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ON THE COVER:

The playable, programmable Microcade (page 52) is dwarfed by a modified Game Boy DMG-01 with Pro-Sound mod (p. 34), blue backlight, and silicone buttons, playing Cat Graffam's *Game Boy Camera Gallery* (p. 28).

Photos: GB/Microcade by Mark Madeo, Chain Chomp Lamp by Jeff Stein

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Mark Madeo, Jeffrey Bunting, Pablo Garcia, John Park, Lee Wilkins, Sam Freeman, Bob Knetzger, Jen Schachter

"A few years ago, the idea of a computer you could put in your pocket was just science fiction."
—Isaac Asimov, in *RadioShack's 1980 ad for the TRS-80 Pocket Computer*

PRESIDENT

Dale Dougherty
dale@make.co

VP, PARTNERSHIPS

Todd Sotkiewicz
todd@make.co

EDITORIAL

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

COMMUNITY EDITOR
David J. Groom
david@make.co

PRODUCTION MANAGER
Craig Couden

CONTRIBUTING EDITORS
Tim Deagan
William Gurstelle

CONTRIBUTING WRITERS
Debra Ansell, Cabe Atwell,
David Battino, Chris Borge,
Daniel Bunting, Sam Freeman,
Pablo Garcia, Jan Goolsbey,
Cat Graffam, Brian Johnson,
Bob Knetzger, Caleb Kraft,
Forrest M. Mims III, John Park,
Marshall Piro, Charles Platt,
Jen Schachter, Ian Scott,
Wayne Seltzer, Bryan Serinese,
Jeff Stein, Ivoine Strachan,
Matt Stultz, Nikola Whallon,
Lee Wilkins

CONTRIBUTING ARTISTS
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

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

CONTRIBUTORS

What retro tech do you not want to see make a comeback?



Catherine Graffam
Portland, Maine
(Game Boy Camera Renaissance)

It might be a hot take, but I'd love if LCD games were left in the past.



Pablo Garcia
Oak Park, Illinois
(DIY Camera Lucida)
All technology deserves study, but dangerous ones should become and stay obsolete: CFCs, the electric chair, and the atomic bomb, to name a few.



Sam Freeman
Santa Rosa, California
(Photo Robota)
Automatic seatbelts. Never met anyone who wanted, liked, or bothered with fixing 'em.

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Dale Dougherty

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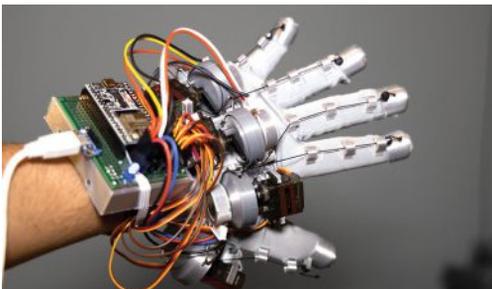
FROM THE EDITOR'S DESK

A FOND FAREWELL

Longtime *Make*: Senior Editor Caleb Kraft is moving on to bigger and better things, so we thought we'd send him off with his own personalized *Make*: cover. In his sign-off post Caleb wrote: "I still truly believe that the act of making, no matter how trivial, poorly skilled, unplanned, or rudimentary, is one of the most wonderful things you can do." Read the rest at makezine.com/go/keep-making-things and follow him on Twitter [@calebkraft](https://twitter.com/calebkraft) to keep up with new builds, farm animal shenanigans, and more. Thanks for everything, Caleb! ❤️

HAPTIC VR GLOVES

Kristine Nelson wrote in to let us know that her son Matt, 12, has spent the last few months getting his version of the "Budget VR Haptic Gloves" from *Make*: Volume 78 up and running and we're impressed! Matt added his own spin by nixing the fabric gloves in favor of custom 3D-printed finger caps to attach to the tension strings. Next step: Custom code!



Lucas, VR Tech, Kristine Nelson

MAKE THINGS

A New Weekly Newsletter from Make:

Make Things is our new weekly newsletter straight from the mind of *Make*: founder Dale Dougherty, focused on the maker community at large and the people behind the incredible builds you see in *Make*:, at Maker Faire, and beyond. Sign up or read past issues at makethings.make.co.

Do Something

by Dale Dougherty, President of Make: Community

Ted Gioia, who writes about music and culture on Substack, wrote about the origins of TikTok in a piece called “Where Did TikTok Come From?” (www.honest-broker.com/p/where-did-tiktok-come-from). In it he points out that TikTok’s founder, Zhang Yiming, believed that technology platforms gave users *too much* control. Gioia says that our attention, as evidenced by TikTok, is increasingly driven by algorithms, not interest. He makes the case that the technology we use every day requires less and less that we do anything. Our user experience in apps and online is increasingly passive — you don’t have to make a choice. “The platform drives the process,” says Gioia. The goal of an application like TikTok is to keep you using it, almost unaware of how much you are using it. It’s like junk food that doesn’t offer much nourishment. Gioia characterizes it as creating a “dopamine culture.” Just keep using. Addiction is what is good for their business, even if it is not good for you.

I wonder if people have become more passive. Are teenagers spending lots of time sitting in classroom lectures and lots of time outside of class dominated by apps that make choices for them? Are adults doing the same kinds of things at work and at home? Do we have the same user experience in real life as we do online? Would we be happier if we were more active and more self-directed?

When I started *Make:* magazine, I was fascinated that makers see technology as a set of tools, something they can do something with. The more they learn about the tool, the more control they gain over it, and the more they can do. And they equate what they can do with their own ability to take control of their own lives. Makers ignore the false promise that technology should be easy. Instead, they try to understand how technology works so that they can do things themselves, even if they are hard — and perhaps realizing that real satisfaction comes from the work being hard.

I still believe in that view of “technology as a set of tools” and that our goal is to teach more people how to use these tools with a maker mindset. However, as Gioia points out, technology is also being used in ways to take control away from people. This is true for AI — another powerful tool that in the right hands and with the right mindset can be a boon for creativity and problem-solving but also can be used without almost any thought as a replacement for thinking or creating — or having to do anything at all.

Social media and AI as a business want to create users and customers. The maker movement, by contrast, seeks to create makers and doers. We have more ambitious goals than a business. We believe there is a way to create producers, to develop more people who take control, who are curious and have many interests, who know all the tools they can use to do things, and who are unafraid to do things that are difficult. As makers, we care about improving our own lives and the lives of others and we know how to use tools to do something about that. 🍌



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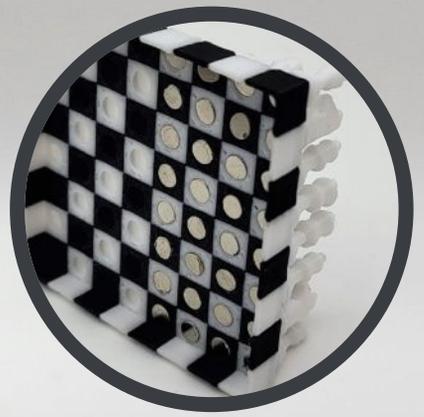
NIKLASROY.COM/MM

From the very beginning of his career as an artist, **Niklas Roy's** focus has been on creating interactive and participatory pieces through technology, and the massive community art project he calls *Maschinenmosaik* may be his most collaborative work yet.

He originally submitted the concept as part of an art competition to clean up the graffiti surrounding Anton-Saefkow-Platz, a square in the Lichtenberg borough of Berlin. Roy's idea was to make a mobile arcade machine capable of designing small pixel-art patterns, to give local residents the opportunity to create the square's new mosaic decorations, one spray-painted tile at a time. His proposal won the competition, and he spent the next month designing the portable design cabinet, dubbed *Mosaikmaschine*, in SketchUp, crafting the frame out of plywood and filling it with a modified flatscreen, a new backlight, an Arduino system to connect the buttons and joystick to a JavaScript program running on a laptop, and a receipt printer to keep a record of the designs. Although this may sound like a lot, Roy says that the *Mosaikmaschine* and its software were only a small part of the project. "Most of the time went into organizing, moving the mobile arcade machine around, getting the people in the neighborhood to participate, and plotting hundreds of stencils. And then, finally, I worked with a graffiti crew for about two weeks to spray the hundreds of pictures onto the walls."

Since being interviewed in our very first issue [*Make*: Volume 01, page 158], Roy has had nearly two decades to think about what art means to him, especially the type of art that's meant to be made and enjoyed with other people. "Creating something together with others and for other people," he says, "is in most cases more fulfilling than making something just by yourself and for yourself." You can see more of the *Maschinenmosaik* by following Roy's Instagram @royrobotiks. —Marshall Piros





LET'S PLAY A LITTLE GAME [INSTAGRAM.COM/FORWARD_FALCON_3910](https://www.instagram.com/forward_falcon_3910)

We've seen 3D-printed chess sets before, even portable ones, but there's just something extremely satisfying about **Aaron Leamon's** tiny playable 3D-Printed Chess Ring.

Leamon, aka Dr. Operator, was inspired by another tiny chess ring that he saw online by Joe Turner (makezine.com/go/smallest-chess-set). Turner wrote that it was impossible to play an actual game. But Leamon wanted to give it a try.

Leamon's chess board is 40mm×40mm and uses 96 individual 3mm×1mm magnets — 64 for the board and 32 for the individual pieces, which range from 8mm to 13mm in height. It took about a day and half to get a working version.

"The most difficult part was probably setting all of the magnets," Leamon said. "If I had to do anything differently, I might have tried to fit a small metal plate under the board instead of magnets. The downside to that would be that each piece wouldn't snap into place like it does now using individual magnets."

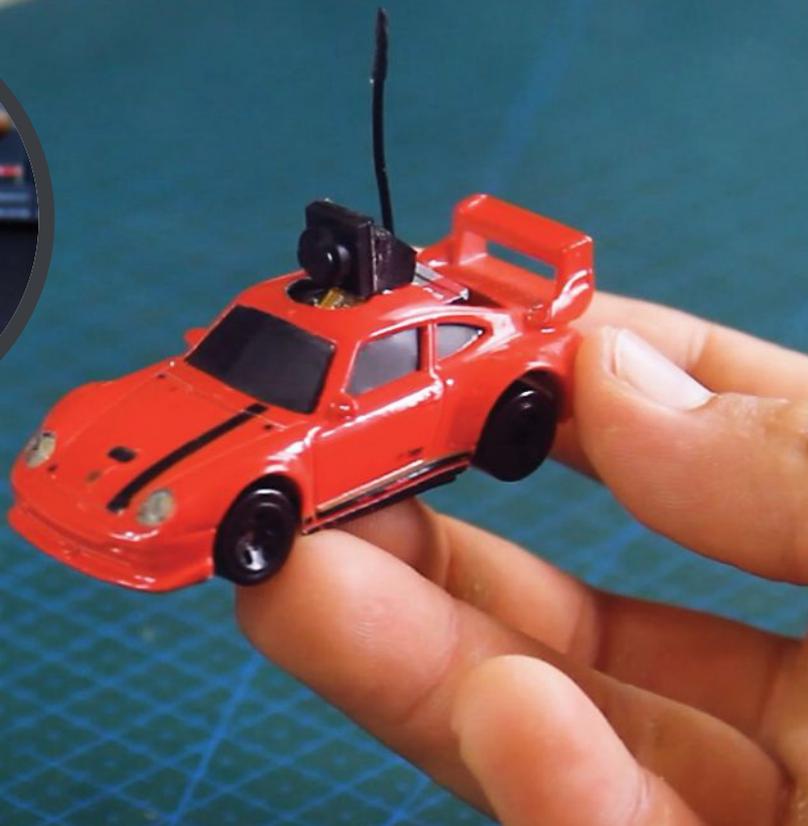
"I had admired 3D printing from afar for a good

decade," Leamon said. "The idea of being able to create something from nothing so easily was appealing, but as a cook with very little technical skills, I assumed it was too time-consuming and complex for me to grasp."

But that changed as the country went into lockdown during the Covid pandemic. "A day before the lockdown took effect here in Canada, my first printer, a birthday present from my brother, arrived at my door. At first, I was satisfied with downloading models from various websites, but it wasn't long before I found myself researching how to create models. That research led me to Tinkercad.com which I used to learn the basics of CAD before switching to the program I use now for all of my designs, Shapr3D."

It's not the most practical chess set to keep on hand, but practicality wasn't really the point: "While I do play chess, this was mostly about the challenge of making a fully functional chess ring."

Find the printable files at linktr.ee/dr.operator and try making your own. —Craig Couden



TAKING THE (HOT) WHEEL [YOUTUBE.COM/@MAXIMAGINATION](https://www.youtube.com/@MAXIMAGINATION)

Back in my carefree days of childhood I would have given anything to be able to drive my Hot Wheels cars like their bigger R/C cousins, but **Max Imagination** has taken it even further by putting himself in the tiny little driver seat.

Max started out his project-building life making fidget spinners when he was 12, developing quite a following. Flash forward and now he's a self-taught 17-year-old inventor who used his ingenuity to bring that R/C wish into existence by designing an R/C car using a Hot Wheels Porsche 993 GT2. What's more, he can drive it using a live FPV (first-person view) video feed.

Max began the project by carefully drilling out the rivets that hold the car together, allowing him access to the internal components. Within that confined space, he dropped in Seeed Studio's Xiao ESP32S3 Sense, which packs Wi-Fi/BLE connectivity and an OV2640 camera, along with a motor sourced from a 9g servo to drive the car, and a miniature 1.5g servo and linkage mechanism for steering. To streamline his build

and provide eye-catching visuals, Max outfitted the car with tiny surface-mount LED headlights that can switch between high, low, and off.

To mitigate the challenge of running a single web server for both FPV streaming and vehicle control, Max added an ESP32-C3 to interpret the camera signals from a secondary web interface. Controlling the FPV R/C car is handled via smartphone, while a second phone is slotted into a VR headset to display the video feed.

Despite the complexity of the wiring and mechanical adjustments, Max successfully transformed the vehicle into a competent racer that would drive any kid's imagination. Check out the build video with his complete design process at makezine.com/go/hot-wheels-fpv.

When talking about inspiration and being creative, Max has some final advice: "Have a bored moment, take a walk outside. See how you can improve and make something better. Give yourself enough time to stop and think."

—Cabe Atwell

MAKING MAKERS

Written and photographed by Debra Ansell



Reyce Krause



Dori Friedman



Barb Noren

Makerspaces in K-12 parochial schools

Makerspaces bridge the gap between abstract knowledge and the practical skills to build things that help our world function. Running a makerspace can be challenging and expensive, but schools that do so often see rewards in increased student engagement, collaboration, and enthusiasm for problem solving.

To learn more about how K-12 schools incorporate making in the classroom, I interviewed three teachers who run parochial school-based makerspaces:

- **REYCE KRAUSE:** Ma'ayanot Yeshiva High School for Girls, a Modern Orthodox school in Teaneck, New Jersey.
- **DORI FRIEDMAN:** St. Matthew's Parish School, a co-ed Episcopal middle school in Pacific Palisades, California.
- **BARB NOREN:** Pressman Academy, a Conservative Judaism elementary school in Los Angeles, California.

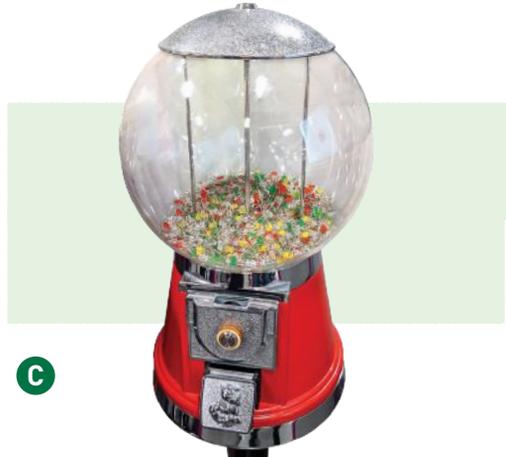
Each took an unconventional and idiosyncratic path to acquire their skills, but they share a high degree of dedication and persistence, a desire to keep current with new tools and technologies, and the flexibility to allow their students to work in ways that best suit their learning styles. It's worth noting that private schools generally have more funding and flexibility than public schools.

Reyce Krause

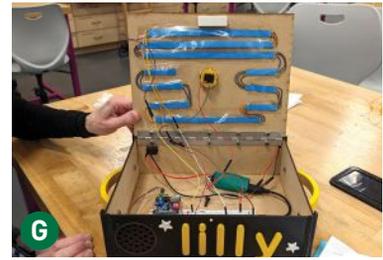
The boxy, industrial exterior of Ma'ayanot Yeshiva High School for Girls is a deceptively dull cover for the energetic milieu of animated young women inside who converse brightly as they walk between classes. The existence of a well-appointed makerspace in a Modern Orthodox Jewish girls' school seems similarly incongruous at first, but this school's mission statement mixes tradition and community with an awareness of the students' responsibilities to the world around them and prioritizes acquiring skills to thrive in an evolving society. Ma'ayanot students learn a core set of technical skills and apply them as expressions of their creative souls and spirits — the *tzelem elokim*, a Hebrew phrase that means the “divine image,” imbued in every person — with a sense of their responsibility to be divine partners in improving the world.

Reyce Krause is Ma'ayanot's Director of STEAM Curriculum and runs the makerspace. She began her tenure here as a conventional math teacher. Inspired to give her algebra class an applied lesson on parabolic curves, she reached out to a local Home Depot and convinced them to provide materials to build a parabolic cooker. She took her students to the school parking lot, pointed the cooker at the sun, and placed a newspaper in front of the reflected rays. The abstract concept of focal points transformed quickly into tangible experience as the paper burst into flames. “This was the first time the girls finally understood that math is just a language describing how the world works,” Reyce recalls. “It was just so powerful. They just loved it.” The cooker still hangs in a corner of her classroom (Figure A).

