and back out.



L

4. PLUG IN THE PIPES

Slide the clock face piece into the base. The tab sticking out of the bottom should be inserted toward the light grid. When inserted correctly the face sits flush with the base, forming an L shape (Figure L).

Next, start cutting up the PMMA light pipes. I recommend cutting as you go. The lengths are not exact. I found that slightly longer than needed works best; if too short they won't have tension on them and they'll fall out. The spreadsheet image (Figure M) lists approximate lengths for each row and how they should be plugged in. I have highlighted a couple to get you started. For reference, the green 0 at the back corner of the grid lines up with the green zero at the top left of the first digit. The yellow 7 at the front of the grid, closest to the face, aligns with the bottom right of the last digit. And so on.

When you insert a light pipe into the back of a lens piece, don't force it all the way. It should catch about halfway, and be slightly difficult to tug back out. Then snap the lens into the face.

Start at the bottom, with the row closest to the face, and work your way up/out. (Figures N - Q).

5. TEST AND ENJOY!

The 7-segment numerals on the face should now be glowing with the correct time!

GLOWING RECOMMENDATIONS

I may revisit this project to make improvements:

- There are 8 unused LEDs on the grid that are blacked out for now, but one day could be repurposed for other things such as showing AM/PM designations.
- It seems that a matte type of PLA holds the light pipes better than glossy PLA. I will be testing this theory more as I make these. ☑

#	Length (mm)	Sum (mm)	Sum (ft)
0	149	5308.4	17
1	133.8		
2	117		
3	106.5		
4	78.6		
5	73.8		
6	55.5		
7	46.3		
8	152.5		
9	126.7		
11	99.7		
12	86		
13	66.7		
15	44.6		
16	148		
17	124.1		
19	95.5		
20	82.5		
21	65.4		
23	41.5		
24	149		
25	133.8		
26	117		
27	106.5		
28	78.6		
29	73.8		

Instructions: For each coordinate, cut PMMA to the length listed. Can be a little longer, but shouldn't be shorter.

M





Make a *Hygge* Book Lamp

A few easy cross-stitches and you'll be reading by cozy candlelight Written and photographed by Anuradha Reddy

TIME REQUIRED: 1–2 Hours

DIFFICULTY: Easy/Intermediate

COST: \$5–\$20

MATERIALS

- » **LED candle tea-light** The kind that uses a coin-cell battery, with an on-off switch in the back.
- » **Perforated paper for cross-stitch embroidery, in white** aka punched paper. It's a lightweight card stock.
- » **White embroidery thread and tapestry needle**

TOOLS

- » **3D printer and white PLA filament** to print the book clip. Or, a service like Xometry will print it for \$10–\$15 shipped, depending how many you order.
- » **Hobby knife, cutting board, hot glue gun, ruler, drawing compass, and pencil**

As the winter cold sets in, it's time to get cozy under a warm blanket with a good book in dim candlelight. In Scandinavia, the term used to describe this cozy feeling is *hygge*. Here's how to make a hygge book lamp for just a few dollars.

1. CUT THE LAMPSHADE

Start by cutting the embroidery paper to size. First, measure the diameter of your LED candle tea light. The one I found in my local store is 4cm in diameter. Then use a compass to draw a circle twice the diameter of the LED candle. In my case, I drew a circle with a 4cm radius (8cm diameter). Add 4cm to the radius and draw a second circle with the same center point. Mine was 4cm + 4cm = 8cm radius (16cm diameter), Figure (A).

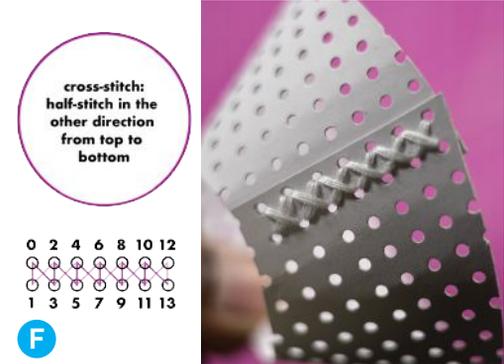
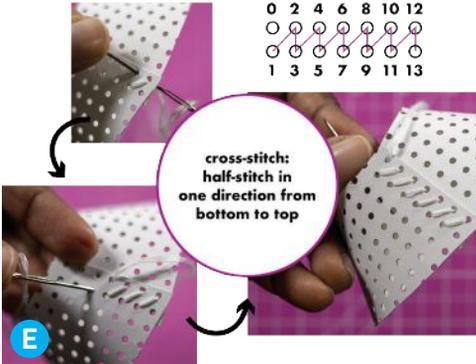
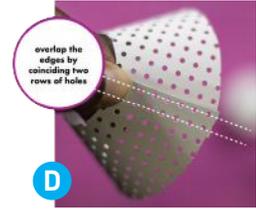
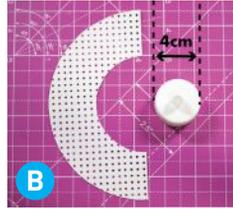
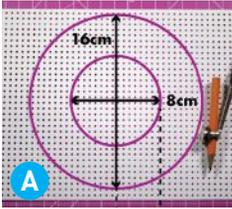
Cut the paper along the two concentric circles to leave a circular disk shape with a hole in the center. Finally, draw a straight line along its diameter and cut the shape in half (Figure B).

2. CROSS-STITCH IT

Prepare for cross-stitch by threading the needle.



ANURADHA REDDY, PH.D. is a design researcher in Malmö, Sweden, who practices "critical making" via craftivisms, hardware hacks, and re-appropriation of data technologies.



Wrap the cut paper shape around the LED candle to form the lampshade (Figure C). Pull tight until the paper's side-edges overlap neatly over one another such that two rows of holes coincide (Figure D).

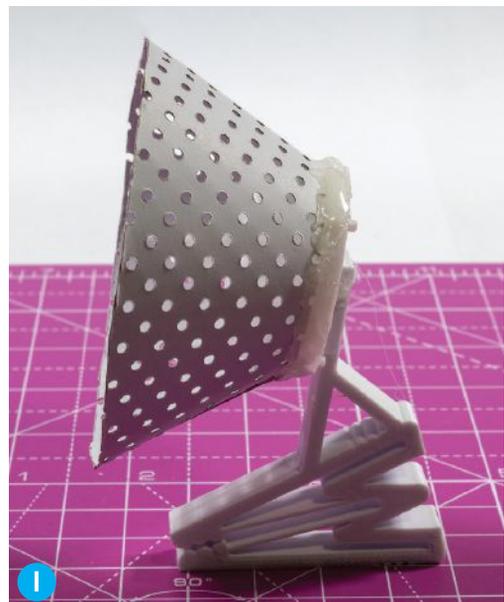
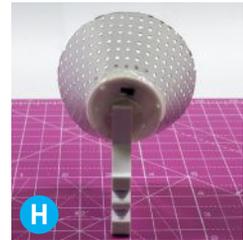
Slowly let go of the LED candle while holding the lampshade in place and start cross-stitching into the holes. I prefer to use the knot-less loop method (see an example at youtu.be/i0Nhw4mQJ5M) for beginning the cross-stitch. Then follow the usual half-stitch in one direction and back down the other direction to complete the cross-stitch (Figures E and F). Hide the leftover thread between the stitches and cut.

3. ADD THE BOOK CLIP

Now for the 3D-printed clip (Figure G). Download the STL file at github.com/anu1905/Hygge/blob/main/hygge_clip.stl. After printing, hot-glue the clip to the backside of the LED candle. Be careful to align it such that you are able to replace the coin-cell battery (Figure H).

Hot-glue the lampshade on. Make sure to glue it all around the circumference of the LED candle so that it doesn't accidentally fall out (Figure I).

Your hygge book lamp is ready. Clip it over some pages and enjoy cozy reading! 📖





Written and photographed by Bob Knetzger

Mini Infinity Cube

Reach for the stars with this simple kaleidoscope

TIME REQUIRED: 1 Hour

DIFFICULTY: Easy

COST: \$2

MATERIALS

» Mirrored acrylic sheet, 1/8" thick

TOOLS

» Drill with 3/16" bit and smaller bits

» Acrylic solvent

» Electrical tape, black vinyl

» Laser cutter (optional)

It's a star-filled universe — in your pocket! Hold the Mini Infinity Cube up to your eye and gaze into an endless galaxy of colored stars. This project is easy and fun!