Inside the bright and airy STEAM classroom, four UltiMaker 3D printers line one wall along with a laser cutter (Figure B). Construction tools ranging from soldering irons to sewing machines are easily accessible, as are the well-organized drawers filled with construction materials and electronic components. An old-fashioned gumball machine is whimsically filled with hundreds of bright-colored LEDs (Figure C). Reyce's desk (Figure D) and the nearby sideboards are covered in attractive DIY project builds, many reproduced from online tutorials and *Make*: magazine articles.



FEATURES: School Makerspaces



Reyce acquired her college mathematics degree decades after finishing high school, waiting until her eight children were almost grown. She was hesitant when Ma'ayanot's principal approached her to develop a STEAM program. She'd never worked with electronics.

"We started off with paper circuitry, which was fun. I had never created a circuit," Reyce says. If information was unclear or hard to come by, she reached out to makers and experts she found online, who were often generous with their time.

Since those first simple lessons, Ma'ayanot's STEAM program has greatly expanded to include two years of engineering classes in 9th and 10th grades. Tenth-graders form small groups to participate in a program called Making a Difference. Each group is paired with a young student at a partner school who has physical impairments and/or learning disabilities. The Ma'ayanot students are challenged to manufacture a customized toy to engage the child and help them reach developmental milestones.

The students interview the child, their teachers, and caregivers to learn their likes, dislikes, and developmental needs. They determine what interactive features best suit their child's capabilities. Does the child have the dexterity for a toy with push buttons, or would proximity detection with a distance sensor be a more practical interaction mechanism? They'll use a Raspberry Pi Pico, and possibly add NeoPixel LEDs, servos, or MP3 breakout boards to respond to a user's actions with visual and audio feedback. The toy's electronics and batteries are secured in attractive laser-cut wooden enclosures enhanced with colorful 3D-printed elements (Figures E, F, and G). As the builds near completion, STEAM students pass the toys around so that every student tests every toy, assuring its durability and safety before it goes to its new owner.

STEAM lessons at Ma'ayanot engage students by fitting seamlessly into the culture and goals of the school. Not only do students learn technical and engineering skills, but they also learn to apply them to make the world a better place.

Dori Friedman

Every year at St. Matthew's Parish School, 5th-grade students enter the Project and Idea Realization Lab (PIRL) to work with Dori Friedman, the school's Maker and Innovation Coordinator. They'll return frequently through 8th grade, building dozens of creative, hands-on projects that represent almost every topic in the school's curriculum.

Dori teaches her adolescent students to use power tools, a prospect most people would find daunting, if not terrifying. Dori relishes the challenge. She is proud of "pushing the bar beyond what a typical middle school would do." Her 5th-grade students will use bandsaws and drills to shape a 4-foot length of 2x2 lumber into a walking stick with an attached compass. However, before they gain supervised access to power tools, students must score 100% on a test of tool usage and safety.

Dori emphasizes collaboration, which she models by designing cross-disciplinary lessons in conjunction with the classroom teachers. The walking stick project is part of a larger science unit in which students also build a "survival compass" using a leaf, magnet, and paper clip; and program a tiny micro:bit computer to translate magnetometer data into cardinal directions. Classes in PIRL are designed to complement the school's curriculum, allow students to take ownership of their own learning process, build their confidence, and help them learn to collaborate effectively and use resources thoughtfully. Dori says her biggest goal is that "I



want kids to know that when they come across a problem, they have the tools they need to solve it.”

In their second semester, 7th graders complete a “passion project” (Figure H) in conjunction with the religion teacher’s service-learning unit, in which they design and prototype a product to help combat food insecurity in the community. Past projects have included a model of a community greenhouse, a solar oven kit, and a functional free food vending machine powered by a micro:bit.

By 8th grade, students have learned to use power tools to drill, cut, and assemble pieces from an 8-foot, 2x2 wooden beam into a free-standing tensegrity structure. They’ll also complete a self-directed science capstone project on a topic chosen from a curated subset of the United Nations’ Sustainable Development Goals (sdgs.un.org/goals). They’ll tackle this real-world problem by doing an experiment, designing an engineering project, or giving a “TED” talk and becoming an “influencer” to raise awareness about their topic.

PIRL is the largest makerspace of the three schools I toured, consisting of a main workspace, a secondary room with machines and power tools, and a third, outdoor space. In the main workshop, well-stocked shelves are color coded (Figure I) in hues that indicate whether students are free to use the items inside without asking (green) or whether they require permission (red). Amusingly, large bags of cotton balls sit in a restricted shelf due to previous fluffy indoor “blizzards.”

Students frequently come to PIRL during supervised “open hours” to use the resources



for independent projects. A student who expressed interest in building an R/C boat was given encouragement, tips, and links to relevant tutorials on Instructables. Collaborative efforts include a modular dollhouse, a sprawling cardboard marble roller-coaster that outgrew its storage space, and an increasingly elaborate series of shoes incorporating materials such as felt, cotton balls, and springs.

Dori is formally trained in education, but her tech skills are all self-taught. “I would go to Egghead [computer store] after school and wander around, and I would ask a million questions.” The store eventually hired her part time to help with educational software sales. Seeing her potential, Davidson and Associates recruited her to work full time helping them design educational software products. After a couple years, she felt compelled to return to the classroom and resumed teaching full time, bringing her upgraded technical toolset with her.

Dori develops all her own lessons, collaborating on about 50 different projects across all subject areas during a typical school year. Designing and building working yo-yos provides instruction on CAD and 3D printing, and cardboard pinball machines are a very popular project combining engineering and coding skills (Figure J). She posts videos of her original lessons and students’ results on Instagram under the handle @dorifriedman, and she speaks at educator and technical conferences. “I’m trying to inspire other teachers,” she says. “So I also provide a lot of mentorship to teachers all over the world. I support them wherever I can.”





When asked how the maker community could better support makerspace teachers, Dori says she'd like to see more entry-level project tutorials, and recommends cardboard and hot glue as a good starting point. She believes the first steps should be as accessible as possible.

Barb Noren

In the small maker classroom in Pressman Academy, the windowsill holds two rows of clear plastic bottles filled with colorful layers of salt water, isopropyl alcohol, and vegetable oil, with small Perler beads suspended at layer boundaries. These are completed "density towers" (Figure K) with the assembly directions still projected on the classroom whiteboard (Figure L). Teacher Barb Noren just shrugs when I ask her if it was a messy lesson. "Less messy than some things," she says, her tone indicating she's seen a good mess or two.

Barb leads K–5 students in project-based instruction covering a wide range of science topics. She creates her own engaging, age-appropriate, and occasionally messy lessons that aim to expand her students' maker skillsets without exceeding their attention span. Every Pressman elementary school student spends 60 to 90 minutes a week in the makerspace classroom. Their multi-year relationship allows Barb to plan long-term progressive development of students' maker skills. She seeks to "cultivate their curiosity and [help them] become proficient in the language of making."

I asked Barb if there are any standardized lesson plans for maker classrooms. Even if there were, she responded, she'd tailor them to fit her specific curriculum. "I want to customize, which is actually part of my personality as a maker." That trait demonstrates to her students that "there are ways to hack everything."



Tools and materials cover much of the STEAM lab's visible wall space, hanging on easily accessible hooks shadowed by vinyl outlines that indicate an item's designated storage spot (Figure M). These colorful silhouettes are part of Barb's strategy to empower even the youngest, preliterate students, to plan, create, and clean up their projects as independently as possible.

Cardboard is a fundamental building block

of the Pressman Academy's STEAM lab. In kindergarten, students learn about classifying vertebrates (Figure **N**), drawing pictures of mammals on cardboard, then lacing yarn through holes around the animal's outline to represent fur and hair. First-graders animate lessons on light and sound with articulated shadow puppets, learning how to create movable joints in the process. In later grades, folded cardboard polyhedra illustrate three-dimensional geometric concepts, and stacked cardboard layers become topographic maps. Fifth-graders researching topics in outer space conceive, design, and build their own models, such as a replica Space Shuttle and a papier-mâché sun (Figure **O**). A series of diagrams that Barb drew, showing cardboard engineering techniques, runs along the top of one wall (Figure **P**). Just below, examples of different types of joints are magnetically attached to a whiteboard for easy removal and examination.

Barb's wide-ranging science lessons also make use of the school's garden, which the students will landscape into a topographic garden map of California, researching and planting a variety of regional native vegetation. A class set of iPads is used for stop-motion videos, light painting, research, 3D modeling in Tinkercad, and Scratch coding. This year the students will design and 3D print regional landmarks for the topographic garden. Barb purposely combines multiple STEAM topics into her lessons because, "Nothing in real life is as segmented as traditional education would have you believe."

Barb has been blending art, education, and making since childhood, when she helped her artist mother to run public workshops. After college, she spent a decade working in the entertainment industry as a sound editor. She missed teaching, and the decisive nudge to return arrived in the form of a social media post from this magazine. As she recalls, "I saw a tweet from *Make*: magazine about MakerEd and its Maker Corps program ... that would do a training program with you online and then send you to work in a makerspace for a summer." Maker Corps started her down the path that eventually placed her in the Los Angeles ReDiscover center, a community nonprofit makerspace, where she ran programs for several years before being hired



by Pressman Academy. She is extremely involved in the local makerspace, CRASH Space, which keeps her in touch with many other Los Angeles-based makers.

Although regular classes in the makerspace end in 5th grade, students continue to use it as a resource. While I was there, a middle school student entered the classroom carrying a 4-foot-tall cardboard giraffe head, part of a costume from the school play. He explained that the padding in the neck had come loose from the headpiece and engaged in a thoughtful discussion with Barb about the best way to fix it. Settling on a combination of zip ties and hot glue, Barb guided him through the process, encouraging him to do as much of the work as he could by himself. He returned to rehearsals and Barb prepared for her next class, having demonstrated that even without formal lessons, her students will continue to develop their skills in the school makerspace. 🌟



DEBRA ANSELL is a maker and educator who will never stop demonstrating that LEDs improve everything. This is her first reported feature for the magazine; you can also find her outstanding how-to projects at makezine.com/author/debra-ansell.



HACK CLUB!



IVOINE STRACHAN,
19, now lives in the San Francisco Bay Area where he is hard at work on a top-secret VR project.
ivoine.dev

Creating a foundation to empower thousands of teen makers worldwide

Written by Ivoine Strachan

I grew up without electricity, Wi-Fi, or running water. I lost my mom at 16. I wasn't afforded a traditional education. But, now 19, I've been able to build amazing things with other young people — some from poverty, some from privilege — who've come together to prove that what matters most is community.

I got into tech by necessity. The world is full of technical problems, and even the “small” ones are very real to those experiencing them. It was hot where we lived in Nassau, The Bahamas, and we needed a fan for my grandmother. The lack of electricity was a problem. So I went to the library to do some research, and realized I could use a small solar panel and an Arduino microcontroller to work a blade from an old fan I'd found. My chess teacher was kind enough to provide the money I needed, and soon the problem was solved. This taught me that I could sit in the heat and be miserable or I could go find a solution — and that when I did the work, people would often meet me on my way with helping hands.

When I was 17, I received a grant to attend a hackathon in San Francisco, run by a group called Hack Club. This is their story, my story, and the story of other teen Hack Clubbers and what we're building together.

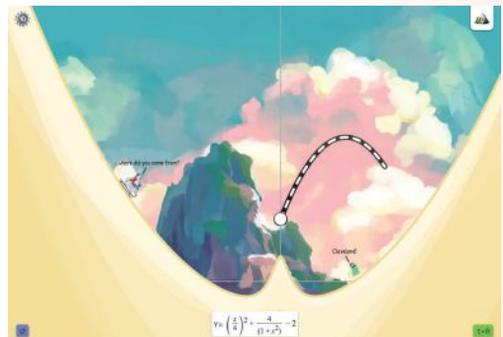
A GLOBAL TEEN HACKER CLUB

Hack Club was founded in 2014 by teen programmer and high school dropout Zach Latta. Zach struggled in a public high school that didn't offer a meaningful computer science program. He'd been looking for friends who also loved computers, and at 16 he decided to build a community for other young makers and leaders. His efforts won him a Thiel Fellowship and \$100,000 to bring his vision to life — a place where bright, tech-curious young people could collaborate and build faster by building together.

Zach was later joined by his co-founder, Christina Asquith, a journalist and war correspondent who'd founded The Fuller Project, a journalism nonprofit focused on issues affecting women and girls globally. Together, they set out to build Hack Club into a worldwide nonprofit program, inclusive of all teenagers regardless of gender or financial background, that will bring together hundreds of thousands of young



My craziest project so far:
Building a bomb for the Outernet hackathon using manure, a bucket, and fire. I'm on Hack Club Slack: @sike



SineRider math game by Hack Clubbers, sinerider.com

people who love to build and make projects with technology, art, and creativity.

It worked. I no longer have to code alone on my phone, and both my social network and comfort zone are much wider now. And it isn't just me.

RIDING THE WAVE

Chris Walker had a typical experience in high school math class: turning to playing on his TI-84 graphing calculator to cure his boredom. But this gave him an idea — making a game where ghosts would sled down graphs, backed by beautiful artwork, to make abstract math problems more engaging.

Chris worked on SineRider for years, but was never able to get it over the finish line — until joining Hack Club, where a team of 20-plus

FEATURES: Hack Club for Teens

teenagers across the globe then spent their evenings and weekends finishing his work. One of those contributing coders was Aileen Rivera. The pandemic era had been lonely for her, as it was for most students, whose social lives were suddenly upended. She had all the curiosity, but without the community, in her words, “I often just didn’t know how to fix issues or improve my projects. My school didn’t have any real resources, and I didn’t have anyone to ask. Now I’ve got best friends working alongside me ... we can make progress together, share ideas, and just be less isolated.”

SineRider’s appeal was obvious, she says. “The game was just very different, bringing art and actual fun to math. And what’s beautiful is that it’s built by young people for other young people.”

Their efforts paid off. SineRider is played by thousands of students worldwide daily to improve their understanding of functions. And Aileen is working on its translation system so that students can play it in their own language. With Hack Club’s help, she has also launched her own hackathon in her native San Antonio, Texas — and is working on an AI education tool while teaching herself biomechatronics.

MAKE ON A TRAIN

“There’s no way this is actually happening. There’s no way a nonprofit is sending like 42 people around the country to make stuff on a train.”

Ian Madden was in the eighth grade when he uttered the above, before beginning the Zephyr hackathon, a 3,502-mile train journey from Hack Club HQ in Vermont, through New York City, Chicago, and the Rocky Mountains en route to Los Angeles, California (github.com/hackclub/the-hacker-zephyr).

One of his first projects was fixing an out-of-control database issue with the ticketing and scrapbooking tools for a big hackathon — while at the airport on his way to attend, which taught him as much about the technical side as the logistical. Hence most of Ian’s work since: helping to build out the unique infrastructure that’s powering both the club’s in-person events and hundreds of clubber passion projects. Those tools include Hackathon.zip, an all-in-one platform for hosting hackathons, and Hack Club Bank (hackclub.com).



A project Aileen’s proud of: Creating an online mood board to collect survey responses around how we physically and psychologically react to light and sounds. @aileen



Ian’s unexpected hobby: When not working on maker projects or doing schoolwork, Ian plays the euphonium. @ian



A special skill: Kevin claims he can find his way around Boston blindfolded. He's also planning a gap year to work on "unhinged projects" like "a Gatling gun for fireworks."
@Kevin Yang

[com/fiscal-sponsorship](#)). The latter encourages Clubbers to get their projects off the ground by giving them a bank account and transparent ledger so that funders can see where every dollar is spent.

Ian still has a few years until college, where he expects to major in computer science. But he feels readier. "I think I'll be better prepared, not only technically, but professionally."

FACE THE FLAMES

Kevin Yang loves to make stuff. The "what" is less important. At 17, he and friends created a flamethrower from a taser, some sunscreen, and a toy guitar. In true hacker fashion, they were out in the woods without access to conventional electronics, so made do with the remains of an old R/C car and other scavenged items — and they created fire.

Kevin started working on circuit boards in middle school, with mixed results. "It was a very lonely, intensive, and difficult adventure. They were expensive to manufacture, I didn't know what I was doing, and I didn't have anyone to talk to."

To remedy this, Kevin teamed up with a Hack Club engineer, Max Wofford, to create OnBoard ([hackclub.com/onboard](#)), a grant program that allows teenagers to design their own circuit boards. He's now working on building out the program's tutorials to help ensure that students have all the resources, guidance, and support he wished he'd had.



SHIPS AND MAKERS

One need that arose as Hack Club grew was creating materials for teens unable to access a local club. Hack Club engineer Leo McElory, a makerspace wizard and creator of the Gram drawing language, worked with Cedric Hutchings, a crack coder hired right out his Appalachian high school, to design Hack Club's first "You Ship, We Ship" project, Sprig — a web-based editor that teens can use to draw, make music, and craft their own tile-based games ([sprig.hackclub.com](#)). Once clubbers "ship" their creations by publishing them online, Hack Club mails them

FEATURES: Hack Club for Teens



Lucas' biggest challenge: Learning English! Like many ambitious teens worldwide, he's self-taught. He practices by listening to the news and chatting in Hack Club Slack. @lucas

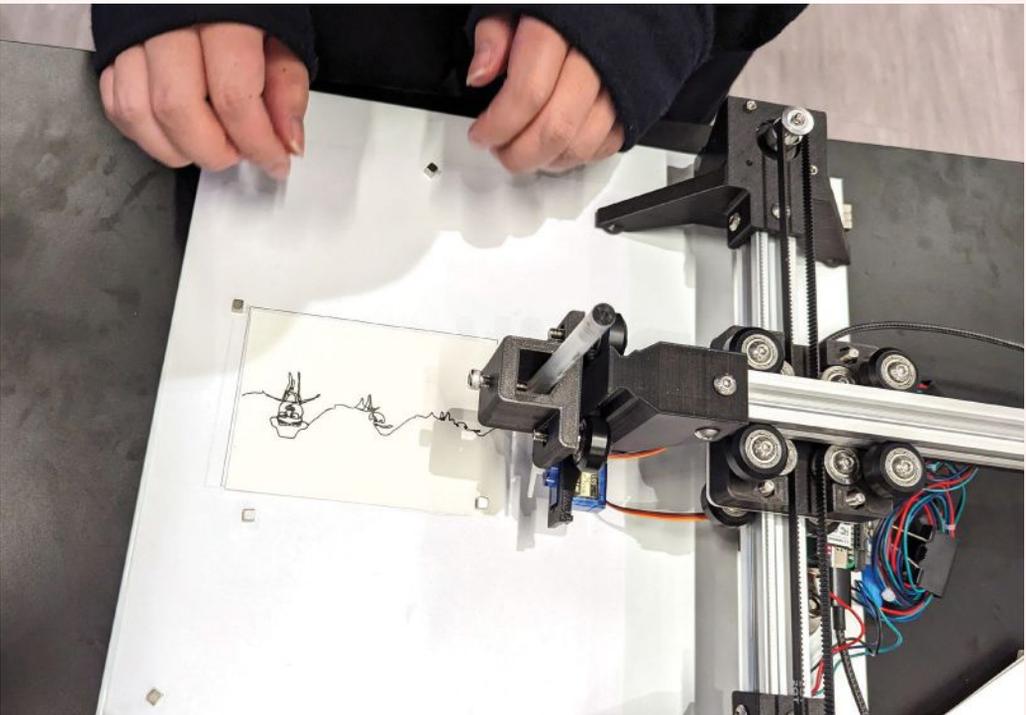
back materials for a miniature console to install them on: a Sprig kit that anchors two D-pads, an audio controller, and a 160×128 color LCD to a Raspberry Pi Pico.

Lucas Honda, 15, from Sao Paulo, Brazil, joined Hack Club in 2022. One of his first self-assigned projects was building and uploading *Flurffy*, a JavaScript-based Sprig game with echoes of the original *Flappy Bird*. But his biggest reward wasn't just the positive reviews from his new friends; it was establishing himself in a community where he could help other young folks to build games of their own.

ART IS MATH

Bright Li, a ninth grader from Southern California, was born to two software engineers, who encouraged his tinkering, including taking apart an old phone to examine its circuits and reverse engineer how its touch technology worked.

Bright also contributes to another of Hack Club's beta You Ship, We Ship projects, Blot, which brings digital art into the physical world. Clubbers use a custom web editor to write a program that creates a piece of art, and Hack



Hack Club members



Bright's current side project: Trained on both the violin and piano, Bright has also been designing an AI program to convert songs to sheet music. @Bright Li

Club then sends out a CNC machine kit that draws it (blot.hackclub.com). Bright is currently working on adding animation features to the editor, and on a music engine.

EVERYONE IS AWESOME

Zoya Hussain is from Dallas, Texas. Her father, who'd come to America from Pakistan, filled her childhood with stories about computers, and helped her break down robots to understand the engineering and design inside. She was quickly hooked.

Though already familiar with hackathons — of which she'd won four consecutively — she noticed something special about the ones Hack Club ran: "I'd never seen a team invest this amount of collaboration with an emphasis on creating a magical event. It's taught me something about how events should cater towards the people they're serving, and how to do that practically."

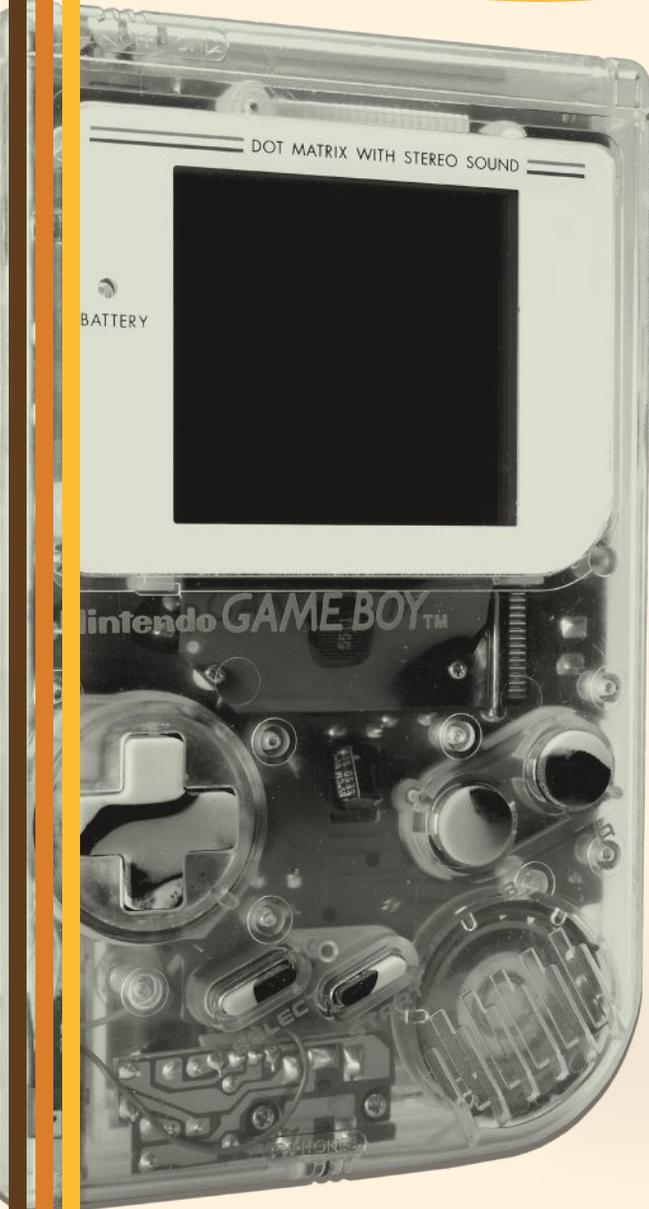
This especially matters for girls. STEM is still only about 20% female, and changing this starts with inclusion made practical. This led Zoya towards Hack Club's Days of Service project (daysofservice.hackclub.com), which hosts one-day hacking events to get girls not just into coding, but into a supportive community where they won't feel like imposters. Alongside her other engineering projects, Zoya is now able to help more of those girls share her own realization: "An entire world was revealed to me that I never knew existed. I wasn't sure before



Another thing Zoya's passionate about: "Making coffee. But don't include that." She's also working on brain-computer interfaces, an AI ethics policy for Congress, and being a strong voice in her advocacy efforts. @zsh

that anything related to computer engineering was really for me. Now I'm sure."

So how can you get involved? If you're a teenager, you can join Hack Club's online community now at hackclub.com. Adults, we'd love if you could support our programs by donating via hackclub.com/philanthropy! 🙌



OLD TECH, NEW THRILL

Yesterday's technology is a playground for enthusiastic new communities

WRITTEN BY DAVID J. GROOM



The author's BBC Master 128 "microcomputer" with unique "mouse" input device, 1986 vintage.

The appeal of looking back to our technological past is undeniable. The tech we use every day does not exist in a vacuum — it was not created spontaneously but rather built upon layers of prior generations of knowledge, ideas, and hopes. It's not surprising then that communities exist which celebrate and explore almost every aspect of technology's complex past.

For me, technology has been a lifelong fascination, from the moment my dad brought home a BBC Micro Model B microcomputer for me to play with one weekend. We ended up buying a BBC Master 128, the Micro's successor, when my dad saw how much I loved the Beeb, and by age 6, I was off and running, creating my own worlds in BASIC. I even founded our school newspaper using crude desktop publishing software and a special hardware device to make working with it easier, called a "mouse." I can still smell the "computer room" where I spent countless days of my childhood at the keyboard, and while my hunger for new, more powerful gear soon sent me down the path of the PC, I still own and cherish that rare 1986 machine.

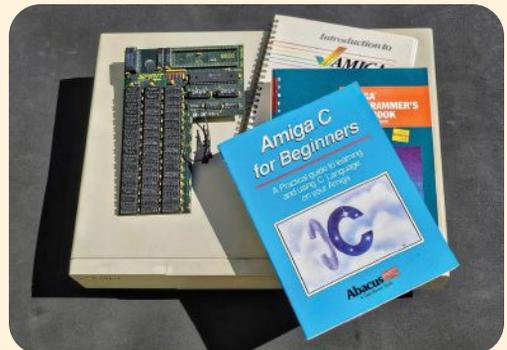
Today I have an extensive collection of computing devices of similar vintage which I never had the chance to experience in their heyday. My Amiga 1000 is the crown jewel among them and has allowed me to explore an entirely different Motorola 68000-based history, parallel



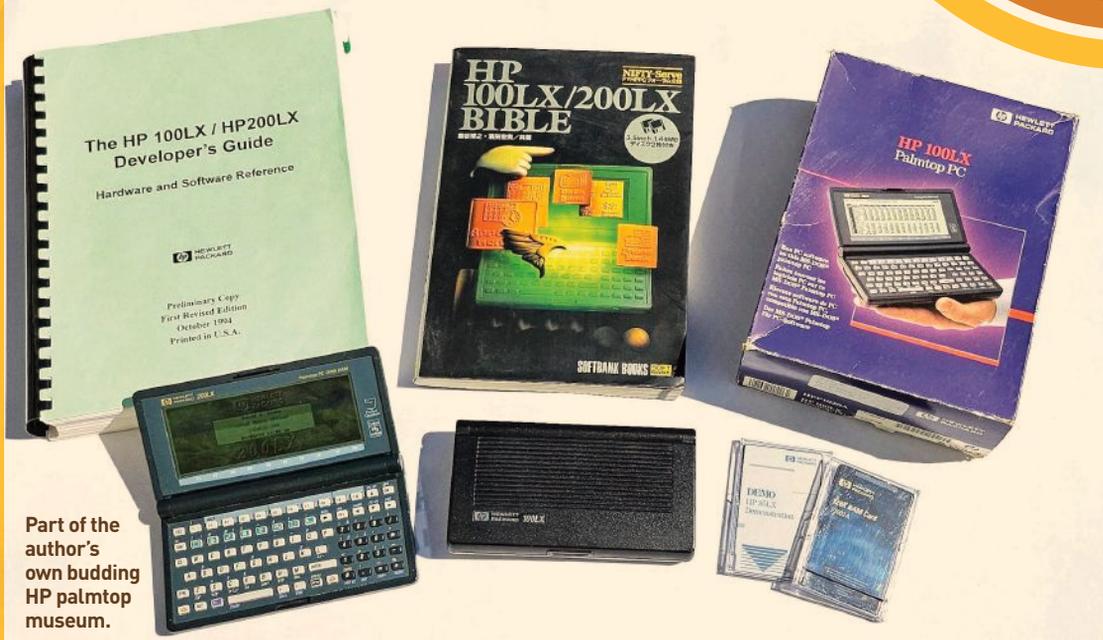
DAVID J. GROOM has been playing with Game Boys since Christmas 1989, and more recently trying to write code and music for them.

to the 6502-then-x86 path that I took. The winter before last, I spent the break immersing myself in the world of the Amiga, refusing the use of my modern PC and spending all of my time learning the OS and how to develop in Aztec C, basking in period documentation and how-to guides. By essentially cosplaying as a 1989 Amiga user, I got to experience a delicious new flavor of tech that I'd missed out on the first time around.

But I didn't do it alone. My Amiga journey was facilitated by an emulation and connectivity



The author's Amiga 1000 1989 cosplay starter pack.



Part of the author's own budding HP palmtop museum.

package from a group in Italy. I supplemented the wonderful paper books that I'd inherited with scanned PDFs from bombjack.org. And when one of my Aztec C disks turned out to have gone bad, I found a replacement image in the Belgian Amiga Club's BS1 disk archive. Locally, I get to share my passion for the Amiga and other old hardware via a monthly meetup at my local makerspace, All Hands Active. My explorations were immeasurably enhanced by passionate communities all over the world that have formed around this wonderful old gear.

Technology has always emanated from and been sustained by such communities, from local computer clubs like the one in Palo Alto where Steve Wozniak debuted the first Apple computer, to trade shows like the one in London where I witnessed the launch of the BBC Micro's ARM2-powered successor, Archimedes. Technology in turn has enabled new forms of community, like bulletin board systems (BBSs), CompuServe, IRC, and modern forums and other digital gathering places where enthusiasts can more easily connect regardless of geography.

Museums like Mountain View's Computer History Museum and The Bloop Museum in Maryland provide context and depth, and even the

chance for anyone to go hands-on with retro gear to see what makes it so special. Digital libraries like the Internet Archive and WinWorld ensure that users can still get their hands on obscure titles that would otherwise be locked away on a dusty floppy somewhere. And in-person events like Vintage Computer Festivals and our own Maker Faires allow enthusiasts to share their passions and discover new ones.

Maybe you're into restoring obscure old computers, or supercharging them with powerful modern hardware, or embracing their constraints to create rad 8-bit chiptunes, wicked tracker music, or mind-bending demos. Maybe you prefer playing "obsolete" music formats, or niche video games from the 80s and 90s — or hacking old ROMs to put your own spin on classic games. In the emerging "fantasy console" scene, you can even create games for retro-style consoles that never existed! Whatever your retro tech obsession, there's a community out there for you.

In this issue of *Make.*, we celebrate some beloved retro darlings, like my own Game Boy on the cover, as well as the chiptune music scene ("Pro-Sound Mod," page 34) and the community that has embraced the Game Boy Camera and homebrew game development ("Game Boy

RETRO PLAYLIST

When I was putting together this section, I asked our contributors to share their favorite chiptune and other retro-oriented songs. I've assembled them into a playlist, which you can find at makezine.com/go/retro-playlist and jam along to while you explore the section.



A glimpse of The Bloop Museum in Maryland.

Camera Renaissance," page 28). The music theme continues with our deep dive into the creation of the Raspberry Pi Pico-based PC sound card emulator PicoGUS (page 46), and our piece on DIY vinyl records (page 38) shares the story of a maker we met at Maker Faire Bay Area who is finding fun new ways to explore this century-old tech. Retro gamers can get their hands dirty building a stand-up arcade console, full-size or mini ("DIY Retro Arcade," page 50), and light up the game room with a *Mario* baddie ("Scary Sconce," page 80). Our examination of the recent NABU craze ("Something Old, Something New," page 44) proves that even weird old tech that nobody's nostalgic for can inspire a passionate new community. And our capacitor replacement Skill Builder (page 118) conveys an invaluable restoration technique for retro devotees.

As retro and future collide in projects like the PICO-8 fantasy console, the FPGA-powered Analogue Pocket handheld emulator, and new retro-inspired gear like the Clockwork Pi uConsole (see *Make: Volume 88*, page 126 for our review), we get to experience the charm of the past without sacrificing the convenience of modern devices. The future of retro is bright. 🍷

The Bloop Museum (blopmuseum.com) is an electronic entertainment museum dedicated to computers, games, media, and gadgets. With more than 20,000 artifacts, they've outgrown their current space and are raising funds for a move to a permanent home. You can help with a donation at their fundraiser page givebutter.com/blopholiday.



GAME BOY CAMERA RENAISSANCE

Hackers and modders have turned low-res “funtography” into an art form

WRITTEN BY CAT GRAFFAM



CAT GRAFFAM is an artist and educator from Portland, Maine. She is obsessed with old technology and creates videos, games, photographs, and paintings inspired by it. Oh, and she always lands on her feet.

I fell in love with the Game Boy Camera in 2022 after seeing it being used as a creative tool by artists like Zoë Wolfe on social media. Within hours, I purchased one off an auction site and bought another device necessary for extracting the photos from the cartridge straight to a computer. I immediately joined the inviting community of enthusiasts on the Game Boy Camera Club Discord server (discord.com/invite/y3Q4Pa2Pkr), and their excitement and positive energy inspired me to create something to contribute to it in return.

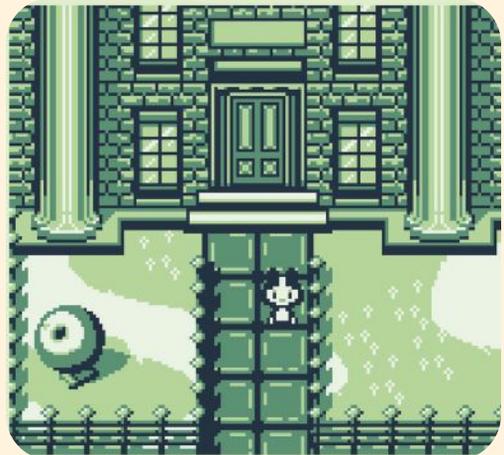
While I may lack the electronics skills to create my own hardware modifications like the other talented folks on the server, I do have a background in curating exhibitions at art galleries. The GB Camera Club's passion for this device stoked that curatorial love again, inspiring me to assemble a virtual exhibition of Game Boy Camera photos — in the form of a playable game cartridge.

The first *Game Boy Camera Gallery in 2022* was a 2D top-down virtual “gallery space” (scratchingpost.itch.io/gbcg2022). Lining the pixelated walls were miniature versions of over 40 photos from more than two dozen photographers, and selecting them allowed you to view them as they were originally photographed. The gallery recontextualizes the Game Boy Camera from a quirky peripheral to a unique art medium in its own right, while still maintaining the “funtography” attitude that Nintendo intended when making the camera.

HACKED FROM HUMBLE BEGINNINGS

Twenty-six years ago, Nintendo released the Game Boy Camera — an unusual accessory for the Game Boy. It fits into the console like any other cartridge, but with an additional swiveling spherical camera lens sticking out on top. At the time it was the world's smallest digital camera — and with its 180-degree swivel, one of the first selfie cameras, too.

The specs are about as high-definition as you might expect for 1998: monochromatic, 4-tone, 0.01-megapixel photos, of which the memory holds just 30 at a time. The memory limit wouldn't be a massive issue, but unfortunately there was no way to get the photos off the cartridge except





Cat Graffiam

Mod squad: (clockwise from top left) Original Game Boy Camera cartridge, PicNRec video capture cartridge, Game Boy console with camera modified to accept powerful lenses, and the author's playable Game Boy Camera Gallery cartridge, plugged into the GBxCart RW read/write adapter.

by printing them out onto receipt paper using the Game Boy Printer that was sold alongside it.