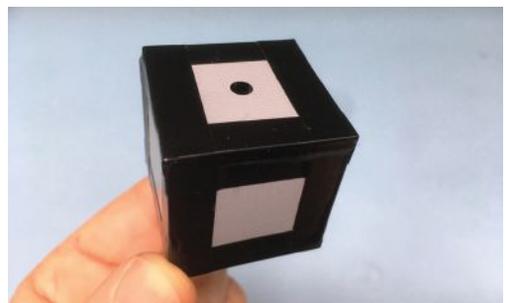
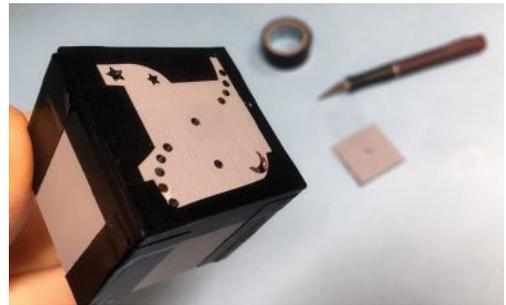
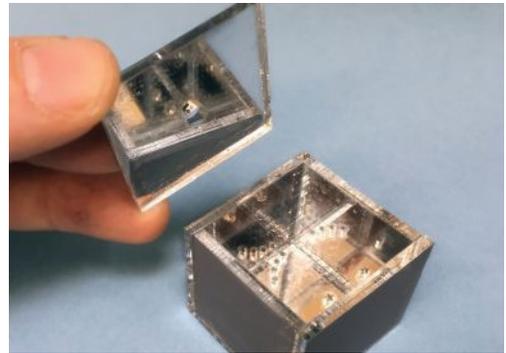
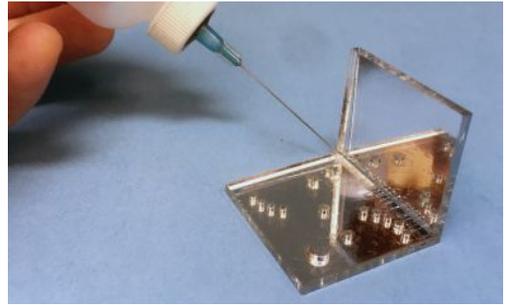
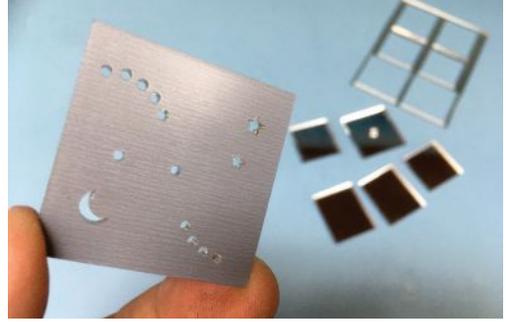
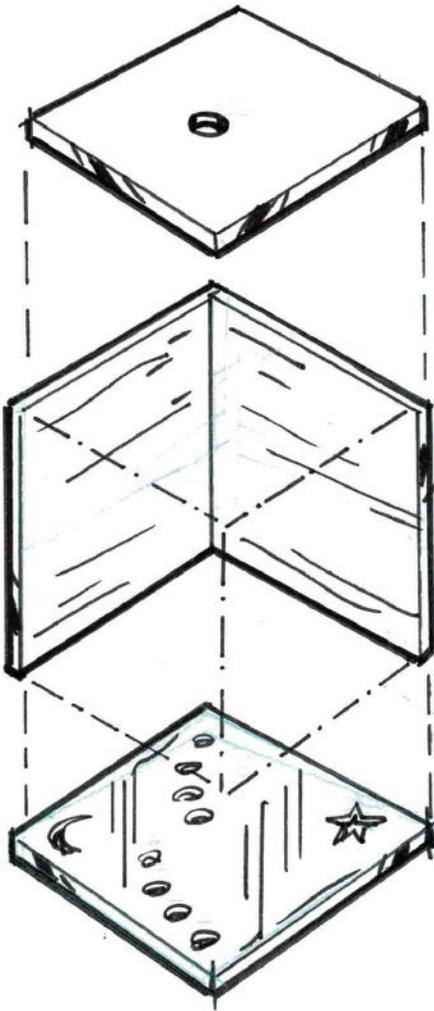
CUT AND DRILL THE ACRYLIC

Make a 1 1/2" cube out of six pieces of mirrored 1/8" acrylic. Drill a 3/16" peephole in the top piece. On the bottom piece drill a series of smaller holes; these will be the "stars." The four side pieces of the cube are left undrilled to serve as infinity box reflectors. None of the dimensions are critical but the sides *must* be parallel for best effect.

If you have access to a laser cutter, go online at makezine.com/go/mini-infinity-cube to download an .svg cutting file. It has little moon- and pointed star-shaped holes for an extra fun look!



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.



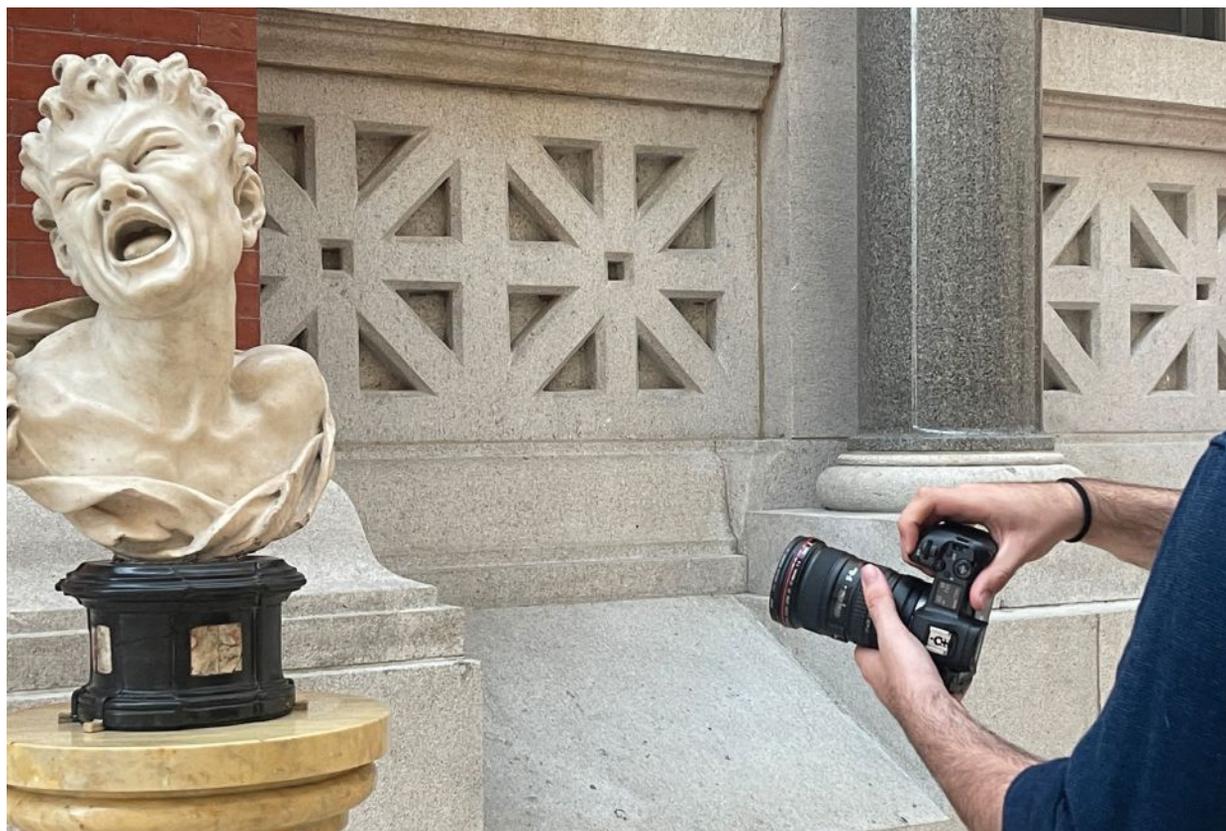
ASSEMBLE THE CUBE

Bond the sides together using acrylic solvent to make a cube. Be sure to assemble the cube with the mirrored sides facing inward.