At least, that was until today's passionate modding community got their hands on it. Folks have created read/write adapters that make it easy to transfer photos off the camera as bitmap image files, such as the GBxCart RW by insideGadgets (insidegadgets.com/gbxcart-rw) or GB Operator by Epilogue (epilogue.co/product/gb-operator). And they've developed countless mods, like a mount to attach full-sized camera lenses onto the cartridge, allowing you to literally photograph outer space! Or the ability to record videos with accessories like the PicNRec cartridge by insideGadgets. Or to fit the entire camera into a typical Game Boy cartridge, including the lens — but that of course sacrifices the all-important ability to take a selfie. This is just the tip of the iceberg of astounding custom software and hardware people have developed around this simple toy camera, and most of it is open source and meant to be shared with other enthusiasts.

CURATING AND CODING MY FIRST GAME

To source the photos for the gallery, I posted an open call to the GB Camera Club, celebrating

the work of those keeping the camera alive and expanding its capabilities. I knew it was imperative that the showcase be playable on an actual Game Boy, and I wanted to make physical cartridges so folks could view the photos the way they were intended to be seen: on the hardware, not just in a web browser or emulator.

The only problem was that I had never actually made a game before and knew next to nothing about doing it. Luckily there is a beginner-friendly game engine for creating Game Boy games called GB Studio, with its own passionate community and useful resources like GB Studio Central.

Even though this was my first attempt at developing a game, it wasn't my first exploration into the world of modded consoles (handheldlegend.com/collections/game-boy-dmg-accessories) and homebrew software. As an insufferable hipster teen I would buy Game Boys from thrift stores mostly just to look cool (it didn't work), but this blossomed into a genuine love for **chiptunes** — music created on Game Boys with audio modifications [see "Game Boy Pro-Sound Mod," page 34]. Joining the community of Game Boy Camera enthusiasts gave me the same excitement I felt for chiptunes a decade ago. I'm



Cartridge readers and flash carts allow transfer of Game Boy Camera photos via microSD or USB, instead of having to print them onto receipt paper!

continually intrigued by how far such extremely limited technology of the past can be taken with present-day creativity.

To create the game, first I needed to learn how to make pixel art, which despite my experience as an oil painter I found challenging due to the limitations of Game Boy hardware. The Game Boy parses visual information in a grid of 8x8-pixel tiles, and can only load a certain number of unique tiles at one time. If you go above that limit, the game crashes. Retro games have so many repeated visuals because reusing tiles doesn't count toward the limit.

I initially set out to just create a very basic slideshow of photos for the Game Boy Camera Gallery, but as I learned more and fell in love with the process, the gallery quickly snowballed into a lighthearted virtual "museum" space that players could explore, full of quirky characters and Easter eggs to discover.

LET'S GET PHYSICAL

Once I had made something that was actually playable, I needed to find a way to get the ROM onto a physical cartridge. There are a few indie publishers for Game Boy games, like Incube8



Physical cartridges of *Game Boy Camera Gallery 2022*, assembled and ready to ship.

(incube8games.com), that handle the creation of physical releases, but I opted to go the self-publishing route in order to have complete control over the production. Thankfully, insideGadgets manufactures custom Game Boy cartridge PCBs in bulk and on demand (shop.insidegadgets.com/product/custom-gameboy-flash-cart). ROMs can then be put on those cartridge PCBs using the same InsideGadgets GBxCart RW device that I use to extract Game Boy Camera photos.

Separately, I purchased clear cartridge shells and had stickers printed for the labels. For the packaging, I found a company that sold blank clamshell cases for Game Boy cartridges. The printed cover, generously designed by another community member, D4nger, slid into the shell's outer sleeve and brought the packaging of the game all together.

I was shocked at the positive response. The game was played almost 10,000 times in the first few months on itch.io and sold about 200 physical copies. Fulfilling those orders, however, entailed flashing each cartridge with the ROM file, screwing the PCB into a cartridge shell, applying the label, testing the cartridge, inserting the cover into the clamshell sleeve, and finally snapping the

cartridge into the case. This assembly may sound simple, but doing it all 200 times by hand was incredibly time consuming, though it was a labor of love.

NEW GALLERY: A MYSTERY SHOW

I intend to create a new virtual gallery of Game Boy Camera photos annually, but instead of just reusing the game visuals, I see it as a chance to reimagine the experience around a specific theme. For the newest iteration, I asked that submissions evoke the nebulous feeling of “mystery.” I believe the camera itself is mysterious because it has a unique ability to abstract our world into the almost unrecognizable. With its simplicity and limitations, it can create a different reality than our eyes see, at the intersection of gaming and art. It’s unlike any other camera, and that’s why it is still so beloved after 26 years.

Unfortunately, I was thrown off course by the discovery of a large, rare kind of tumor inside my spinal cord that required intensive surgery to remove. The supportive community generously donated an itch.io bundle which raised enough money to pay my medical bills, but it wasn’t until I was approached by *Make:* magazine to write this piece that I was inspired to finally finish the game.

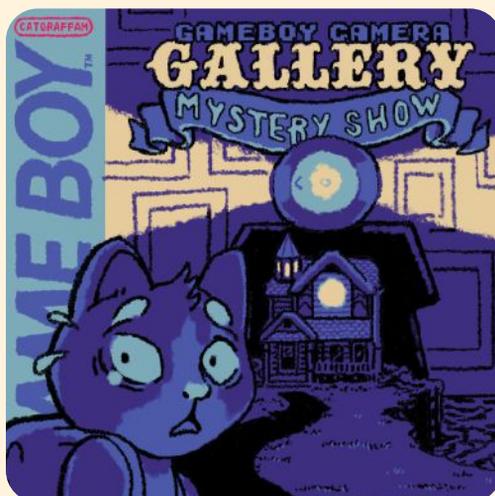
In *Game Boy Camera Gallery: Mystery Show*, there is more narrative to carry you through the exhibition.

You play as an anthropomorphized cat who is covering the opening of the exhibit for the local art magazine — but you were not prepared for the show to be located inside a haunted Victorian mansion owned by a suspicious raccoon. As you explore the mansion, you can see over two dozen photos taken on the Game Boy Camera by artists from around the world, and get to the bottom of the unexpected events that unfold, presented as a point-and-click-style game (scratchingpost.itch.io/gbcg2023).

When approaching the creation of this game, I felt the setting and gameplay should coincide with the theme and contain a degree of mystery too. I grew up playing 90s edutainment point-and-click series like *I Spy* and *ClueFinders* (both with



what IS this place?



8-BIT VISIONS

A curated selection of Game Boy Camera photography from the *Game Boy Camera Gallery* project



Untitled
by Xukkorz



The Eye of the Artist
by GBcameroid



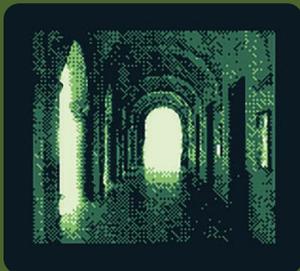
Portal
by Jake Pink



Glitchy Dog
by Chris Graves



Twister
by Cat Graffam



Hallway Into Light
by Oretal



Crowrupted
by Zoë Wolfe



Sadako in the Kitchen
by Raphaël Boichot

their own titles set in mansions) on the shared family computer, and fell in love with exploring the environments and discovering hidden secrets from one scene to the next. For the Game Boy there are only a handful of point-and-click games, and only one that successfully captured the feeling of mystery: *Scooby-Doo: Classic Creep Capers* for the Game Boy Color. I still own the cartridge to this day! *Scooby-Doo* became a primary inspiration for the Game Boy Camera Gallery: *Mystery Show*. It wasn't until I began trying to create a point-and-click game that I realized just how impressive the functionality of *Scooby-Doo* was for the system.

Jumping off from that foundation, I attempted to make the gallery feel fresh and unique. I took the visuals a step further to include large avatars over text and detailed background art. The soundtrack created by Sloopygoop and the cover art by Polyducks enhance the world inside the game and elevate the experience. Though I wasn't able to include every function I envisioned, the unconventional format will give players a unique gaming experience for the Game Boy. I couldn't have done it without the Game Boy Camera community and the support of friends and the talented artists included. It takes a village to make projects like this special. 🗝

PRO-SOUND MOD

Dive into Chiptune and the Game Boy modding scene with this easy first mod!

WRITTEN AND PHOTOGRAPHED BY NIKOLA WHALLON



“WHAT IS CHIPTUNE?”

- Cool documentary about the chip scene: reformattheplanet.vhx.tv
- Inverse Phase’s talk on chiptune history: youtu.be/_TBOQXCvp4
- Academic article on chiptune history: journal.transformativeworks.org/index.php/twc/article/view/96/94



NIKOLA WHALLON is a chiptune and VGM musician, ex-physicist, AI engineer, and amateur game dev. He loves exploring the intersection of creativity and technology both old and new!

The Game Boy modding scene has seen decades of development, and continues to evolve even as we celebrate the 35th anniversary of the original Game Boy release in 1989. While many certainly do cherish using modded or unmodded Game Boys to enjoy a vast library of classic games, the scene has been fueled largely by a different use: music-makers utilizing the Game Boy's audio chip to create **chiptune** music.

"What is chiptune?" The question itself has become a meme in the community because there are so many different takes! One definition is music that uses or emulates sounds from the audio chips of old computer hardware — music made with Game Boys certainly fits these criteria!

Probably the most popular way to make music with a Game Boy is to use music-making software directly on the Game Boy itself (as opposed to using special software on a modern computer to create files that can be exported to a format that old hardware can play). A few prominent programs have been written to make music directly on the Game Boy, with the most popular probably being **Little Sound DJ** (aka **LSDJ**), a music tracker, and **nanoloop**, a sequencer.

Because the Game Boy is so portable and can be used with headphones, using these programs on the device itself is a compelling way to make music on the go, but for most recording studio and live sound situations, it's much better to use the line-out audio signal coming more directly from the sound chip, before the headphone amplification circuit. Modifications that do this are referred to in the scene as "pro-sound" mods, and there are many variations.

THE PRO-SOUND MOD

Let's dive into the pro-sound mod, as it is arguably both the most important mod for chiptune and the simplest mod to do! While this mod can be performed on many models of Game Boys, we will stick to the original model, or **DMG** (from "Dot Matrix Game," Nintendo's code name during development), as it has arguably the best audio quality among Game Boy models (and among DMGs, those with later board revisions produce the best audio signal — see sidebar link). Variations of this guide by other authors exist

PRO-SOUND MOD RESOURCES

- **Game Boy Types:** moddingfridays.bleu255.com/Game_Boy_Types
- **Pro Sound by Michael Television:** ohmnohmnohm.com/wiki/ohmnohmnohm-chiptune-wiki/modifications/nintendo/gameboy-dmg/pro-sound
- **Joe Bleeps' complete guide to DMG stereo line out mods:** youtu.be/j2xoeR_nPfo

online, as blog posts, forum posts, and YouTube videos, so if you get stuck, or require a different perspective, there are plenty of resources to get you through!

A soldering iron, solder, and Phillips-head screwdriver are all tools of the trade for modders. Additionally, a tri-wing screwdriver is needed for most Game Boys as Nintendo famously uses this less common screw type to prevent repairing/tampering.

There are two main ways to perform the pro-sound mod. One way will have you cutting some current connections to your DMG's audio jack and making new ones — this is referred to as an "internal pro-sound mod." The other way will have you drilling a small hole in your DMG's case to mount a new audio jack to wire up — this is referred to as an "external pro-sound mod." Which one you choose is up to you. Both will be covered here.

If you decide to do an external pro-sound mod, you could look to obtain the audio jack and wire separately, however there are many Game Boy modding retailers that sell kits you can use as well, which I recommend! Sites like store.kitsch-bent.com, retromodding.com, and handheldlegend.com are good places to start, and they often sell the tri-wing screwdrivers you will need to open the DMG.

I'll also mention here that you can use types of audio jacks other than 1/8" stereo jacks. Using two separate RCA jacks is also common, and I have even seen a Game Boy modded with a stereo 1/4" jack — it must have been hard to make the space for this in the shell! This guide will only go over the 1/8" jack.

1. DISASSEMBLE THE DMG

Remove any cartridges and batteries you may have in your original Game Boy (DMG), as well as the battery cover. Next, unscrew the six screws on the back of the DMG holding the two halves of the shell together; two of these screws will be in the battery compartment (Figure A). If you have a very old DMG revision, the screws may be Phillips-heads, but most DMGs will have tri-wing screws holding the shell together.

Once the two halves of the shell are separated, carefully and gently tug at the ribbon cable attaching the front-board to the back-board (Figure B). Set the front-board aside for now.

2. PREPARE THE AUDIO JACK

For the Internal Pro-Sound Mod:

Cut the two leftmost wires attaching the main board to the small board where the DMG's audio jack is mounted (Figure C). That's it!

For the External Pro-Sound Mod:

To install a new audio jack, we will need to find space in the DMG where it will fit. Some Game Boy modding retailers sell new DMG shells which are bigger and have more room to add internal components, but there is usually just enough room for a 1/8" audio jack in the lower left corner of the front-case. However, we have to do one trick first.

Remove the two screws fastening the small board with the DMG's audio jack, then remove that board, and carefully bend the two capacitors at the end around so that they fit snugly between the board and the shell (Figure D). Re-attach the board to the shell with the screws. This will create the space we need to install the new audio jack.

Now, in the lower left corner of the front-case, drill a hole just big enough for the new audio jack to mount. You will almost certainly want to remove the front-board from the shell here so as to not damage it; simply unscrew all the screws, pop it out, and put it back together after you've made your hole.

Finally, mount your new 1/8" audio jack in the hole on the front-case, and verify that it will fit in the space you freed up from bending those capacitors by carefully sandwiching the two cases back together. This part of the process is much

TIME REQUIRED: 1–2 Hours

DIFFICULTY: Easy

COST: \$60–\$75

Game Boy: \$50 (highly variable price)
Wire: \$10
Audio jack: \$1–\$5
Tri-wing screwdriver: \$10
Total: \$75

MATERIALS

- » **Wire, 28 gauge** (though anything around that will do), at least 3 wires, 6" long
- » **1/8" stereo audio jack, panel mount (optional)** for the external Pro-Sound Mod
- » **Solder**

TOOLS

- » **Phillips screwdriver**
- » **Tri-wing screwdriver**
- » **Soldering iron**
- » **Drill (optional)**

more involved than it is for the internal pro-sound mod, however you will end up with a DMG that has both a line-out audio signal and an amplified signal perfect for headphones!

3. WIRE UP THE AUDIO JACK

For the internal pro-sound mod, locate the pins on the DMG's audio jack corresponding to the left (L) audio signal and the right (R) audio signal using Figure C. For the external pro-sound mod, locate the L, R, and ground pins on your new audio jack. We will use the wire, solder, and soldering iron to connect these to pins on the DMG's main board.

There are two sets of three pins that we can connect the jack to — “post-pot” or “pre-pot.” Refer to Figure C to help locate these. The pins that are “post-pot” carry the audio signal after it has passed through the volume wheel (a potentiometer, or “pot”). Connecting to the “pre-pot” pins will pass through the audio signal at full volume, before it has passed through the volume wheel. Which you choose to use is up to you, but I tend to recommend going with the pre-pot pins, as you can always adjust volume in a studio or live sound setting using a mixer, and because the volume wheels on DMGs are susceptible to degradation over time.

Once you've made your decision, solder your

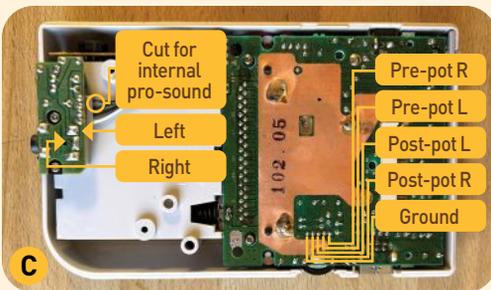


A



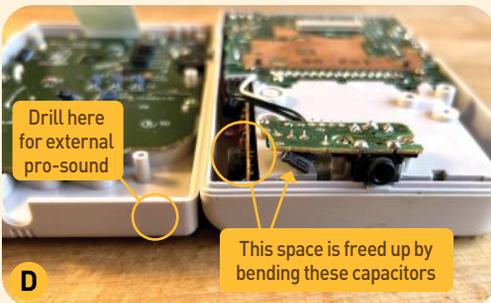
B

Be careful when removing the ribbon cable connecting the DMG front- and back-boards.



C

The back-board of a DMG with the wires and pins relevant to pro-sound mods highlighted.



D

The most common location to mount an audio jack for the external pro-sound mod.



E

wires connecting the L and R pins of the audio jack to the pre- or post-pot L and R pins. If performing the external pro-sound mod, also wire up the ground pins. I like to use white wire for L, red for R, and black for ground, to follow some audio convention, but it doesn't really matter. Make sure you use enough wire that you can still move the front- and back-boards/shells relatively freely, but not so much that it will be difficult to sandwich the two shells back together at the end of the day.

4. REASSEMBLE

We are essentially done with the mod and have to put the Game Boy back together now (Figure E). Carefully re-insert the ribbon cable connecting the front-board and back-board, and slowly sandwich the boards/shells back in place, paying extra attention to the new wires you installed (you can use electrical tape to help with the wire routing if the wires are making it tricky to close up the Game Boy). Screw in the six screws you took out in Step 1, put your batteries back in, jam in a cartridge, boot up the Game Boy, and test out the new jack with headphones, speakers, a mixer, or an audio interface, as you please!

CHIPTUNE TIME!

Hopefully this was a reasonable introduction to the world of Game Boy modding in its relation to chiptune music. The next step for fully utilizing the pro-sound mod is to write some chiptunes! I highly recommend the following to get started:

- DEFENSE MECHANISM's YouTube channel: [youtube.com/@DEFENSEMECHANISM](https://www.youtube.com/@DEFENSEMECHANISM)
- Chipmusic.org forums: chipmusic.org/forums

There are many wonderful and cool mods that weren't mentioned here, including backlighting mods, LED mods, pitch-shift mods, and mods that chiptuners perform on other consoles to enhance their music-making (and/or gaming) activities. For those interested in learning more about Game Boy modding, I highly recommend checking out the following resources:

- retromodding.com/blogs/tutorials
- wiki.handheldlegend.com

as well as various forums, Instructables, and Reddit subs like [r/gameboymods!](https://www.reddit.com/r/gameboymods/)

"VINYL" RECORDS

The art of recording direct
to polycarbonate discs

WRITTEN BY DANIEL BUNTING



As a high school senior, I used to be under the impression that vinyl was an outdated medium for audio. But a few years ago I discovered that it was actually quite an amazing format. Almost extinct for new music for 45 years, vinyl has made an enormous comeback as of late. In 2020, more vinyl records than CDs were sold for the first time since the 1980s. And it's not simply for the sound either; surveys suggest that over 25 percent of vinyl purchasers do not own a turntable. People want to hold and feel albums, read liner notes, collect, *and* listen to them. Creating records has become its own art form.

I got into collecting and listening to vinyl records first. I like to listen, but I also had the urge to make vinyl records. The idea of making custom records, whether that be a private mixtape record or a small batch for a local band, was appealing but most people told me it couldn't be done.

TRADITIONAL PRESSED RECORDS

The traditional way of producing records is a pressing plant with massive machines. In pressing plants, records start out as a master disc cut by an engineer with a machine known as a **record lathe** using a soft acetate blank. The master is then metallized, first as a negative and then a positive to create a metal stamper. A hot blob of vinyl is pressed between two stampers (and paper labels) to create a record.

Pressing machines use high temperatures, along with steam and hydraulic pressure that aren't feasible for a do-it-yourselfer. And while this process is very efficient, it requires a high minimum order and can be subject to extremely long turnaround times, making it less than ideal for small artists.

RECORD LATHES

Lathes that cut Hi-Fi masters are huge and extremely complicated machines that have not been manufactured since the 1980s and can cost over \$100,000. However, there is another class of record lathes that were used for general recording before audio tape was available. These professional-grade lathes were used from the 1920s until the early 1970s to record just about anything on acetate discs for later playback. Live



events, advertisements, and official proceedings could be recorded on "transcription" discs up to 16 inches in diameter for later playback or archiving. Almost every radio station had at least one recording lathe, as did many courts, governments, and businesses.

Using refurbished and modified lathes of this kind, a dedicated community of makers has developed the process and technology to make lathe-cut records. These lathes emboss or cut directly onto hard plastic discs, one at a time. There's no minimum-quantity production, and each copy benefits from more attention. The process is more art than manufacturing.

FINDING A LATHE

So, I went hunting to find a lathe, which was a lot more difficult than I thought. Although these machines were in widespread use for 60 years, they became essentially obsolete after audio tape recording became prevalent. It was easier, cheaper, faster, and more convenient to record on tape rather than big, expensive, fragile discs. Plus, you could reuse audio tape.

As a result, most of these machines were junked long before anyone had a notion to reuse them. Today it is very rare to find an intact machine or even the parts necessary to rebuild one.

After searching long and hard, I got lucky and found one through an online ad about 100 miles from my home. This machine was a portable Rek-O-Kut (Figure A) from the 1950s. After a



DANIEL BUNTING is an 18-year-old DIYer from Albany, California, who came to his first Maker Faire Bay Area in 2013 and brought his Razy Records project to Maker Faire Bay Area 2024.

He specializes in the art forms of records and audio.



thorough cleaning, oiling, and adjusting, just about everything on it worked. As I took the lathe apart, I found a “Property of the Los Angeles Court System” label on the inside, which made me wonder how it was used.

I then spent a three-day weekend learning the ins and outs of these machines with Mike Dixon in Arizona. Mike sells record lathes, parts, and supplies, including the must-have sapphire stylus needed to put grooves in tough polycarbonate plastic — far more durable than the old acetates. He is also a great guy and helps newbies get started. At the same time, I got a more capable Presto record lathe (from the 40s or 50s) that Mike had restored (Figure B).

THE RECORD CUTTING PROCESS

After a large amount of trial and error (hundreds and hundreds of test cuts), I optimized my repeatable process to make high quality lathe-cut records (Figure C). Here’s how it goes:

• DISCS

I get the best results from polycarbonate. There are a variety of colors, shapes, and thicknesses available. Transparent blanks can be used to create cool picture discs. The blank discs need to be properly cleaned, treated with anti-static fluid, heated to around 110°F, and lubricated for best results (Figure D shows me checking the temperature). I cut 7” squares out of full sheets of polycarbonate and buy pre-machined round discs in various sizes.

• CUTTING HEAD

The cutter head (Figure E) contains a needle called a *stylus* that vibrates back and forth with the music signal by a wire-wound magnetic



armature. It works similarly to a speaker moving a paper cone. While you can use carbide or tungsten styluses, I get the best results with the sapphire gems custom cut into a cone shape. These are expensive and easy to damage, and they do wear down with each record cut. I use a jeweler’s loupe to examine the stylus tip to see if it needs to be rotated or replaced.

It’s important to adjust the cutting head to the proper cutting weight and angle. This took a lot of trial and error and is different on each lathe. We are technically not “cutting” grooves but “embossing” — that is, making a groove without removing material from the disc.

“Cutting” requires a much more advanced setup and a much more expensive cutter head and diamond needle — but it can produce somewhat better audio quality and supports stereo.



Jeffrey Bunting

• SIGNAL PROCESSING

We are only able to make monophonic records with this process, which actually isn't as big of a difference as it might sound when it comes to vinyl. I use audio editing programs to mix stereo signals down to mono, equalize levels, and remove any non-audible parts of the signal that could cause problems. I also use this software to apply the all-important **inverse RIAA curve** (see sidebar) to the signal so the records can be played back on any turntable. I'm also working on building a mastering circuit to apply the curve in real time so I can record live sources.

• SPEED AND GROOVE SPACING

Most lathes allow recording at different speeds (33, 45, and 78 RPM) and at different LPI (lines per inch). Changing the LPI involves physically changing a feed screw in the lathe with the different LPI pitch. The higher the recording speed, the higher the quality but shorter the recording time. The higher the LPI, the longer the recording time but lower the recording volume level. I also have an anti-static ionization fan pointed at the disc as it cuts, to help reduce noise from static electricity.

• LEAD-IN, LOCKS, AND TRACK SEPARATORS

When you play an album, there is almost always a **lead-in groove** to help show where to lower the turntable playback stylus. To reproduce this on a lathe-cut record, you need the first few seconds of the groove to be widely separated to make it easy to see where the groove starts. You do this manually on the lathe by turning a small wheel on the feed screw before the music starts.

Similarly, you can see the different tracks on an album because there's a gap — a few widely spaced rotations that separate the end of one song from the start of the next. Again, you do this manually by turning that wheel — so you better pay attention and not miss the end of the song!

Pressed records also have a **lock groove**. This keeps the playback stylus from skipping

THE RIAA EQUALIZATION CURVE



It turns out that in making grooves in records, there are some physical properties that should be considered. Low-frequency signals, for example, make a wider groove and thus require fewer lines per inch on the recording. This means less music can be recorded on the disc. Clicks, pops, and other noise inherent to the recording process are usually high-frequency and can be annoying on playback.

Manufacturers of recording systems realized that by de-emphasizing low frequencies and over-emphasizing higher frequencies on recording, and then reversing the process on playback, they could get more recording time on a disc with higher quality. Unfortunately, each manufacturer created their own frequency standards and at one point there were over 100 different, non-compatible systems on the market.

In the 1950s, the Recording Industry Association of America (RIAA) created a standard frequency curve that all manufacturers eventually adopted. This allowed any record recorded on any lathe to be played back on any turntable, a huge boon to the industry.

Most receivers and amplifiers built before the demise of vinyl have an input jack labeled PHONO which has an RIAA curve decoder built in. If you were to play a record through an AUX jack (that uses the same RCA connector), it would sound tinny. Many turntables sold today have a built-in RIAA curve decoder. You can also buy a record pre-amp with a built-in decoder for hooking up to modern equipment that lacks a PHONO jack.

When recording on a lathe, it is vital that the RIAA curve (actually the inverse curve) be applied to the mastered recording. The easiest way to do this is by using an audio editor while mastering the music. I'm also working on an analog box that will apply the curve in real time to allow me to make recordings of live performances.

RETRO ZONE: Cutting DIY Records

across the label at the end of the music; instead, the stylus stays in an infinite loop in the special lock groove. This is a bit trickier to reproduce. Once the final song is complete, you turn that wheel on the feed screw a few times to give a visible **lead-out groove** and then flip a lever to stop the linear motion of the cutter head for one full revolution. Once that revolution is complete, you pull up the cutter head to complete the lock groove.

As you can see, this isn't a set-it-and-forget-it technology. It is very hands-on.

• AMPLIFICATION

I use high-power modern amplifiers for the cutting heads. Too much power can burn out the windings in the heads and lead to a very expensive and time-consuming rebuild. Excess power can also cause skipping on playback. Too little power and playback volume will be low and noisy. Again, lots of trial and error to find the right levels. Fortunately, I only saw the magic smoke once and shut things down before it was too late. Having a fast-blow fuse in line to protect the cutting head is not optional!

TESTING AND PACKAGING

I test each and every record on both a "really good" turntable and a "really bad" cheap turntable to make sure the results sound good and the players track properly. After testing, I apply a stick-on, printed custom label.

Each project may have different packaging. Some people just want transparent 7" squares with one song. Some want picture discs. Some want handmade covers with graphics. I've become pretty handy at printing, cutting, and gluing cardstock to make covers.

MAINTENANCE

These machines are older than my parents but the build quality is amazing. Both of my machines have the original high-torque synchronous motors and both are accurate to within 1% of proper rotational speed.

Each lathe has multiple mechanisms like the one that holds the cutting head and moves it over the spinning record linearly to cut the



F



G

Jeffrey Bunting

groove. Since these are completely mechanical, you need to get good with tightening, adjusting, oiling, and cleaning. Even the motors in these babies need oil!

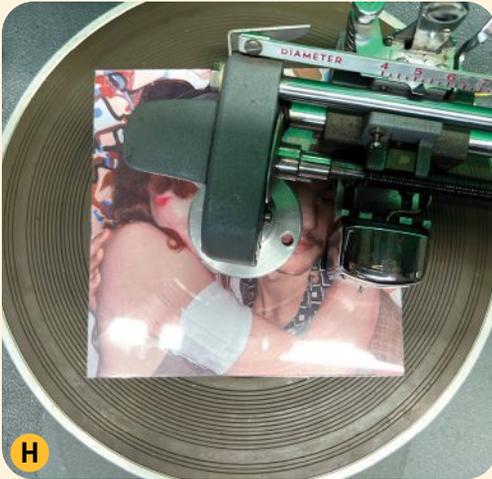
REPAIR

Even though these lathes are nearly bulletproof, things can break. The results can be just irritating or tragic. The manufacturers of these lathes have been out of business for many decades and spare parts are, in many cases, unobtainium.

While transporting the Presto lathe from Maker Faire Bay Area last October (Figures F and G), I managed to break the lead screw mount. It is impossible to find a replacement and the lathe would be unusable without it. Fortunately, my uncle is an amateur machinist and was able to make me a replacement!

PUTTING IT ALL TOGETHER

When you have everything right — a good stylus, the correct cutting head weight and angle, a proper cutting temperature, a well-



Daniel Bunting

mastered source signal, and the right speed and LPI — you can produce, in real-time, a record with surprising audio fidelity. The results have probably 85%–90% of the fidelity of a pressed vinyl record and most casual listeners are not able to tell the difference.

Getting all of this process down, I was able to start my company, Razy Records (razyrecords.com), while still in high school. I create one-off records for people for all occasions. I also cut short runs (10–100) of 7" records for bands and musicians to sell to their fans. I'm currently gearing up to do a multi-disc box set of 12" albums for a local musician.

POPULAR VARIANTS

Here are some of the variations that you can play with as an art form:

- **Clear square records** are the least expensive option, and they have a uniqueness factor because most people have never seen them before. Other record shapes include stars.
- **Traditional round records** in a variety of colors. These are a bit more expensive since the blanks need to be machined into circles instead of simply cut into squares.
- **"Picture discs"** are clear records where one side has a picture stuck to it that shows through the transparent side (Figure **H**). This is preferable to a traditional picture disc where the image is pressed into the disc itself, which usually doesn't sound very good.
- **Wedding favors** typically are a picture disc of the couple that has their favorite song.

- **A hybrid CD/record** is one where we cut grooves into a CD and end up with a few minutes of analog and 20 minutes of CD music. It will play on a turntable *and* a CD player.

I have made many interesting projects. One client did a picture disc of him and his Dad with their favorite song. For one of my teachers, I cut a rap mixtape his brother did as a teenager.

I'm very glad I got into this hobby, as I finally have a creative outlet. I am one of a select group of people who can do this art form. As I am on the autism spectrum, I'm really glad to have found a craft to focus on and produce great results. It is my hope that I can make my livelihood bringing new life to people's music. 🎧

SOMETHING OLD, SOMETHING NEW

A brand new community hacks the NABU

WRITTEN AND PHOTOGRAPHED BY BRIAN JOHNSON

Everything old is new again. It's not every day you see an entirely new community spring up around a retro PC almost overnight, but that is exactly what happened with the NABU (Natural Access to Bi-directional Utilities) PC. The NABU is unique and interesting because instead of loading its software from cartridges, tapes, or even floppies, it used an external adapter to download the software over a cable TV connection and then transfer it onto the computer via RS-422.

Little more than a year ago, the NABU was

a relatively unknown Canadian Z80-based computer from the 1980s. Its rebirth started in late November of 2022 when well-known retro computer YouTuber Adrian Black made a video about the system and mentioned that there was a large collection of them being sold new-in-box on eBay. James Pellegrini, the seller, had originally purchased them during NABU's bankruptcy in the late 1980s for a project that never came to fruition, and they had been sitting in storage ever since.

With the sudden introduction of a couple of thousand relatively inexpensive new-old-stock



BRIAN JOHNSON

is a software engineer from Ann Arbor, Michigan, with a passion for retro computers. In addition to his contributions to the NABU community, he has designed and created hardware expansion cards for the Epson QX-10 computer.



NABUs into the market, it was not long before roboticist/hacker DJ Sures (see *Make: Volumes 27 and 55*) started reverse-engineering the RS-422 protocol to create a network adapter emulator, documenting his progress on YouTube (tinyurl.com/nabu-djsures). When DJ asked viewers if anyone had NABU software, former NABU developer Leo Binkowski came forward. He had saved much of the software from his time at NABU and has been able to restore many of the original titles from his collection of floppies. Leo has documented much of his NABU archeology on YouTube as well (tinyurl.com/nabu-leo).

While waiting for my own NABU to arrive, I began work on creating an emulation core in MAME. I believe emulation of retro systems is important, as it allows those who do not possess the physical hardware to still be able to enjoy it and the software that was written for it. In addition, MAME contains a debugger that's quite helpful for those who wish to write software for such systems. I had worked on the Epson QX-10 support in MAME, so I was already familiar with the framework. That experience plus existing schematics published for the NABU meant that I was able to have a fairly complete and working emulator by the middle of December 2022.

Due to a lack of schematics for the keyboard, the original keyboard implementation was done using high-level emulation (emulating just the serial protocol). Later in 2023, while tracing out the keyboard's schematics in order to properly emulate it under MAME, I made the interesting discovery that the NABU actually supported paddles, not just in hardware, but in firmware as well. The NABU uses the standard 9-pin Atari controller port, and the two paddle pins of each port are attached to an ADC on the keyboard.

Despite the fact that the NABU was clearly designed to support paddle controllers, no official paddles or paddle games were ever released for it. In order to test paddle support on the NABU, I ended up writing a basic version of *Pong*, which works with hardware-modified Atari paddles. In doing so, I also discovered a firmware bug in the keyboard that caused the second paddle not to work as intended. I was ultimately able to patch the keyboard firmware to fix this issue, allowing proper two-paddle support on the NABU.



Paddle support unlocked! *Arkanoid* (top) and *Pong* (bottom) running on the 1982-vintage NABU.

In an interesting quirk of fate, the NABU uses the same CPU, video, and sound hardware found in the MSX1 computers. This makes it relatively easy to allow a 32k MSX ROM to run under the NABU environment, especially if the MSX ROM uses the MSX's BIOS calls instead of direct hardware access. There have been several conversions or ports done of MSX software titles including an excellent port of *Lode Runner*, updated to include all the Apple II levels. I have also done a few conversions myself of some of my favorite titles, including *River Raid*, *Arkanoid* (with paddle support), and *Choplifter*.