Then use some strips of black vinyl electrician's tape to cover all the exposed edges. This will keep light from leaking in along the edges of the acrylic. You want a nice, dark cube "universe" for gleaming stars! Make sure not to cover up any of the star holes on the back.

LOOK TO THE STARS

Hold the cube right up to your eye and look in the peephole. Swivel the cube and look around inside to see the infinity effect. Point the cube around to change the colors of the stars like a kaleidoscope. Wow, man! 🌟



3D SCANNING **ARTWORKS**

Tips on capturing the classics volumetrically

Written and photographed by Austin Beaulier



AUSTIN BEAULIER is a Los Angeles-based VFX artist and a pioneer in photogrammetry and volumetric capture. He has been working in the *Star Wars* universe on such shows as *Obi-Wan Kenobi*, *The Mandalorian*, *The Book of Boba Fett*, and *Ahsoka*. His 3D scanning work is also featured in the films *The Gray Man*, *Nope*, and *Black Adam*, and TV series including *Star Trek: Discovery* and *The Orville*.

Scanning in museums is the perfect challenge for the photogrammetry hobbyist. Not all museums have in-house scanning programs, but it's important to archive and share these objects with people all over the world. You can help make it happen.

Photogrammetry is the process of converting hundreds of photos into a 3D model. The principles of 3D scanning and photogrammetry

are similar to photography; if you can take great photos, you can make great scans. I shy away from using iPhone lidar as it doesn't always work at smaller scales, and you get way more flexibility from using photogrammetry.

How many photos do I take?

The answer is not as simple as it seems. Photogrammetry works by comparing two photographs and finding common points, and then using those to triangulate points in 3D space. The more photos you have, the more detailed your 3D mesh will be. To ensure good photo alignment, aim for at least 60% overlap between two images — you can use your camera's built-in "rule of thirds" guide to include two-thirds of your last image in your next — and make sure you go in linear order instead of skipping around to different parts of the subject. But be aware that overshooting a subject can make the texture appear blurry, or cause parts of the texture to overlap. A balance must be struck between the mesh detail and the texture.

So how many photos do you need to take? Well, that depends on the subject's size and your camera's resolution. The higher the resolution, the fewer photos you need. When I use my iPhone for scanning and I want to get all sides of an object, I will try to get over 200 photos.

Can I use a video?

Nope. Video often has motion blur, and blurry photos are photogrammetry's worst enemy. You should avoid burst mode for the same reason. Slow down, it's not a race. Your scans will be better if you take your time capturing the photographs.

Always check the photography rules.

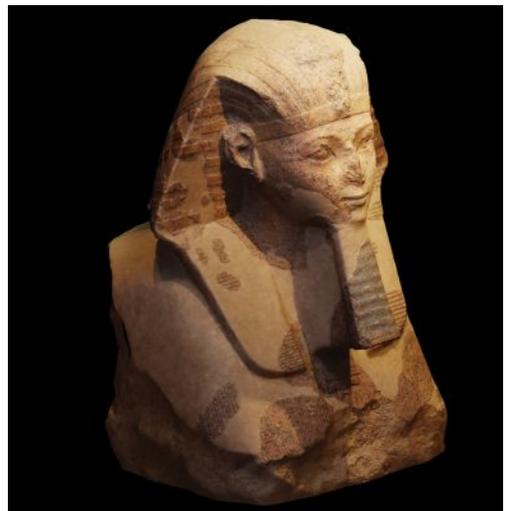
Scanning can be quite obtrusive. Some exhibits will not allow photography at all, while others will, as long as you take off the flash. A phone will draw way less attention than a camera. Email or call the museum if you're unclear on their policy, or check the FAQ on their website.

Go handheld, and leave your tripod and selfie sticks at home.

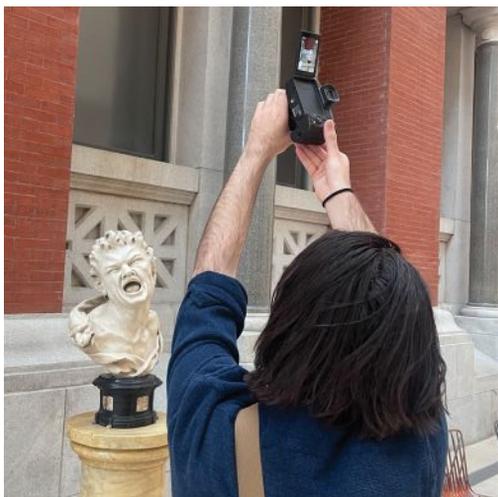
Most museums don't allow tripods or selfie



BLENDER RENDERS: Corinthian pillar pedestal from the Metropolitan Museum of Art in New York, paired with a Greek bust from the Getty Villa in California, scanned with Reality Capture and rendered in Blender.



Head and Shoulders of a Sphinx of Hatshepsut, scanned at the Met with Reality Capture and rendered in Blender.



Scanning Balthasar Permoser's bust of Marsyas at the Met with a Canon EOS R.



Écorché bust by Jean-Panrace Chastel created with Polycam, scanned at the Getty Center in Los Angeles.

sticks. To combat this, keep the shutter speed high and crank up the ISO for dark exhibits. Remember that the most important thing for photogrammetry is to take the sharpest photos possible. Most museums are dark and absolutely do not allow flash photography, so prioritize cameras that work well in low light.

Be polite!

Stop every few photos and stand back from the subject to allow other people to enjoy the work. Be aware of your surroundings and make sure you're not blocking anyone's view. If it's a busy exhibit just be patient and wait, enjoy the art.

Use a color chart.

If you plan to share your models, a color chart is a must-have. If you can't afford a color chart (e.g., ColorChecker Classic), or you left it at home, a white piece of paper will do in a pinch to ensure the white balance is set properly. Just snap a quick pic of your color reference after your scan. This frame will also double as a great way to separate the photos and subjects when you sort through them later, as photo thumbnails can often blend together in the folder.

Cite your sources.

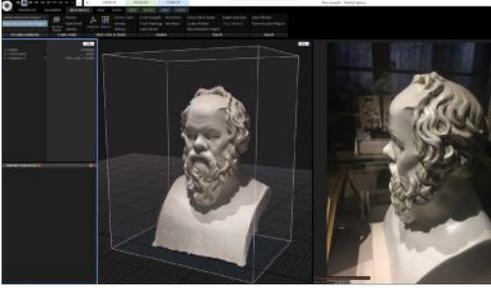
Before or after you scan, take a photo of the art's plaque. A great tip for iPhone users is to use the Copy Text tool from the image to create the descriptions. This trick will save a ton of time.

Color correct your photos.

Bulk color correction can be tricky, but Lightroom Classic does an OK job. Color pick the white area of your color checker and add a bit of denoise to combat the high ISO required for photos in dark areas of the museum.

Convert photos to 3D scans.

For photogrammetry software you have several options, each with various learning curves. For beginners I recommend Polycam's web version and also its mobile app, which now allows you to export the raw images. Polycam limits you to 250 photos, but most exhibits won't require that many for a successful scan. You'll get a feel for the required number of photos after some practice.



Bust of Socrates, scanned with Reality Capture at the Houston Museum of Natural Science.

For years I have used Reality Capture for all of my photogrammetry because it gives you a lot of control and is an extremely powerful tool for creating beautiful 3D models. That being said, it can be expensive, requires a beefy computer with an Nvidia graphics card, and the GUI and workflow make the learning curve steep, especially if you don't have a background in 3D.

Clean up your scans.

Photogrammetry often creates artifacts that will need to be deleted. I recommend using Blender for your clean-up, as it is free and extremely powerful and there are thousands of tutorials on how to use it. You could also upload the raw, uncleaned model, just make sure in the listing you specify that it has not been cleaned.

Posting your scans.

Sketchfab is the best 3D art platform because of their in-browser viewer and thriving community; for an example, check out my page at sketchfab.com/Austin.Beaulier. When posting to Sketchfab, your scans will probably have shadows baked into the textures, as museums utilize dramatic lighting to help show off the art. Uploading directly from Polycam to Sketchfab will automatically set the model to "shadeless."

Archive your work.