As of today, there is a large and thriving community of NABU owners. Many software and hardware projects now exist for this retro system that was until a few years ago simply an obscure, 40-some-year-old, Canadian computer. 🎮

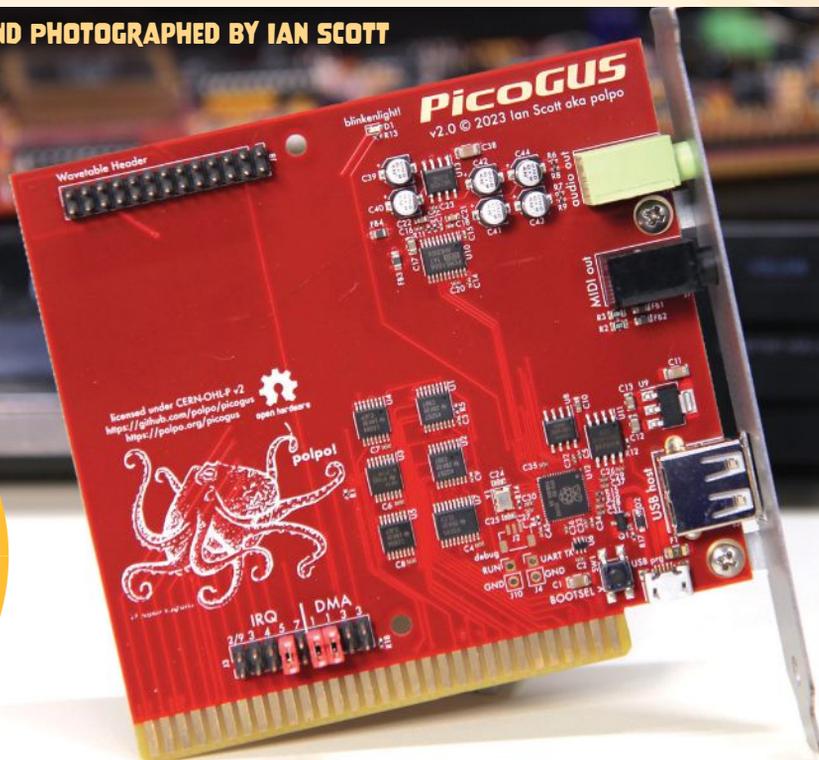
Further information and documentation can be found at nabu.ca or nabunetwork.com. Or join our Discord community at discord.gg/NgxTXvND2A.



DEMOCRATIZING THE DEMOSCENE

PicoGUS brings the 90s tracker sound to the masses

WRITTEN AND PHOTOGRAPHED BY IAN SCOTT



IAN SCOTT is a longtime tinkerer, maker, and generalist software developer with a day job in the robotics space. At night he lives the dream of making retro

hardware more usable and accessible through open-source hardware and software.

Sometimes an offhand comment can start you down the path of making something you hadn't thought possible. For me, it was a lamentation by the DJ and coder Hoffman on Twitch about the Gravis Ultrasound, an old PC sound card with a cult following that's now eye-

wateringly expensive. In that moment, a half-remembered old social media post by hardware hacker Foone Turing entered my mind: that it'd be cool to interface a retro PC's bus with a Raspberry Pi's GPIO pins.

Huh, I thought. What if you could use a Raspberry Pi to emulate the Gravis Ultrasound in a PC?

There's lots of open-source code for that card out there in PC emulators like DOSBox already, so it might actually be possible! I believe that the retrocomputing hobby needs to be more accessible to people and that high prices on interesting cards keep them out, so I felt like

something needed to be done about it. I hadn't made anything nearly as complex before, but the seeds were planted long before that moment.

BETTER THAN A BLASTER

A computer's ability to make music and sound has always been the most interesting thing to me. When I was a kid in the early 90s, I convinced my parents to get a Sound Blaster card, and learned it could do more than add sound effects and music to games. It came with a demo of a program called Tetra Composer that played music that was far more advanced-sounding than anything I'd heard before: a full-length song with "real" sounds, yet the file was only 40 kilobytes. I knew I had to find more of these files, so I dialed into every BBS in the area and eventually discovered what they were: MOD files, also known as tracker music.

In the days before MP3s, having a source of free, practically unlimited new music was incredible. I realized a simple Sound Blaster wasn't going to cut it if I wanted the best quality music playback and the ability to watch the coolest demos. I'd need a Gravis Ultrasound, also known as the GUS. Getting the GUS (for Christmas!) got me even deeper into the tracker music and demo scenes. Even after I moved on from using those old PCs, I never could bring myself to get rid of my GUS; maybe somehow, I knew it'd remain iconic.

RE-MAKING THE GUS

In 2021, I had stumbled upon my GUS card in a box of old stuff and put together a retro system just to hear it make music again. Now I knew I wanted to emulate the GUS with a Raspberry Pi. I really didn't know what I was doing — I'd dabbled in electronics and once designed a PCB with a friend — but I decided to just dive in.

Early DOS PCs took expansion cards based on the Industry Standard Architecture (ISA) bus, and it's pretty well documented; after I determined the signals that I thought I needed, I dove in on designing a prototype PCB. I called my first version "very dumb prototype" and immortalized that in the board's silkscreen printing, along with the name PiGUS (Figure A). Of course, this being my first board, I made a lot of mistakes. But when



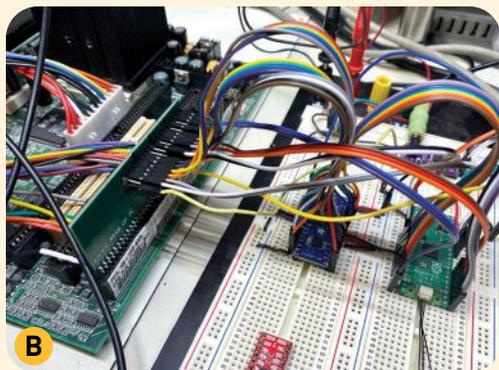
Original Gravis Ultrasound card (top) and first-gen PiGUS emulator (bottom).

I finally plugged the board in, nothing exploded, so I was good to proceed on trying to get sound out of it.

I found another open-source Pi-to-ISA project, eigenco's RPiISA, that had successfully implemented AdLib sound card emulation, so I adapted the code and pretty quickly got sound from my prototype board! I started picking apart the GUS emulation code from the DOSBox Staging project, and after about a week, I finally experienced that glorious moment: real, actual music playing from the prototype that I made! The song I chose was one of my favorites from back in the 90s: "Satellite One" by Purple Motion. It's still the first song I use to test new cards or playback routines, since I'm so familiar with how it should sound. (Hear this and other retro-themed tracks at makezine.com/go/retro-playlist/!)

MOVING TO THE PICO

I shared my results on social media and the Vogons forum, where a short comment by the user `rasz_pl` set me off in yet another direction: using the Raspberry Pi Pico. He suggested that a Pico, paired with a certain serial PSRAM chip, could possibly emulate any sound card. At this point in 2022, we were in the depths of the semiconductor component shortage, and Raspberry Pi's single-board computers were extremely hard to come by compared to their plentiful \$4 Pico. The Pico's RP2040 microcontroller also has PIO, an extremely fast and powerful method for interfacing with external devices, which seemed ideal for interfacing with the ISA bus.



B Breadboard prototype of PicoGUS.

Using one of my original prototype PCBs, I broke the connections out from the Raspberry Pi connector to a mess of a breadboard filled with a Pi Pico, multiplexer chips, and an external DAC for audio output (Figure **B**). After a lot of work, I finally had the RP2040's PIO reading and writing data on the ISA bus.

Getting AdLib working was the next logical step, but I ran into an issue: most OPL2 emulation code out there runs too slowly on the RP2040, due to its lack of floating-point hardware. Then I remembered Graham Sanderson's amazing feat of running *Doom* on the Pico, performing incredible optimizations, including massively speeding up the code of an OPL2 emulator. Graham's open-source audio code ran with no issues on the Pico when combined with my bus interfacing code, and amazingly, I had AdLib sound playing on a Pico!

Encouraged by this success, I designed the first PicoGUS PCB in a hurry (Figure **C**). That meant I made a lot of mistakes, and getting my AdLib code working again was a major challenge. After a modicum of precision "bodge" work, I was able to get the DOSBox Staging emulator to start to make GUS music, but I ran into two stumbling blocks. First, the emulator was too slow to play more than 8 voices at one time — far short of the GUS's 32 — and second, the RP2040 only has 264kB of RAM, while the GUS needs a full megabyte for the samples alone. The DOSBox Staging emulator has quite a bit of floating-point math, but fortunately I found the GUS code in the related DOSBox-X emulator didn't, so I hacked it in and got it performing great with lots of voices.



C The first PicoGUS PCB. It works — after some bodge wiring fixes.

On to the next issue: the sample RAM. Using the suggested serial SPI PSRAM chip at the speed the GUS demands was a major challenge. It required very close reading of the chip's datasheet and writing of a custom PIO program to speak SPI slightly differently from the RP2040's built-in SPI interface. This took about a month.

DEMOCRATIZING HARD-TO-FIND TECHNOLOGY

There are many other rare sound cards for retro PCs out there, and PicoGUS has the potential to emulate a lot of them. In an early hardware revision, I added a MIDI port to drive an external synthesizer module. Many DOS games had amazing MIDI soundtracks composed for Roland modules like the MT-32 and SC-55, and the earliest ones required a genuine Roland MPU-401 MIDI interface with "intelligent mode." As per usual, original units sell for big money, and even the clones and hardware emulators are not cheap. PicoGUS could easily emulate the Roland MPU-401 by using open-source code, so I was able to add that too.

I also had the original AdLib sound card support from my first experiments, so the PicoGUS was starting to become an emulator for multiple cards. Supporting several other early PC sound standards like the Creative Music System and the 3-voice audio on the IBM PCjr and Tandy 1000 was possible on the PicoGUS, so I added those as well. A generous contribution of code for the sound chips in those systems was made by emulator developer Aaron Giles.



The assembled PicoGUS v2.0 is available on Tindie.

MASS PRODUCED AND DIY VERSIONS

As I finalized the public release of the PicoGUS hardware, I aimed to use parts with high availability and low cost, and tried to avoid adding features that raised the cost unless they were really necessary. All of this was with the ultimate goal of creating a board that was relatively simple to make, low cost, and easy to use.

Once I started building these cards by hand, I realized I wanted to make a new version that could be mass produced. This ended up as PicoGUS v2.0: an all-in-one card that could be 100% assembled by low-cost PCB assembly services (Figure **D**). You can purchase it at tindie.com/products/polpo/picogus.

I also want to keep supporting the maker community that wants to make their own boards, so I “backported” a lot of the improvements from v2.0 to a DIY-friendly revision of my v1 board (Figure **E**). You’ll find the build guide at github.com/polpo/picogus.

NEW PORTABLE POWERS!



Kevin Moonlight’s **Pi Pico PCMCIA** takes the PIO paradigm on the road, jamming the whole computing kitchen sink into a PC card, including NE2000-compatible wireless networking, serial modem, and Sound Blaster-compatible audio over Bluetooth. Follow his progress at yyzkevin.com.

RETRO FUTURE

For a first major hardware maker project, PicoGUS has been way more successful than I ever could have imagined. Being able to leverage the hard work people have put into open source accelerated my progress incredibly, and it’s exciting to see what people are doing with the work I’ve contributed back to the open retro hardware community. It’s been an incredibly gratifying experience. 🙌



This article has been condensed for print. Read the full version online at makezine.com/go/PicoGUS.



PicoGUS v1.1 for DIY builders (right) adopts many improvements from v2.0, including MIDI — while correcting the body bits of v1.0 (left).



KEITH HAMMOND

is editor-in-chief of *Make:* and grew up gaming in video arcades and on first-gen consoles and computers from Atari and Apple.

DIY RETRO ARCADE!

Build an arcade cabinet to play all your favorite old games — from full-size to micro

WRITTEN BY KEITH HAMMOND

The most popular retro gaming project? Gotta be the DIY arcade console — an all-in-one gamer's paradise that can replicate hundreds of vintage video games from stand-up arcade machines, home consoles, and PC titles from the 2000s back to 8-bit classics of the 1970s and 80s.

Most makers start with a **Raspberry Pi** mini computer running **RetroPie** emulation software. Built atop a full Linux OS and arcade interfaces EmulationStation and RetroArch, plus lots of open source emulators, RetroPie runs on Pi 4 and earlier models, and can reproduce 50+ vintage consoles and PCs from Atari, Nintendo, Sega, Sony, Apple, Commodore, and many more. Just add vintage controllers or a keyboard. Popular

alternative arcade OSes include **Recalbox** and its offshoot **Batocera** — good for beginners.

(Note that the new Pi 5 can emulate 5th- and 6th-gen consoles like Wii, GBA, and Dreamcast. RetroPie hasn't caught up yet, but you can install separate emulators; K.G. Orphanides wrote a great guide at magpi.raspberrypi.com/issues/138/pdf/download.)

Arcade games work differently than console emulation, so choose your **arcade-specific emulator** (MAME or FinalBurn), then download **ROM files** of your desired games. Get started with the tutorial at retropie.org.uk/docs/Arcade.

To build a real arcade machine, get an **arcade controller board** like Pimoroni's Picade

X Hat or Adafruit's Arcade Bonnet (both with 3W amp for a speaker), or PetRockBlock's ControlBoard or Ultimarc's I-PAC (without). Then plug in your heavy-duty **arcade buttons and analog joysticks**. Try Adafruit, Pimoroni, Ultimarc, and The Geek Pub, or Amazon stores EasyGet and EG Starts.

Here are some favorite DIY arcade builds, from full-size Pi machines to tiny Arduino kits.

FULL SIZE VERTICAL

1 EASY ARCADE CABINET

by University of Idaho Tech Club

[instructables.com/Easy-Cab-arcade](https://www.instructables.com/Easy-Cab-arcade)

Straightforward and serviceable, this 2-player stand-up cabinet has a hidden keyboard/mouse drawer for those PC games too. Dimension drawings are provided, and the edges are even finished with arcade-accurate plastic T-molding.

2 RETRO ARCADE CABINET

by Bob Clagett

[iliketomakestuff.com/arcade-cabinet](https://www.iliketomakestuff.com/arcade-cabinet)

With today's tiny electronics and flat screens, a full-size cabinet is mostly empty space. YouTube legend Bob Clagett took full advantage and designed this one with hidden storage shelves and drawers, plus extras like light-up marquee, vinyl graphics, and a proximity sensor and Arduino to drive automatic RGB LED lighting. It's inspirational and super well documented, and he'll sell you his plans for \$22.

BARTOP

3 2-PLAYER BARTOP ARCADE MACHINE

by Tom Rolfe

[instructables.com/2-Player-Bartop-Arcade-Machine-Powered-by-Pi](https://www.instructables.com/2-Player-Bartop-Arcade-Machine-Powered-by-Pi)

More than 150 people have shared their builds of this popular DIY cabinet with 19" screen. Designer Tom Rolfe provides parts list, dimension drawings, printable templates, even a list of other helpful arcade tutorials. A great place to start.

4 PICADE KIT by Pimoroni

[pimoroni.com/picade](https://www.pimoroni.com/picade)

Beautiful 1-player bartop kit includes cabinet and 10" display, buttons, joystick, and Picade X Hat controller that stacks onto your Pi 4.





MINI

5 GALAGINO by Till Harbaum

github.com/harbaum/galagino

This clever DIY project has ported *Pac-Man*, *Galaga*, and *Donkey Kong* to run on an inexpensive ESP32 microcontroller and 2.8" color TFT LCD display (320×240); contributors have added *Dig Dug* and *Frogger* too. Grab the vectors for a laser cut cabinet at the GitHub repo, or try John Bradnam's 3D-printed version at hackster.io/john-bradnam/galagino-esp32-arcade-355dde.

6 CUPCADE REV 3 by Adafruit

adafruit.com/product/1783

This cute RetroPie-based kit comes with literally everything but the Pi. You get a cool mini joystick and mini arcade buttons, Arcade Bonnet board, laser-cut cabinet panels, and a nice 2.8" color PiTFT Plus touchscreen (320×240) to mirror the Pi's HDMI output. It's a full retro gaming system in a very small package, supported by Adafruit's excellent build instructions and tutorials.

MICRO

7 MICROCADE by Jack Daly

playmicrocade.com

A brilliant kit made entirely of PCB! You solder the 0.96" monochrome OLED display (128×64), speaker, and LED to the main board, then snap off the PCB panels to assemble your micro arcade machine, based on an 8-bit Microchip ATmega32U4. Enjoy 30+ games from the Arduboy and Pokkito communities, including *Choplifter* — wow I used to load that off a cassette drive in 1983! — and online tutorials for coding your own.

8 TINY ARCADE by Tiny Circuits

tinycircuits.com/products/tinyarcade

This no-solder kit gives you a playable palm-sized vertical machine, with 32-bit Microchip ATSAM21G18A and 0.96" color OLED (96×64). It's not an emulator but an open source platform where makers develop games in Arduino. There's a great tutorial and dozens of free games including analogs of *Asteroids*, *Space Invaders*, and *Flappy Bird*. And it's the tiniest we've seen! 🎮

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generate



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Luxembourg



May 19-20, 2024
Hudson Valley



May 23-25, 2024
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May 25-26, 2024
Sarajevo



June 1, 2024
Ostrava



June 1, 2024
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Maker Faire Yukon: Whitehorse, Yukon, Canada July 27

Maker Faire Wayne County: Wooster, OH, United States July 27

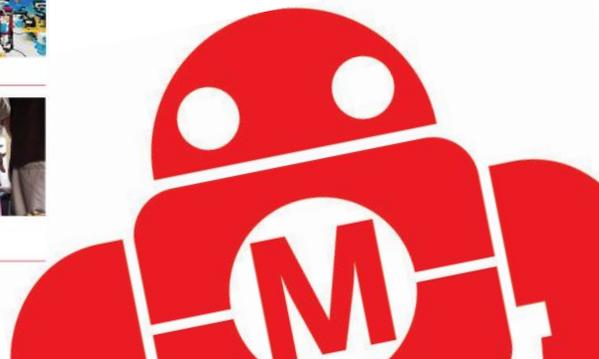
Maker Faire Hannover: Hannover, Germany August 17-18

Maker Faire Trieste: Trieste, Italy August 31-September 1

Maker Faire Schwedt-Uckermark: Schwedt/Oder, Germany September 7

Maker Faire České Budějovice: České Budějovice, Czech Republic September 14

Maker Faire Bay Area: Mare Island, Vallejo, CA, United States October 18-20



DIY Camera Lucida

Written and photographed by Pablo Garcia



Build the optical gadget that lets you draw accurately by tracing from real life



PABLO GARCIA is associate professor at the School of the Art Institute of Chicago where he researches the history of drawing technologies. Since 2013, he

has manufactured the NeoLucida, a modern camera lucida (neolucida.com). He loves to draw, and wants to encourage more people to enjoy putting pencil to paper.

Have you ever tried to draw what's in front of you in real life, but struggled to capture it? There's a secret gadget that's long been used by artists to draw from life. It's called the *camera lucida* and you can build one in an afternoon.

The camera lucida is an optical drawing aid that lets you trace what you see. This simple device uses a beam-splitting prism on a telescoping arm clamped to your drawing board. When you look down into the prism, you see a ghost image of the world in front of you floating over your paper. You can also see your hand, so you are able to trace directly from real life (Figure A). For amateurs and beginners, this device offers a less frustrating way to capture your subject accurately. For professional artists and scientists, it allows new levels of precision in drawing from life.

THE BIRTH AND REBIRTH OF THE CAMERA LUCIDA

Invented in 1807 by chemist William Hyde Wollaston, the camera lucida was immediately popular with artists, architects, scientists, and engineers. In its heyday, the device helped draw archeological sites from Central America to Pompeii. Professional and amateur artists rendered views from Egypt to the Americas. Scientists accurately drew specimens, and illustrators made scaled reproductions of drawings and paintings. It was, for more than half of the 19th century, the state-of-the-art imaging technology of the age. One that I, centuries later, still find fascinating.

Yet, despite its profound impact on art, design, and science, the camera lucida's life was cut short. Paradoxically, its use by one aspiring artist led to its demise.

On his honeymoon along Lake Como's idyllic shores, an English scientist decided to commemorate the trip by capturing the picturesque Italian landscape. It's 1833, so the only way to record his view was to draw or paint it. He was an amateur and, in his own words, not particularly skilled in the visual arts. On the advice of a friend, he took up the camera lucida and started to draw.

Our amateur artist thought this device was beautiful but lamented his poor drawing skills. He recounted that he was making sketches "but

TIME REQUIRED: 3–4 Hours

DIFFICULTY: Easy–Intermediate

COST: \$65–\$85

MATERIALS

- » **Hardboard, ¼" thick, 18"×18"** aka high-density fiberboard (HDF), such as Masonite. You can also use wood or MDF.
- » **Adjustable arm for cameras with table clamp** such as Amazon B08D3H7BJ9, \$30
- » **Smartphone holder with ¼-20 thread mount** for camera tripods and adjustable camera arms. I use Amazon B01L3B5PBI, \$8.
- » **Glass mirror, 3"×3"** such as Amazon B01H2KCB8O, \$12. This is an ordinary back-silvered mirror. It comes in a pack of ten, but you only need one.
- » **Teleprompter glass, cut to 3"×4¼"**
Go to twaymirrors.com/teleprompter-mirror, scroll down to "Order a Sample," and select the 4"×4" 40R/60T 2mm thickness (\$10). They list it as 4"×4", but the piece I received was 6"×6".
- » **Strong wood glue**

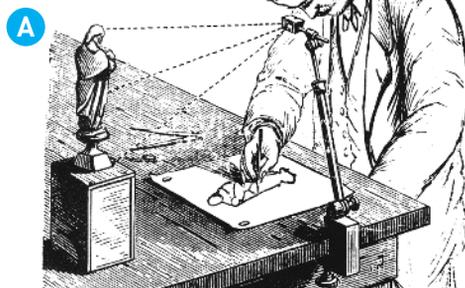
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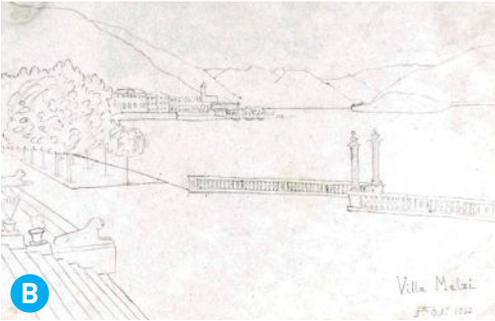
- » **Spray paint, matte black** I used Rust-Oleum Ultra Matte Black.
- » **Polycarbonate sheet, 0.030" gauge, tinted grey** not opaque
- » **Small alligator clip** such as Amazon B00JMYCZ12

TOOLS

- » **Table saw, band saw, or hand saw**
- » **Drill and drill bits**
- » **Sander or sanding block** with sandpaper
- » **Glass cutter**
- » **Eye protection** for cutting wood and glass
- » **Heavy gloves** for cutting glass
- » **Straightedge and clamps (optional)** helpful for cutting glass

The camera lucida in operation. From *Scientific American Supplement* no. 158, January 11, 1879. Collection of the author.





William Henry Fox Talbot, camera lucida drawing of Lake Como from the Villa Melzi, 1833. Image courtesy UK Science Museum Group Collection

with the smallest amount of success. For when the eye was removed from the prism — in which all looked beautiful — [he] found that the faithless pencil had only left traces on the paper melancholy to behold” (Figure B). He continued, “After various fruitless attempts, I laid aside the instrument and came to the conclusion, that its use required a previous knowledge of drawing, which unfortunately I did not possess.”

Vexed, he became philosophical. His frustration with the camera lucida, and the camera obscura before it, “led me to reflect on the inimitable beauty of the pictures of nature’s painting which the glass lens of the camera throws upon the paper in its focus; fairy pictures, creations of a moment, and destined as rapidly to fade away.” His musings quickly turned to practical solutions: “How charming it would be if it were possible to cause these natural images to imprint themselves durably, and remain fixed upon the paper!”

For the next ten years, he did just that. That amateur artist was William Henry Fox Talbot, and his frustration with the popular optical drawing tool inspired him to invent photography.

Photography changed the world. Images instantly “fixed to paper” superseded laborious — and lower-fidelity — representation in pencil. The camera lucida was still useful in the commercial illustration industry but was no longer valued in a modern art world less concerned with accurate renditions of real life (Figures C and D).

I first heard of the camera lucida when British artist David Hockney published *Secret Knowledge: Rediscovering the Techniques of the Old Masters* in 2000. By then, the world had mostly forgotten the camera lucida. Hockney and physicist Charles M.



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- Copy of commercial art
- Outline letters, hand-drawn letters
- Copy photos, other pictures, sketches, etc.
- Copy designs, blueprints, diagrams, etc. for study, work, teaching, for handbooks, etc.

FREE 10-DAY TRIAL COUPON!

NORTON PRODUCTS, Dept. FAC-9
298 Broadway, New York 7, N. Y.

Stick my “Magic Art Reproducer” this FREE 10-day trial and I will pay someone no delivery order \$1.98 plus postage. I don't want to be bothered that I can draw anything like an artist, so I am returning merchandise after 10-day trial and not my money back.

Name: _____
Address: _____
City & Zone: _____ State: _____

Check here if you wish to save postage by sending this to me with money. (Some States Block Government)

The ignoble decline of the camera lucida, from precision art instrument to plastic toy. Figure C: 1838 brochure for the Charles Chevalier camera lucida. Figure D: Norton Products’ “Magic Art Reproducer,” advertised in pulp magazines and comic books, 1950s–1980s.

Falco revisited optical technologies used since the Renaissance, arguing that these tools should not be shamed but lauded. From mirrors to lenses to prisms, artists have always been innovators and early adopters of new technologies.



I was caught off guard by pushback from artists and historians who decried Hockney’s claims as tantamount to calling master painters “cheaters.” The Hockney-Falco thesis celebrates the avant-garde attitude of artists across the centuries. I hadn’t heard of the camera lucida before Hockney wrote about it, so I bought one on eBay in 2004 and started drawing, mostly to amuse myself.

Nearly a decade later, I was talking about Hockney with fellow art professor Golan Levin. We wondered if it was possible to share the Hockney-Falco thesis with students in a practical way. Could we make an inexpensive camera lucida for more people to try? Our modest goal in 2013 was to use the crowdfunding site Kickstarter to make 500 new camera lucidas — the NeoLucida (Figure E). After raising nearly \$430,000, we made 15,000 of them, and a new conversation about old technology went viral. As demand grew, I went on to make new NeoLucidas: the NeoLucida XL in 2017 and the NeoLucida Plus in 2023. Ten years on, the project is still about a simple goal: share an obsolete art technology to help people draw. And maybe, just maybe, more people will welcome technology into art, even if it’s just a simple prism on a stick.

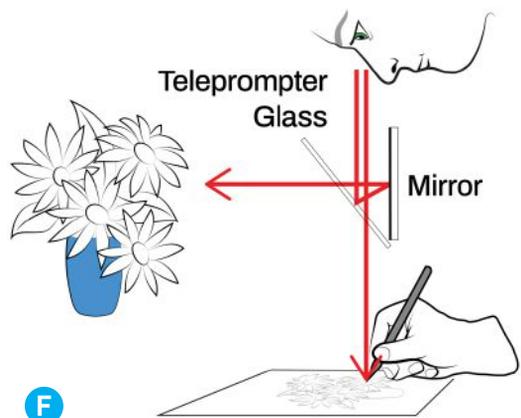
You can buy a NeoLucida at neolucida.com, but since I want to make this technology accessible to everyone, here’s how you can make your own camera lucida, using a mirror instead of a prism. It’s an easy project for those with basic wood-shop tools such as a saw, sander, and drill. Some simple glass cutting is also required.

HOW IT WORKS

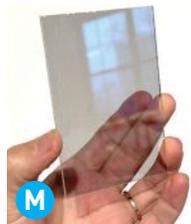
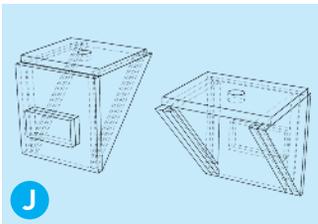
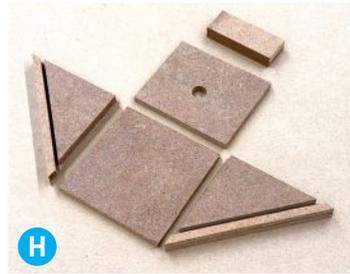
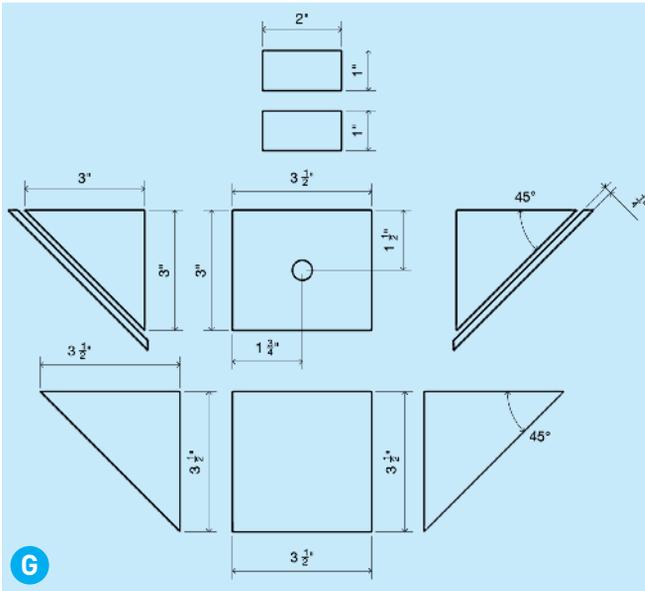
The simplest camera lucida uses a mirror and a partially silvered piece of glass. When a vertical mirror is behind a 45° angled piece of glass, and

you look down between the glass and mirror, you see a ghosted image of the area facing the eyepiece. And because your vision is reflected twice, first in the silvered glass and then in the vertical mirror, your ghost image is both correct from left to right and right-side up.

Plain glass transmits around 95% of light. This is good for transparency, but to get a visible ghost image, you will need partially silvered glass to transmit between 60–70% of light and reflect 30–40%. This balance allows you to see through the optical system to your hand while still reflecting enough to see the ghost image of your scene. If the glass is too clear, it will be hard to see your subject; if it’s too reflective, it will be hard to see your hand. For this build, we will use a piece of teleprompter glass, which uses a glass coating to achieve a good balance between transparency and reflection. When paired with a mirror, this optical assembly will give you a sharp ghost image to trace. The basic arrangement is shown in Figure F.



How the mirror-based camera lucida works.



BUILD YOUR DIY CAMERA LUCIDA

1. CUT THE HARDBOARD PIECES

Use the dimension drawing (Figure G) to cut your Masonite pieces (Figure H). This will be your camera lucida eyepiece that will hold the mirror and glass. This can be cut by hand, or you can use a laser cutter to make these pieces.

Drill a 1/2"-diameter hole centered on the top piece as shown.

2. GLUE THE EYEPIECE

Use wood glue to assemble the eyepiece. First glue the side pieces together to make the grooves to hold the mirror and glass pieces (Figure I).

Following the diagram (Figure J), glue the side pieces to the rear piece. Ensure that you leave the grooves for the glass and mirror clear of excess glue.

Glue the top piece to the eyepiece assembly making sure you leave room at the front and rear to fit the glass piece and mirror (Figure K).

Finally, glue the two rectangular Masonite

pieces together, then glue them to the rear of the eyepiece (Figure L). This will be a ledge for the smartphone holder to grab and secure the eyepiece to the adjustable arm.

3. PAINT (OPTIONAL)

Spray the whole assembly matte black. While this is not required, it will help reduce glare inside the eyepiece.

4. CUT GLASS

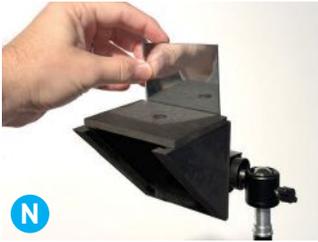
Using a glass cutter, cut your partially silvered mirror — the teleprompter glass — to 3"x4 1/4" (Figure M).

5. INSERT MIRROR AND GLASS

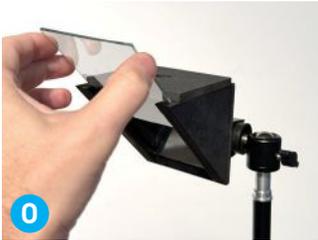
Insert the ordinary 3"x3" mirror into the rear vertical slot (Figure N). Insert the teleprompter glass into the front angled slot (Figure O).

6. CONNECT THE ADJUSTABLE ARM

Thread your smartphone holder to the adjustable



N



O



P



Q

arm and clamp the arm to a table. Clamp the eyepiece to the smartphone holder as shown. The mirror will be vertical, and the teleprompter glass will be in front, facing your subject (Figure P).

READY SET DRAW!

You are now ready to draw! Look down into the eyehole to see your paper below and a ghost image of your subject (Figure O). Trace the world just as you see it.

ADDING AN OPTIONAL SHADER

The lighting of your subject is probably different from the lighting on your paper, and this can vary the visibility of your hand or your subject. For better lighting control, use a shader.

To make a simple shader, you can arrange a piece of tinted polycarbonate plastic held by an alligator clip to shade either your paper (Figures R and S) or your view of the subject (Figures T and U). ✓



R



S



T



U

Using a shader with your camera lucida. Figures R and S: Use a shader below if you have trouble seeing your subject. The paper is likely too bright and overpowering the ghost image of your subject. Figures T and U: Use a shader in front if you have trouble seeing your paper. If the subject is in very bright light, the paper will be hard to see.



Watch Pablo demonstrate the use of the camera lucida with Norm Chan on *Tested*:
youtube.com/watch?v=R_p9z-tRzCs



Lucida 3D

Print a truly portable, stand-alone camera lucida for drawing anywhere

Written by Chris Borge



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

It was a pleasant winter afternoon when YouTube served me a decade-old ad for a Kickstarter. The pitch was so clear that I was instantly enthralled — not something I think an ad has ever done for me before — as it described a camera lucida, a prism of shining glass that I am still not entirely convinced isn't magic. On page 54 of this issue you can find a detailed history and description of the camera lucida by Pablo Garcia, the creator of the very advertisement that had caught my interest.

The product looked good but I had the bank account of a student and was far more interested in making my own. Looking online I found that DIY versions were actually simple to make if you ditched the prism and instead used a piece of mirror and special glass. I set out to design one for 3D printing.

If all you want is a simple camera lucida to print and mess around with (Figure A), then I have a set of files that will do just that for you (printables.com/model/695381). But I was keen to tackle a problem that hadn't been really solved by any DIY or commercial option out there, and that was making it portable — truly portable in a way that requires nothing to use apart from a notebook, pencil, and the device. Basic camera lucidas are easy to move, but you still need

something like a table to clamp them to.

My reasoning for this is that I'm an avid hiker, and being able to use a camera lucida like the explorers of old was an appealing thought. With this in mind, my design goals were simple. It needed to be:

- able to be used anywhere, when set down beside the user
- compact and lightweight enough to be unobtrusive in small bags
- made without any uncommon tools (lathes, mills, etc.)

The result, which I call Lucida 3D, looks rather complex but the design came around easily. It's a combination of several existing lucida designs, taking the telescoping arm from antiquity, the ability to fold afforded by mirror-and-glass designs, and my own new input of using the case as a stand. I'm surprised I never saw it done before. There's a reasonable amount of non-printed hardware, including nuts, bolts, a back scratcher, the optical components, and optionally some felt or foam. Aside from a 3D printer, you'll need a glass cutter, hacksaw, and drill. A laser cutter is nice for the felt but you can use a knife.

Looking closer at the design the first thing you see is the case, which features a symbol depicting the optical arrangement of the camera lucida (Figure B). Opening the case, you see all the parts needed to set up, clean, and use the camera lucida. Taking the optical element out, it latches into shape (Figure C). The telescoping arm is extended and the optics affixed (Figure D). This can then be positioned over a drawing surface and used. Because the case is the stand, it can be used anywhere (Figure E).

The case also includes a frame to use as a neutral density (ND) filter. I use cellophane here, but more ideal would be a stiff tinted plastic or car window tint. This is to counter having too much light on your paper which will blow out the image. This can be addressed by lighting your subject more, using non-glossy paper, shading your paper or lighting it less, or by using the shade filter.

With the design made, the story came full circle. While making my video on the design, I thought rather than regurgitate information off the internet, it would be much more engaging to reach out to an



expert to interview. So I emailed Pablo, whose ad I had been served just weeks prior, and showed him my creation. I was unsure if he would agree, given that I was releasing a free version of a product he sells, but he was happy to help, and very pleasant to interview.