The world of photogrammetry is always updating and changing. Archive your hard work, and never delete your photo sets. You never know when a new program or technique will change what we can do with photos. The future is bright for 3D capture! 🍷

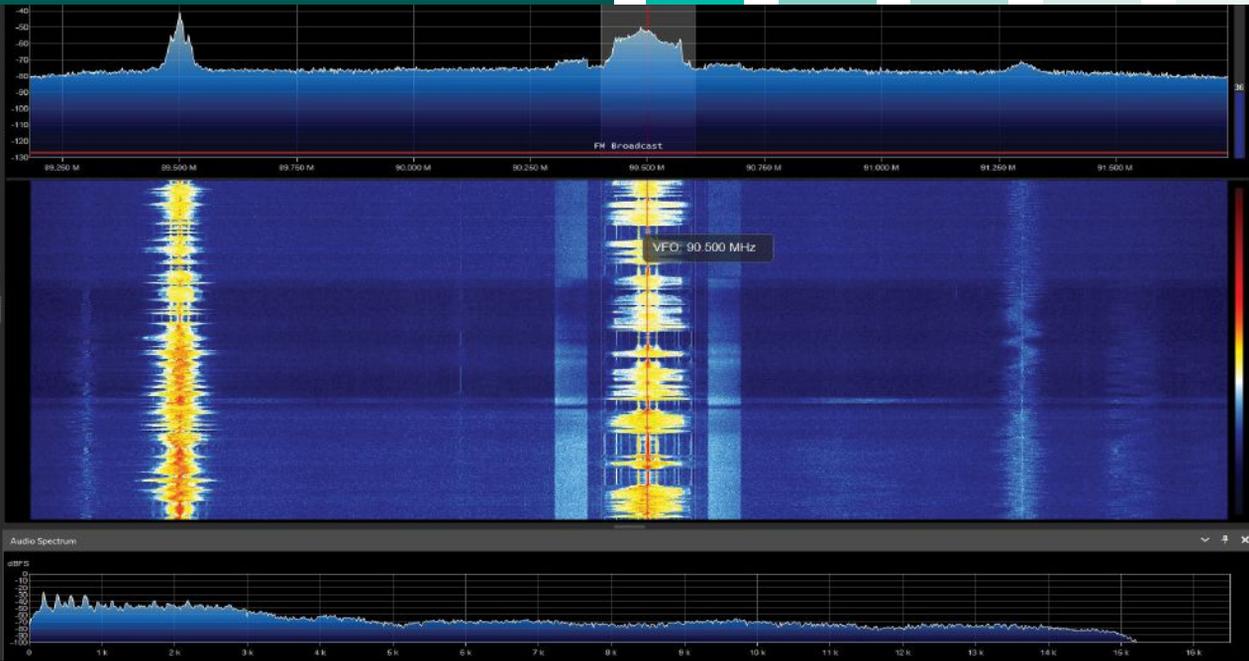
SCAN THE WORLD

The world's great works of art and architecture are difficult to experience firsthand, stashed away in far-flung museums and temples. But one by one, they're being 3D scanned by a global network of volunteers and shared, open source, in the **Scan the World** project, a non-profit initiative of MyMiniFactory. So far they've captured an impressive digital archive of 25,000 "fully 3D printable sculptures, artworks, and landmarks for the public to access for free." Enjoy the collection at myminifactory.com/scantheworld, 3D print your favorites, and email @myminifactory.com if you'd like to contribute. —KH



Michelangelo's *David*, scanned in Florence, Italy, with both photogrammetry and structured light, and released open source, as part of the Scan the World project.





TIM DEAGAN makes, breaks, and collects things in Austin, Texas. He loves the experience of using software to breathe life into hardware, with Linux and any microcontroller he can get his hands on.

GETTING STARTED WITH **SOFTWARE DEFINED RADIO (SDR)**

Eavesdrop on virtually the entire radio spectrum — for 30 bucks!

Written and photographed by Tim Deagan, KJ8U

Not long ago, enthusiasts with an urge to listen to radio broadcasts had to make hard choices about what equipment to buy based on their interests. “Multi-band” radios provided circuitry for a selected set of frequencies, usually requiring crystals specific to each band. A basic one might receive AM, FM, shortwave, and NOAA weather radio; for more than that, you’d be looking at serious cash.

But today, a little USB dongle costing around \$30 can receive AM, FM, shortwave (SW),

amateur/ham HF, VHF, UHF, SHF, maritime, aviation, EMS, satellite, NOAA, HD radio, trunked radio, P25, GPS, APRS, radar, HAARP, CW, TV, GSM, pagers, baby monitors, DMR, D-STAR, PSK, RTTY, SSTV, and pretty much anything else broadcasting from 500kHz up to 1.75GHz. More expensive models can extend that range and even transmit!

Keep reading to learn more about this game-changing technology.

From Analog to Digital: A Capsule History of SDR

Sending and receiving radio waves has traditionally been the province of analog electronics. Tuning, detecting, oscillating, mixing, filtering, (de)modulating, and amplifying — the basic functions of a radio — involved crystals, capacitors, inductors, tubes, transistors, and other electronic components. These components can be assembled into gloriously complicated circuits to make use of the radio frequency (RF) spectrum. But analog radios have constraints, most importantly limitations around how much of the spectrum they can operate in. All but the most elaborate analog radios have a very restricted frequency range or include multiple sets of components to allow operation in different bands.

Starting in the 1970s, various U.S. government research groups began experimenting with using software signal-processing techniques to replace hardware components. *Digital signal processing (DSP)* math and code advanced rapidly in Defense Department labs and universities. The tremendous power and flexibility of software became extremely appealing as it provided a way to avoid many of the limitations of hardware. Research and development in the 1990s of *software radio*, a term later eclipsed by *software defined radio (SDR)*, rapidly spread out of government into commercial efforts, showing up in high-end car radios by 1997.

With the introduction of the European digital TV standard known as Digital Video Broadcasting -



A popular USB SDR dongle, \$30.

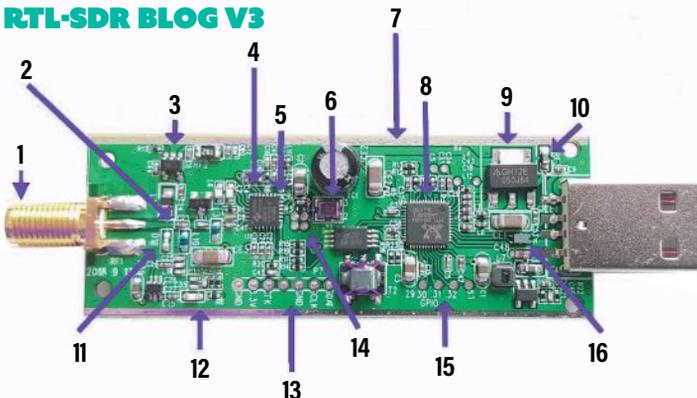
Terrestrial (DVB-T) in 1997, manufacturers such as Realtek and others began producing low-cost integrated circuits like the **RTL2382U**, capable of decoding DVB-T signals in the 174MHz–786MHz range and packaged in small USB dongles. By 2010–2012, Eric Fry and Antti Palosaari had determined that the RTL2382 was usable as a general SDR, and Steve Markgraf and colleagues at the Osmocom project had released **rtl-sdr software** (osmocom.org/projects/rtl-sdr) that allowed Linux, Windows, and Mac users to receive and decode radio signals from an astonishing range of 500kHz–2.2GHz, depending on which chip variant is used.

How Do SDRs Work?

The heart of an SDR is the *analog-to-digital converter (ADC)* found in a *demodulator chip* like the RTL2382U, where the analog electrical signal that the radio antenna receives is converted to 1s and 0s, similar to the way a signal from a microphone is digitized. A *digital tuner chip*, like the R820T, simply captures a selected frequency range from the antenna and sends it along to the demodulator. Once the signal can be numerically represented, the power of math can be applied via DSP software to filter, decode, and process the data into targets of interest.

Tim Deagan, RTL-SDR.com

RTL-SDR BLOG V3



What's inside the latest RTL-SDR Blog V3 dongle.

1. SMA FEMALE CONNECTOR
2. IMPROVED FRONT END DESIGN resulting in higher L-band SNR
3. 4.5 BIAS TEE software controlled
4. REDESIGNED THERMAL LAYOUT helps fix VCO lock problems
5. RAFAEL R820T2 DIGITAL TUNER CHIP
6. 1 PPM TCXO temperature-controlled oscillator
7. ENTIRE PCB REDESIGNED for lower noise
8. REALTEK RTL2832U DEMODULATOR CHIP
9. BETTER LDO less noise, lower voltage operation
10. 5V LINE FERRITE CHOKE
11. ADDITIONAL ESD PROTECTION
12. DIRECT SAMPLING CIRCUIT enables HF reception (with LPF)
13. EXPANSION PORTS
14. CLK SELECTOR JUMPER
15. GPIO EXPANSION PORTS
16. USB RF CHOKE removes USB noise

We Want the Airwaves!

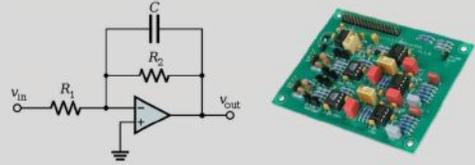
Check out this amazing list of things to do with your SDR, with links at RTL-SDR.com. Not all may be legal in your country. Please be responsible.

- Use as a police radio scanner.
- Listen to EMS/ambulance/fire communications.
- Listen to aircraft traffic control conversations.
- Track aircraft positions with ADS-B decoding.
- Decode aircraft ACARS short messages.
- Scan trunking radio conversations.
- Decode unencrypted digital voice transmissions such as P25/DMR/D-STAR.
- Track maritime boat positions with AIS decoding.
- Decode POCSAG/FLEX pager traffic.
- Scan for cordless phones and baby monitors.
- Track and receive meteorological agency-launched weather balloon data.
- Track your own self-launched high altitude balloon for payload recovery.
- Receive wireless temperature and power meter sensors.
- Listen to VHF amateur radio.
- Decode ham radio APRS packets.
- Watch analog broadcast TV.
- Sniff GSM signals.
- Use rtl-sdr on your Android device as a portable radio scanner.
- Receive GPS signals and decode them.
- Use rtl-sdr as a spectrum analyzer.
- Receive NOAA weather satellite images.
- Listen to satellites.
- Radio astronomy.
- Monitor meteor scatter.
- Listen to FM radio, and decode RDS information.
- Listen to DAB broadcast radio.
- Listen to and decode HD-Radio (NRSC5).
- Use rtl-sdr as a panadapter for your traditional hardware radio.
- Decode taxi mobile data terminal signals.
- Use rtl-sdr as a high-quality entropy source for random number generation.
- Use rtl-sdr as a noise figure indicator.
- Reverse-engineer unknown protocols.
- Triangulate the source of a signal.
- Search for RF noise sources.
- Characterize RF filters and measure antenna SWR.
- Decode Inmarsat STD-C EGC geosynchronous satellites.
- Listen to the ISS (International Space Station).

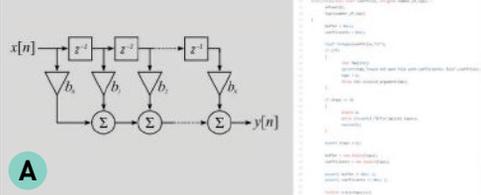
Furthermore, with an upconverter or V3 RTL-SDR dongle to receive HF signals, you can:

- Listen to amateur radio hams on SSB with LSB/USB modulation.
- Decode digital amateur radio ham communications such as CW/PSK/RTTY/SSTV.
- Receive HF weatherfax.
- Receive Digital Radio Mondiale (DRM) shortwave.
- Listen to international shortwave radio.
- Look for radar signals like over the horizon (OTH) radar, and HAARP signals.

ANALOG FILTER



DIGITAL FILTER



Analog vs. digital filters.

In practice, real-world issues force some compromises. For example, since the analog signals may be very faint, amplification is often necessary. Amplifiers bring their own issues in filtration, noise, dynamic range, and other considerations. Bandpass filters are often used to constrain these problems, but limit the range of frequencies received (Figure A). Many SDR designs have multiple analog input channels, each with optimized amplification and filtration to provide consistent results over the broadest range.

DSP software has been the engine at the heart of the most amazing advances in technology since Bell Labs put the first T-1 network into service in 1962. By shedding the constraints of physical properties that limit analog circuit construction, it is possible to manipulate audio, video, seismological, medical — any signal with changes that can be measured over time — with a degree of precision and flexibility analog designers can only dream of.

Getting Started in SDR

The minimal equipment needed to start experimenting with SDR consists of an antenna, an SDR peripheral, and a computer. The **RTL-SDR USB dongle**, generally available for around \$30, is the most popular starting rig for new SDR users. There are plenty of more advanced SDRs available at a wide range of price points. Some provide a broader frequency range, offer

transmitting capabilities, or offer more advanced circuitry. But the humble RTL-SDR is an awesome place to start.

While many SDRs are able to decode signals in the lowest end of the spectrum (varying according to the SDR, usually below 300MHz) via **direct sampling** or **direct conversion**, this is often at reduced clarity. As an alternative, many SDR owners will purchase an inexpensive **upconverter** — a device that converts signals below the SDR's reception range, often down to "DC" (0Hz), up into the SDR's normal range,

More advanced SDR units offer users with more than casual listening needs extra capabilities. In the sub-\$200 range, **Airspy** offers a receiver with advanced DSP filtering (always great for cutting through noise). In the sub-\$400 range, the **HackRF by Great Scott Gadgets** is designed as an RF experimentation and prototyping platform with a 1MHz to 6GHz operating range and the ability to transmit.

Owning more than one SDR is a joy. I personally dedicate two RTL-SDR units to a P25 trunked radio decoder for EMS and police scanning (Figure B), while using a HackRF for experimenting and as a panadapter for my HF radios.

Antenna Considerations

As is true with most radio applications, the biggest difference in experience often has more to do with the antenna than the radio. While all antennas are optimized for specific frequency ranges, receiving antennas are more forgiving than transmitting antennas.

A simple extensible **whip antenna** (think portable radio) (Figure C) directly connected to an RTL-SDR can provide surprisingly broadband performance in the 60MHz–700MHz range. Better antennas such as a **discone** type (Figure D), mounted at some height outside, can provide startling reception across a tremendous range of signals between 25MHz–1300MHz. **Directional antennas** (Figure E) can make a huge difference in filtering out noise and improving reception. Getting the most out of antennas often relies on a combination of height, obstructions, feedlines, and other factors, but that's a subject for unlimited study.



SDRTrunk software, listening to Travis County, Texas, EMS and police traffic.

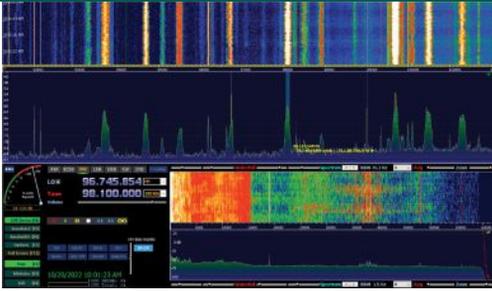


Directional antenna. Build Becky Stern's DIY Yagi antenna at beckystern.com/2021/03/29/tape-measure-yagi-antenna.

CAUTION: Always install a lightning arrestor connected to a good outside ground on any antenna installed outside. This will divert the energy from a lightning strike before it enters your house and turns your computer into a light-emitting circuit board.

SDR Software

As with many modern devices, the hardware is the generalist and the software is the specialist. SDR software takes the broadband signal provided by the SDR device and displays, filters, and decodes it into usable



Screenshot of PC running HSDR software.

signals. Digital radio protocols have become so ubiquitous that, without software, much of the spectrum's interesting activity would be unintelligible. Whether it's mapping ADS-B location signals from airplanes, following frequency-hopping trunk systems, decoding digital FM broadcasts, functioning as a spectrum analyzer, or identifying satellites currently overhead, SDR software gloriously explodes the SDR hardware's utility.

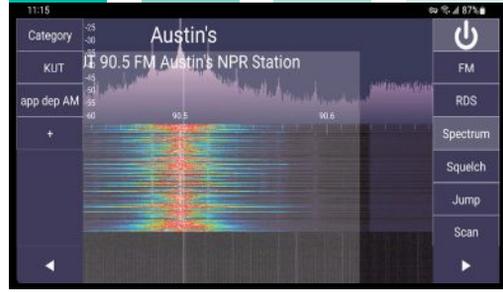
Most new SDR users will scroll the waterfall display around the frequency range to hunt for things to listen to. Online tutorials for pursuing specialty interests like trunked police radio, aviation tracking, or satellite telemetry provide a next-level set of activities.

It's hard these days to find a laptop, desktop, Raspberry Pi, tablet, or phone that isn't capable of running some version of SDR software. Windows has the broadest set of apps, though Linux, Android, MacOS, and iOS have powerful tools as well. **SDRangel** (sdrangel.org) and **CubicSDR** (cubicsdr.com) are two of the few cross-platform (Windows, Mac, Linux) apps.

SDR Fast Start

So you bought an RTL-SDR USB dongle with a simple telescoping antenna. You now have a world of signals available to you, but many are digitally encoded, many are trunked (switching programmatically from frequency to frequency), many require a good outdoor antenna at height, and many are just infrequent and require long periods of waiting before someone does something to listen to. So what can you do to just hear something and know your setup is working?

Like many peripherals, your first step is to get the proper driver for your device and operating system. A great writeup that details getting



Android device running SDR Touch software.

Airspy's **SDR# (SDRSharp)** running on Windows and Linux can be found at rtl-sdr.com/rtl-sdr-quick-start-guide. For Macs, Adafruit has a good writeup for CubicSDR at learn.adafruit.com/getting-started-with-rtl-sdr-and-sdr-sharp.

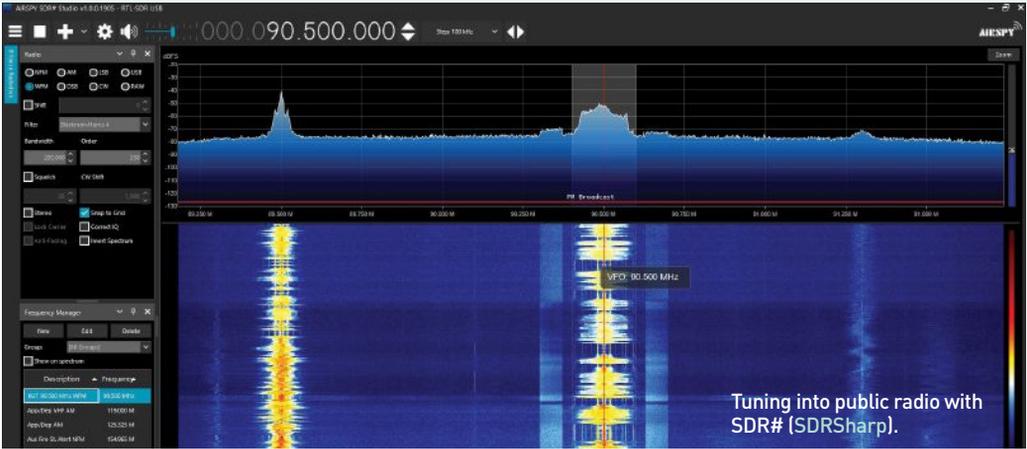
Before you start pulling coax, installing lightning arrestors, and setting up antenna masts, the easiest thing you can listen to with a simple antenna on your desk is the ever-present FM commercial radio spectrum. Ranging from 88MHz–108MHz, using **wideband frequency modulation (WFM)**, these broadcasts are available nearly everywhere and powerful enough to receive with the most basic antenna setup.

Set your SDR's **tuner mode** to WFM, then scroll around your **spectrum display** in the range of 88MHz and up. On your **waterfall frequency display**, you'll see bright bands of FM activity wherever there's a station your antenna can pick up. Now click around on these bands to **demodulate** the signal and hear it as audio!

While there are lots of ways to receive FM broadcasts, listening to it via SDR is a great gateway experience that will start you off on your listening journey. As you add more versatile antennas you'll use these same steps to explore shortwave, amateur (ham), and other new bands on the radio spectrum.

Using Online SDRs

If buying and configuring hardware and software isn't on your list, you can still check out the SDR experience with just an internet-connected phone, tablet, or computer! Thanks to **WebSDR** server software written by Pieter-Tjerk de Boer, PA3FWM, numerous sites around the world have set up web-based access to their SDRs and antennas and offer free access to use them. **WebSDR.org** hosts a listing of sites with



SDR servers running. You can click on a site and tune the SDR to the band you're interested in, see a waterfall display of the band, choose the tuner mode (AM, FM, SW, etc.), filters, and other controls just as if you were operating a radio or SDR directly.

Most of these servers support between 30 and 80 concurrent users and are limited to a specific set of bands. The band limitation is generally an aspect of the connected antennas. The majority of the WebSDR servers trend toward supporting the HF (high frequency, 30MHz–300MHz) Amateur and Shortwave bands, but they are increasingly adding UHF, VHF, and other frequency ranges.

WebSDR servers are even useful to folks with their own radio or SDR setups. Remote online SDRs provide the ability to compare your reception locally to reception from other locations or using alternate antenna setups. Many hams also use WebSDR servers in different parts of the country to listen to their own broadcasts and hear how they're "getting out."

Conclusion

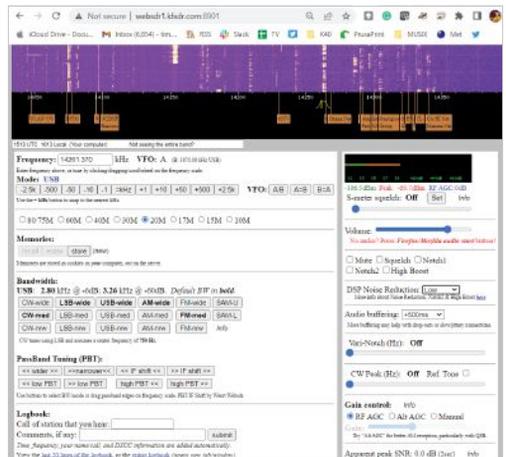
SDRs are rapidly becoming the dominant radio technology of the 21st century. Substituting math for circuitry allows for such tremendous flexibility that we can expect to see SDRs integrating into a wide range of applications and devices. Given the low cost of entry, makers with an interest in the radio spectrum can't go wrong experimenting with this exciting technology. 🎧



Map of online SDRs around the world.

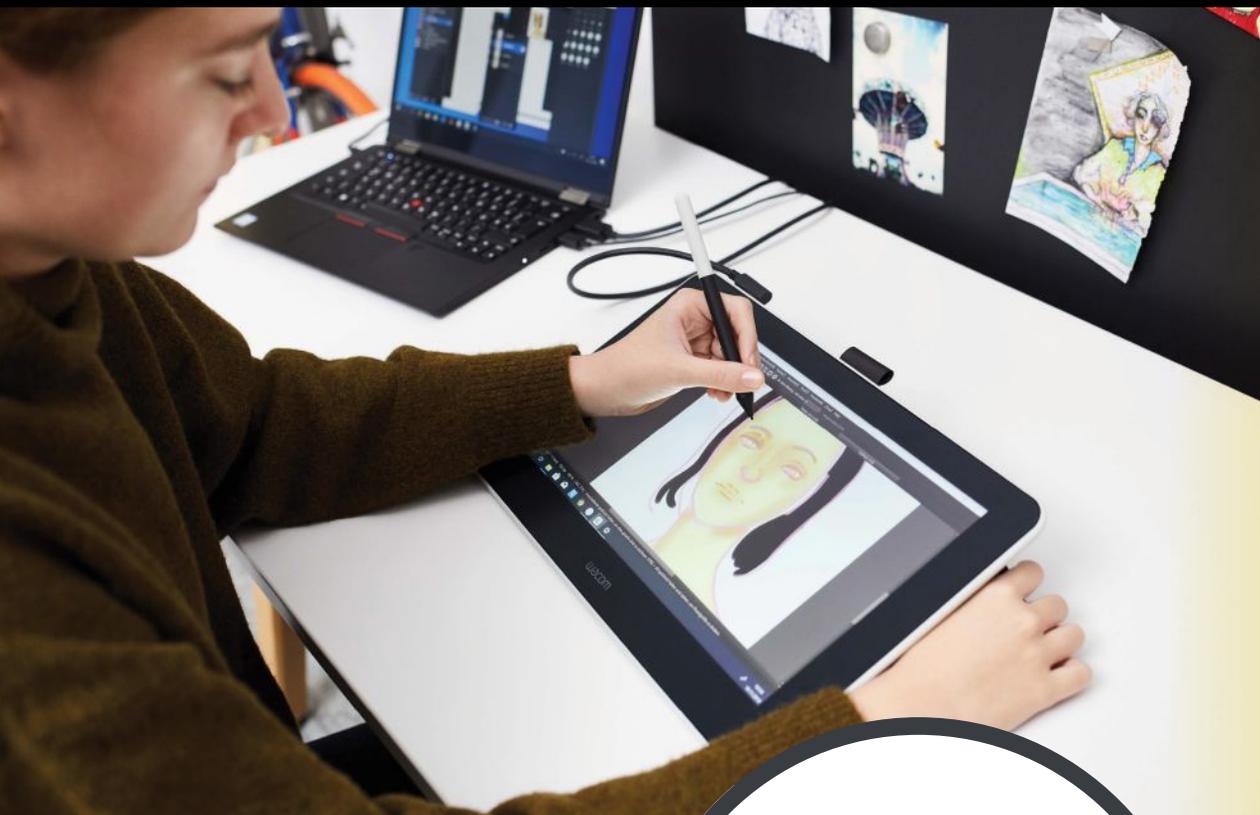


Screenshot of WebSDR server page.



KFS WebSDR server, Half Moon Bay, California.

For more great SDR resources online, visit makezine.com/go/intro-to-SDR



Wacom One \$399 wacom.com

In the world of tablet input devices, Wacom is royalty. The Wacom Cintique series of display tablets that let you write directly onto your screen have been highly sought after for many years, but they typically came with a steep price tag. Wacom has seen the market shift a bit and decided to put out a more budget-minded tablet and display combo. At about \$400 the Wacom One is very competitive compared to other brands.

On the downside, the Wacom One doesn't have a laminated screen, so there's a tiny gap between your pen tip and the cursor. It also doesn't have any hot keys built into it. It has half the pressure resolution of the Cintique. On the plus side, it has polished software, feels great in my hand, works reliably, and honestly without reading it, I would have never noticed it didn't have the same



pressure sensitivity.

A professional might justify the more expensive Cintique line to get a bigger screen and built-in quick keys, but I see this as a great entry point for someone who tinkers in Photoshop, ZBrush, and Blender. —Caleb Kraft



Pokit Pro

\$198 pokitinnovations.com/pokit-pro

The Pokit Pro is one of those devices you almost seem to dream into existence: “Wouldn’t it be cool if…” and then along comes this pocket-sized multimeter/oscilloscope/data logger/spectrum analyzer just like you imagined! The Pokit takes advantage of the powerful phone display you already carry in your pocket, connecting via Bluetooth to custom Android and iOS apps. And just like your phone, the Pokit goes anywhere, freeing you from the bench that larger tools are forced to inhabit.

The app’s user interface is functional, if not completely intuitive, but thanks to a wealth of tutorials, it’s easy to become adept in a relatively short timeframe. With attachable probe clips, it’s just like having a tiny (~100kHz) scope in your pocket. And because the app and firmware are being upgraded all the time, the Pokit Pro’s utility will continue to increase; the company recently launched the world’s first multimeter smartwatch app (currently available for watchOS, with Android coming soon)! The Pokit Pro provides the functionality of a small bench’s worth of equipment in a portable form factor about the size of a soldering iron. It’s quickly becoming our go-to around the lab — and beyond! —*David Groom*

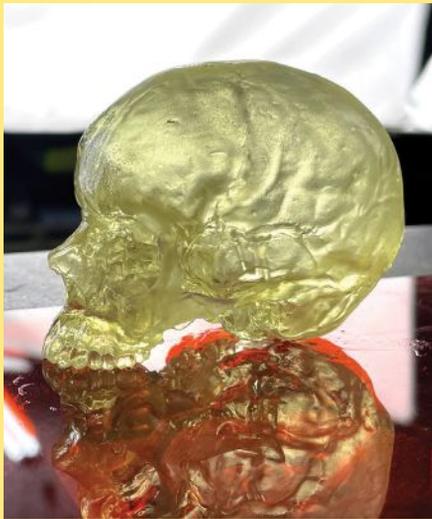
Monoprice Voxel 3D Pro

\$899 monoprice.com/product?p_id=44091

Monoprice’s fully enclosed Voxel 3D Pro was a breeze to set up and get printing. I pretty much pulled it out of the packing material, plugged it in, and loaded filament. The print results using the default settings were absolutely perfect. The bed is 200×200×250mm and sits inside a fully enclosed and quite stylish body. With nice features such as a quick-change nozzle, built-in camera, and HEPA filter, it’s impressive.

I wouldn’t call this thing a speed demon, but so far it has been very reliable. It does have a few quirks, like the “9 point auto bed leveling” which is actually a manual process, and the lack of documentation for accessing things via the web. These are minor annoyances though, in a very solid machine. —*Caleb Kraft*





Mayer Makes Engineering Resin

\$70/1kg mayermakes.at/engineering-resin

Resin-based 3D prints are notoriously brittle, even when advertised as tough. Mayer Makes Engineering Resin surprised me, though, with how durable it really is. Right off the printer, this stuff looks yellowish but gets clearer as it cures. The durability is impressive: Thin parts can flex and bend without shearing and thicker parts hold up to considerable abuse. I would actually feel confident using this to print an enclosure for something and then dropping it without worry.

At the cost, this probably isn't something you want to use for printing everything, but if you need to do some rugged parts or quick production pieces, this might be exactly what you're looking for.

—Caleb Kraft

Bernzomatic FirePoint Creator Tool

\$75 bernzomatic.com

Bernzomatic's new FirePoint Creator Tool seems to be a push to change the torch from a blunt object to a more precise tool. They've done this in a few ways. It has more control over the shape and size of the flame than you'd expect for a home torch, and the torch is on a pistol grip at the end of a hose, allowing for easier use than the ones attached directly to the top of a bottle.

If you're just using a torch to heat up stuck lugs on a rusty old car or start a bonfire, get the cheapo. However, if you even rarely want more precision, this is totally worth the money. —Caleb Kraft





Julluann Brown, Adobe Stock, pia



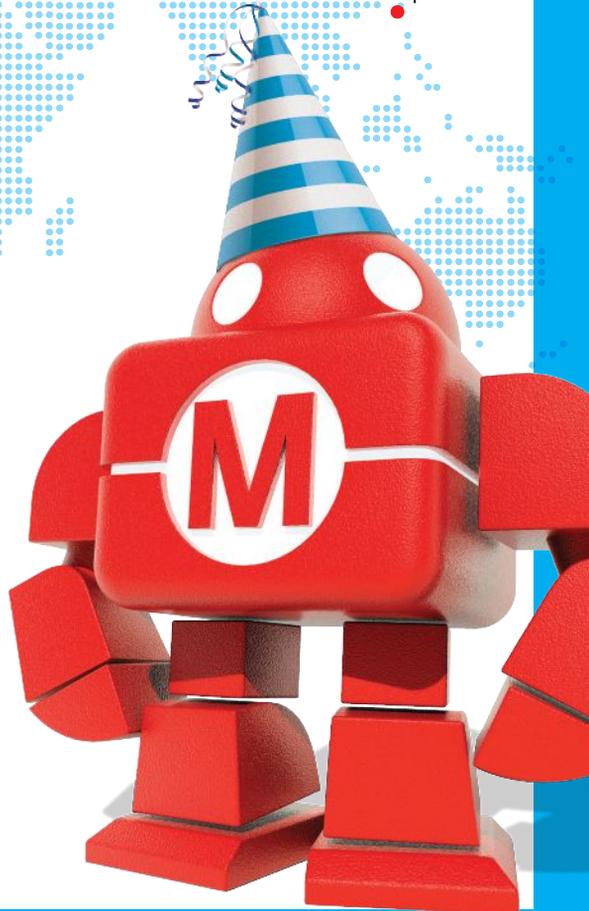
CONGRATS FAVOLOSO おめでとう

Make: would like to celebrate our global community of Maker Faire Producers and congratulate the events that celebrated their 10th Maker Faire!!!

Maker Faire®

Maker Faire is the ultimate event for crafty inventors and tech tinkerers! Since 2006, people from all walks of life have come together with their self-made projects to collaborate and celebrate DIY culture. From robots to 3D printing to arts & crafts — Maker Faire packs a serious punch when it comes to inventive ingenuity!

makerfaire.com



FROM MAKE:'S GUIDE TO BOARDS

Visit makezine.com/comparison/boards to get more reviews and easily compare specs with the Maker's Guide to Boards.



DFRobot LattePanda 3 Delta

\$279 dfrobot.com/product-2594.html

DFRobot's LattePanda line began with a 2015 Kickstarter campaign promising "a £45 Win10 Computer for Everything." While single-board computers like the Raspberry Pi were already widely available, it was far less common to see Intel-based offerings that could run Windows.

The LattePanda 3 Delta represents the third-generation evolution of the line, with a bump in performance and also price, at \$279 for the 8GB RAM/64GB eMMC model (without Windows 10 IoT Enterprise). In addition to the powerful quad-core Intel Celeron N5105 CPU, the LP3D sets itself apart with its extensive interface options, including Wi-Fi 6, Bluetooth 5.2, Gigabit Ethernet, USB 3.2 and Type-C, HDMI and DisplayPort, plus 12 analog inputs and up to 23 digital inputs/outputs, as well as UART, I²C, SPI and RS232. Makers looking for more grunt from their SBC, as well as the option for a familiar Windows environment, and a plethora of I/O, should consider adding the DFRobot LattePanda 3 Delta to their arsenal. —*David Groom*



ElecFreaks Pico:ed V2

\$13 elecFreaks.com/elecFreaks-pico-ed-v2.html

As we related in detail last issue ("The Replacements," *Make*: Volume 83, page 46), you can't always get what you want board-wise in recent years. One board we've found hard to come by at times is the BBC micro:bit, which is a problem for add-on products that expect the unique form factor, like our own Makey:bit Adventure Board (makershed.com/products/makeybit).

The ElecFreaks Pico:ed V2 fills this recurring gap in the market (literally) with its micro:bit form factor, but rather than directly cloning the Nordic nRF52833-based Beeb, sets itself apart with the popular dual-core Cortex-M0+ RP2040 MCU, and a dense 7×17 LED matrix in place of the usual 5×5. The RP2040 means that the board is easily programmed via MicroPython or C++, as well as MicroBlocks for beginners. And at just \$13, the decision to avoid micro:bit scalpers is easier than ever! —*David Groom*

ALPENGLow INDUSTRIES



NEW!
Solder-less Kits!

Soldering Kits!

We're a woman-owned business making frivolous circuits & useful tools for makers & engineers

Ask us about volume discounts for your workshop or makerspace!

Use coupon code: **MAKEMAG10** to get 10% off your order thru April



MicroKits
Theremin
Electronic Kit



MUSIC AND SOUND FROM ELECTRIC FIELDS!

- 30 Parts
- No Tools Needed
- Assembled in USA
- 3 AA Batteries Included

Build your own Theremin with this beginner friendly electronics kit!

Use code "Make23" for 15% off at

MicroKits.net

Inventive cardboard building kits

DAZZLINKS



Shop at **www.DazzLinks.com**



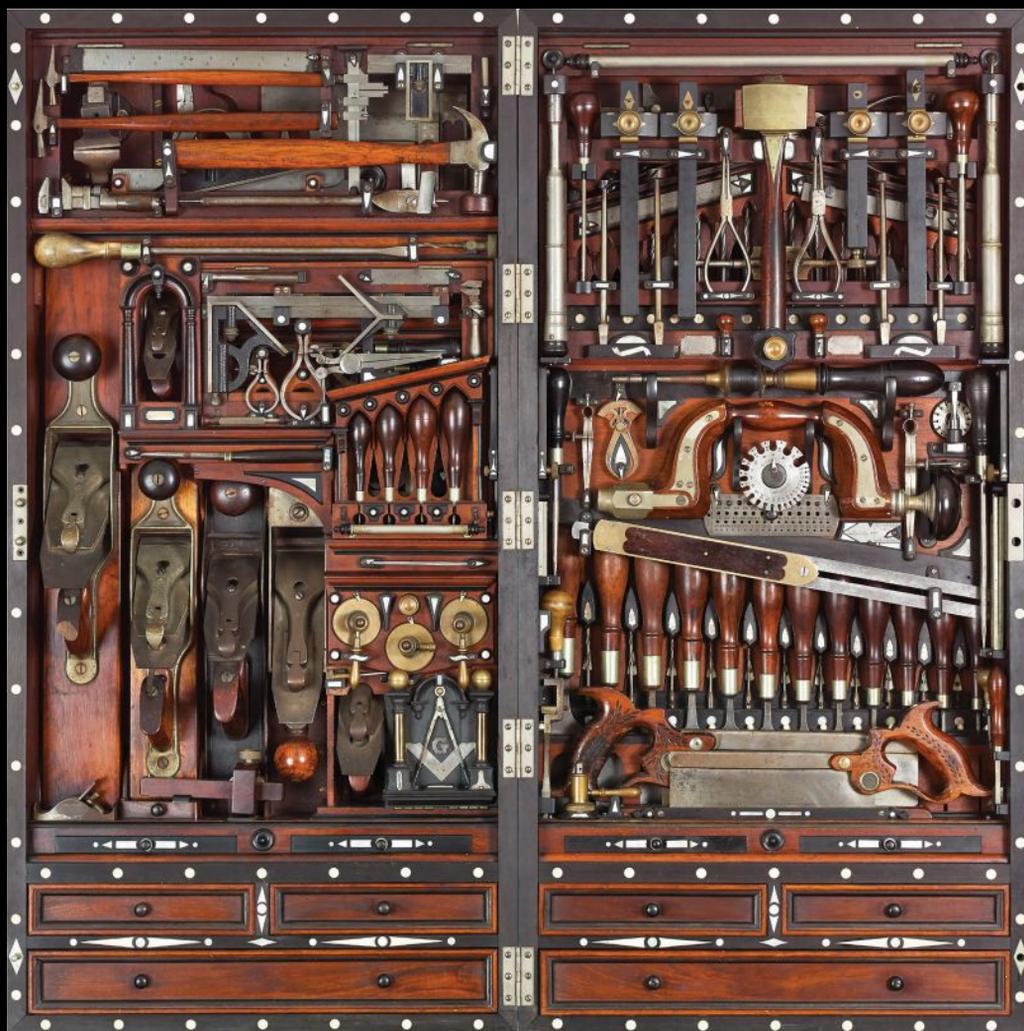
Make:cast

EXPLORING IDEAS, TOOLS & PEOPLE BEHIND **THE MAKER MOVEMENT**

Available on Spotify, Apple Podcasts, makezine.com, and more

OVER THE TOP

"A SHRINE TO HIS TOOLS"



Photograph by Narayan Nayar

Master carpenter Henry O. Studley (1838–1925) built pianos and organs in Boston for 46 years, but his masterpiece is surely his tool chest, adorned with ebony, ivory, rosewood, mahogany, and mother of pearl. Yes, it's a wonder of efficiency: To pack nearly 300 tools into a case $19\frac{1}{2}'' \times 39'' \times 9\frac{1}{2}''$, Studley designed clever flip-up trays and swing-out layers. But it's also a work of art: Gothic arches, hand-carved S-scrolls, even a Masonic vignette with symbolic square and compass. Rediscovered by *Fine Woodworking* magazine in 1988, Studley's tale is told in the book *Virtuoso* by Donald C. Williams (Lost Art Press, 2015), with photos by Narayan Nayar. Mindful of Adam Savage's "first-order retrievability," I was struck by this recollection from William Robertson, who helped set up the chest for exhibition at the Smithsonian: "A well-worn tool might be stored two layers deep, but there was no wear on the chest to have gotten to that tool. ... It made me think this chest was not used much but made more as a shrine to his tools." —Keith Hammond

INTRODUCING



FUSION MAKER

- Laser engrave, cut, and inlay wood
- Customize projects for added value
- 24" x 12" x 7" work area
- IRIS™ Camera for artwork layout
- Affordable pricing for entry-level
- Made in the USA

YOUR 30 DAY CHALLENGE TO LEARN CIRCUITS AND CODE



**START THE CHALLENGE AND JOIN
50,000+ OTHER MAKERS:**

[HTTPS://INVENTR.IO/DISCOUNT](https://inventr.io/discount)