You can make the Lucida 3D yourself, and watch the video, at printables.com/model/526409.



Cat Tracking with ChirpStack

Build a GPS pet tracker that maps location via your own LoRa network

Written by Luna the Cat with Bryan Serinese



BRYAN SERINESE aka Back Scratcher works as a software project manager during the day, and at night channels all the horror of Luna's reign of terror into his forthcoming *Zombie Musical*.

Recon Log 4269L: *The mice are organizing. I believe they have formed an alliance with the crows and other flying vermin to take down the cell towers. Fortunately, the hairballs back at HQ set up a backup communications network to track my reconnaissance missions. I don't need those nannies looking over my shoulder when I'm out in the field, but I do like to show off how deep into enemy territory I patrol. The hairballs say the recon teams from other sectors complain about my off-the-books operations on their turf. As if I care. It's probably that traitorous tabby in Sector 6. I see that useless carpet dweller inside his bunker while I'm out keeping the world safe. Let them all track my work on their computers; it'll still be too late for the mice. I am Luna. I am legend.*

I've been assigned to patrol Sector 4 of my suburban neighborhood. I live in rural Vermont where few people fence in their yards. This gives me free range to hunt where I please, and where regulations say I'm not supposed to go. Every once in a while the top brass receives Bigfoot-blurry photos of me in Sectors far on the other side of the neighborhood. The neighbors claim I scare the other cats and stalk their bird feeders — as if anyone else is feeding on those birds but me. So, to continue to be allowed to perform my missions, I reluctantly let Back Scratcher from HQ outfit me with a tracking device.

Originally BS wanted to buy a GPS module with a cellular connection, but he balked at the monthly data fees. He decided to build out a LoRaWAN wireless network and transmit my GPS coordinates to a web page to share with all the Sectors, presumably so the fraidy-cats can go hide in their litter boxes when I'm close by.

BS enlisted the help of our neighbor, a master network troubleshooter and fabricator of canine gear named Pete, or Pet Fixer as I call him. (I gave him that call sign not just due to his technical skills, but after he brought back his Canine Slobber Unit as a eunuch from the vet. The mutt deserved it.) Currently there are only two gateway nodes on the network, but since it is open source and the gateways are built on Raspberry Pis, they plan on extending the network to other Sectors.

Here's what the hairballs did.

Photographs by Maeve Serinese

TIME REQUIRED: A Weekend

DIFFICULTY: Moderate

COST: \$110–\$145

MATERIALS

- » **Raspberry Pi mini computer(s)** (1 per gateway) Model Zero W, 1B, 1B+, 2B, 3B, 3B+, or 4B, \$25–\$60
- » **WM1302 LoRaWAN Gateway Module(s), SPI** (1 per gateway) Seeed 114992969, \$25
- » **WM1302 Pi Hat(s)** (1 per gateway) Seeed 113100022, \$20
- » **LoRa GPS module** Heltec CubeCell LoRaWAN HTCC-AB02S dev board, \$30
- » **Active GPS antenna** \$10
- » **LiPo battery, 3.7V**

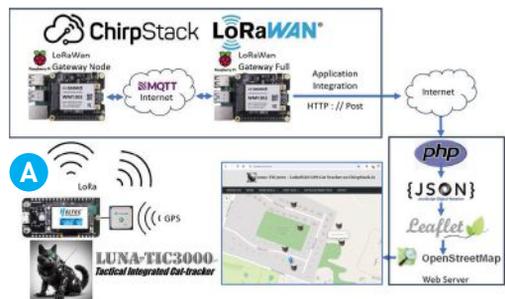
TOOLS

- » **Computer with SD card writer**
- » **3D printer (optional)** for case

1. BUILD THE GATEWAY FOR THE CHIRPSTACK LORAWAN

When PF said they were going to set up ChirpStack, I thought he said “chirp snack” and I was excited for a feathery treat. It turns out ChirpStack is the open-source **LoRaWAN network server (LNS)** he wanted to use instead of relying on cellular to broadcast my position (Figure A). ChirpStack proved to be very user friendly with a web interface for managing gateways, devices, and tenants, as well as data integration setup with major cloud services.

A big benefit of ChirpStack was being able to run it on an older Raspberry Pi he had lying around — it can run on Raspberry Pi Zero W, 1B, 1B+, 2B, 3B, 3B+, or 4B. Additionally, he had to buy a **LoRa gateway** module to run the ChirpStack **concentrator daemon** — basically an API that lets other applications access the gateway's data.



PROJECTS: LoRa GPS Cat Tracker

ChirpStack Concentrator currently supports SX1301/8-, SX1302-, and SX1303-based gateways as well as the SX1280-based 2.4GHz reference-design gateway. PF chose the Wio-WM1302 LoRaWAN Gateway Module (SPI) from Seeed Studios and paired it with the Pi Hat they sell for quick assembly. With the gateway module mounted on the Pi Hat with the included screws, it easily slips onto the Raspberry Pi's 40-pin GPIO header (Figure B). Check out chirpstack.io/docs/chirpstack-concentrator/hardware-support.html for a list of other hardware options.

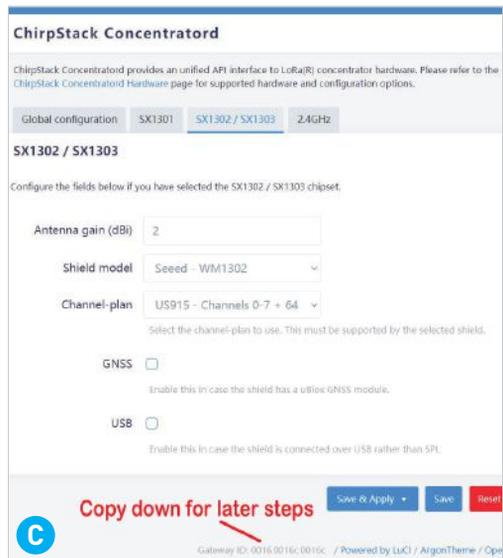
2. CONFIGURE THE GATEWAY

With the gateway hardware set, PF downloaded the ChirpStack Gateway OS from chirpstack.io/docs/chirpstack-gateway-os/install/raspberry-pi.html and burned the image on an SD card for the Pi using Rufus Image burner. The Gateway OS comes in two flavors, Base and Full. Since the plan was to cover as much of my territory as possible, they decided to make one of each: The Pi with the Full OS can be used as both the LNS and a gateway, while the Base OS supports just the gateway. Here's how the rest of the setup goes:

With the SD card inserted, turn on the Pi and add it to your local network in order to access the ChirpStack interface from the internet. Enter the Pi's IP address, found using `ifconfig`, and follow the prompts to change the ChirpStack gateway password. This is highly recommended as our network is constantly under hack attacks, probably by that warren of rabbits with too much time on their feet.

After logging on, configure the unified API interface with the concentrator hardware information by navigating to Concentrator on the left panel. Under the Global Configuration tab, set the Enabled Chipset as SX1302/SX1303 because that's the chipset the Seeed gateway module uses. Now under the SX1302/SX1303 tab, configure the chipset: for Shield Model, select Seeed-WM1302, and for Channel-plan, select US915 Channels 0-7 +64 because that's the channel range that our CubeCell LoRa GPS module (see Step 5) works with in the USA.

In order for the ChirpStack Concentrator to communicate with the network, the MQTT Forwarder also needs to be configured. On the



MQTT Configuration tab of the MQTT Forwarder section, set the Topic prefix with the region (`us915_0` for the U.S.) and then enter the IP address of the Network Server and create a Username and Password.

Finally, in the System section, set the Time Zone in the System → General Settings. Before moving on, make sure to copy down the Gateway ID from the bottom of the page (Figure C) because this is going to be needed during the LoRaWAN Network setup.

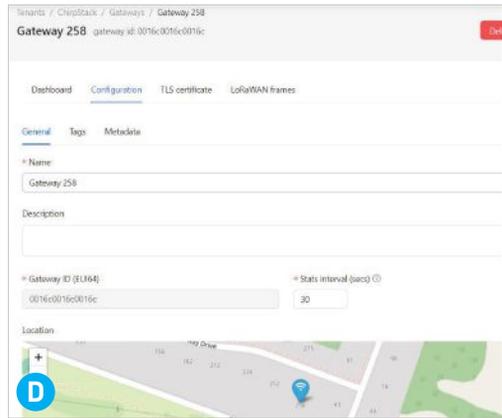
3. CONFIGURE THE LORAWAN NETWORK WITH CHIRPSTACK

With the gateway online, it was time to build out the ChirpStack LoRaWAN network. PF started

by creating Users in the Network Server section and then added that same email as a User in the Tenant section. It is possible to create multiple users, but only one gateway user is necessary.

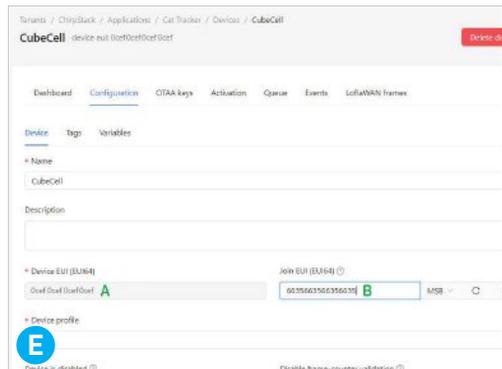
Next, create a Device Profile (we named it DP1) in the General section with values specific to the CubeCell and the local region. Turn on Device supports OTAA and leave the rest to the defaults.

Finally, add the gateways to the network. In the Gateways section, click the Add gateway button. This opens up a form where a Name for each gateway goes. Copy that Gateway ID from the bottom of the Gateway screens into the Gateway ID (EUI64) field (Figure D).

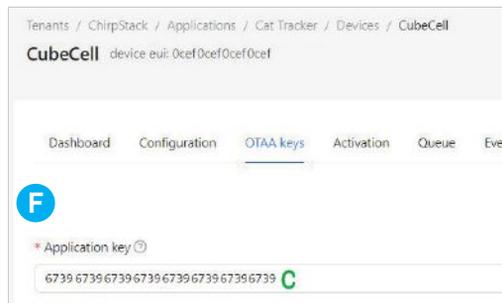


4. INSTALL THE CAT TRACKER APPLICATION

At this point I was grateful to have nine lives because I was bored to death waiting for him to finish. Fortunately, creating the actual Cat Tracker application was the last component that PF needed in order to finalize the ChirpStack LoRaWAN Network. After clicking Add Application and giving it a name, add the CubeCell as a Device (Figure E). Here you'll give it a Name, select DP 1 as the Device Profile, create a Device EUI and then Join EUI by clicking the refresh icon. Copy both of these numbers down because they will need to be added to the Arduino code later.



Next, create an Application key in the OTAA Keys tab by clicking the refresh button and then copy this down for later too (Figure F). The Activation is automatically created, so the Cat Tracker application is now ready to receive data.



In order to do something with the GPS data that comes over the LoRaWAN Network, PF had to create an Integration for the Cat Tracker application. ChirpStack provides several options for extracting the data the network collects and publishing it externally. The easiest route was creating an HTTP Integration and posting the Uplink Event data to a PHP script on the web server that will host the map. The PHP script parses out the latitude, longitude, and timestamp and writes it to a JSON file, which is used in Step 6.

5. ASSEMBLE THE GPS TRACKER

As PF was building out the network, BS constructed my tracking device. In my favorite spy

movie *Octopussy*, James Bond used a tracking device smaller than a mouse head to hunt down his prey. Not the case with my device. BS insisted he bought the smallest all-in-one LoRa/GPS module he could find with the CubeCell LoRaWAN HTCC-AB02S Development Board. The board is only 65mm×30mm, and thin since the header pins aren't needed. It is easily assembled by snapping the included LoRa antenna into the socket on the front side with the LCD screen and then snapping the optional, but recommended, external GPS antenna into the socket on the back

PROJECTS: LoRa GPS Cat Tracker

(Figure G). With the LoRa and GPS antennas plus the battery, it barely fits inside the 3D printed case (Figure H; download the STL files at serinese.com/luna). The case has two slots on the side to attach it on a collar, if you are a British Shorthair or one of those other freakishly large-headed cats. I have a normal-sized head, so they strapped it onto my harness.

6. PROGRAM THE GPS TRACKER

Coding the CubeCell module with the Arduino IDE was easy but there was some setup for BS to do. First, download the board information: in the Arduino IDE, go to Preferences → Additional Boards Manager URLs and add https://github.com/HelTecAutomation/CubeCell-Arduino/releases/download/V1.5.0/package_CubeCell_index.json. Next, go to Tools → Board → Board Manager and install the CubeCell Development Framework. Add the extra Libraries by going to Tools → Manage Libraries and installing *SSD1306wire* and *TinyGPSPlus*.

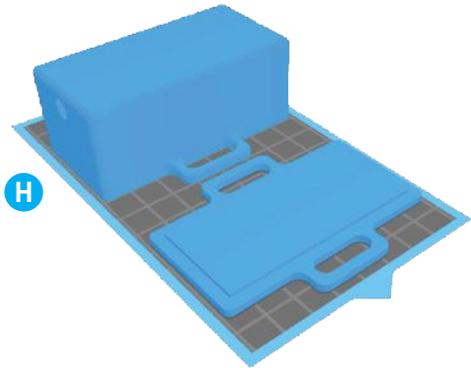
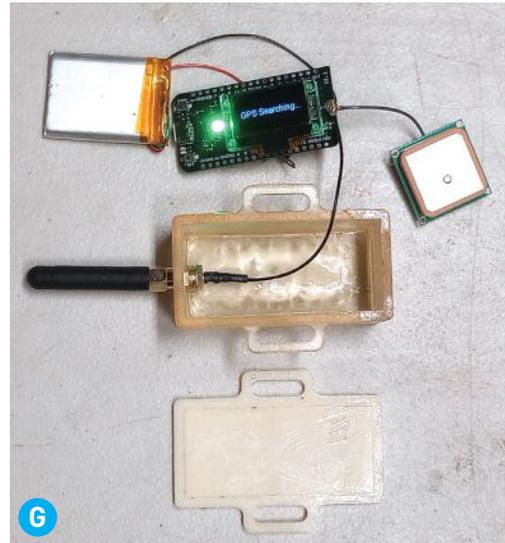
After restarting the Arduino IDE, load the *LoRaWAN_OnBoardGPS_Air530* example sketch that came with the Heltec library by going to File → Examples → Examples from CubeCell → LoRa → LoRaWAN → *LoRaWAN_Sensors*. There are a few tweaks needed to get this sketch to work.

First, set the OTAA parameters in the setup section by entering the values from ChirpStack. Figure I shows how to find the **devEui**, **appKey**, and **appEUI** (JoinEUI) from ChirpStack and their corresponding hex values in the Arduino code.

Next, modify the GPS timeout to wait an hour before turning off (even with the external antenna, the CubeCell took more than the default 2 minutes to find a signal):

```
#define GPS_UPDATE_TIMEOUT 3600000 //  
wait 3600 seconds (1 hour) before  
timing out
```

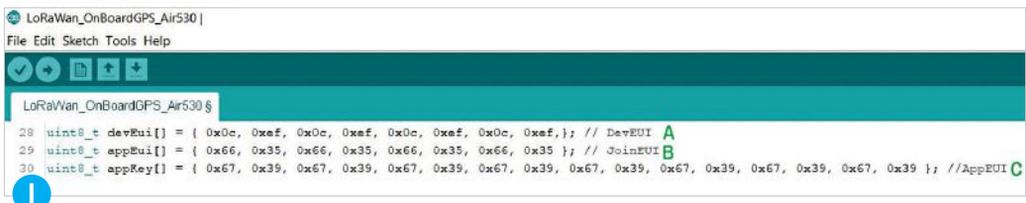
Optionally, adjusting the **appTxDutyCycle** value will change the time in between broadcasts:



```
uint32_t appTxDutyCycle = 300000; //  
wait 300 seconds (5 minutes) between  
broadcasting GPS coordinates
```

Finally, comment out the sleep function. It's buggy, and I certainly don't sleep during my missions so this tracker shouldn't either.

```
case DEVICE_STATE_SLEEP:  
{  
  LoRaWAN.displayAck();  
  // LoRaWAN.sleep();  
  break;  
}
```



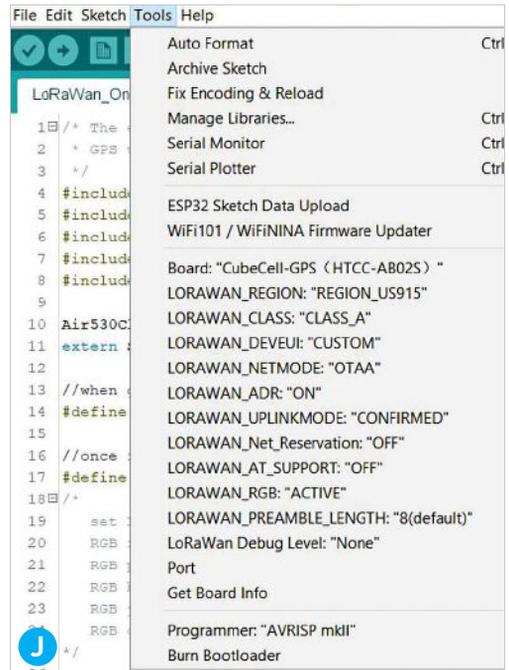
You can tweak these yourself or just grab all our code from serinese.com/gps-lora-cat-tracker.

The last step is to load the code onto the CubeCell. There's some setup work here as well, but the Arduino IDE made it easy. See Figure J for the settings that BS used for our region.

After uploading the code, the LCD screen on the CubeCell showed us that it was working. First it searched and joined the LoRaWAN network and then it searched for the GPS signal. Once it got a lock, it displayed the GPS data on the screen and then sent it to ChirpStack. By leaving the USB cable connected to the CubeCell, BS was able to charge the battery through the board with enough juice to send me on my first mission.

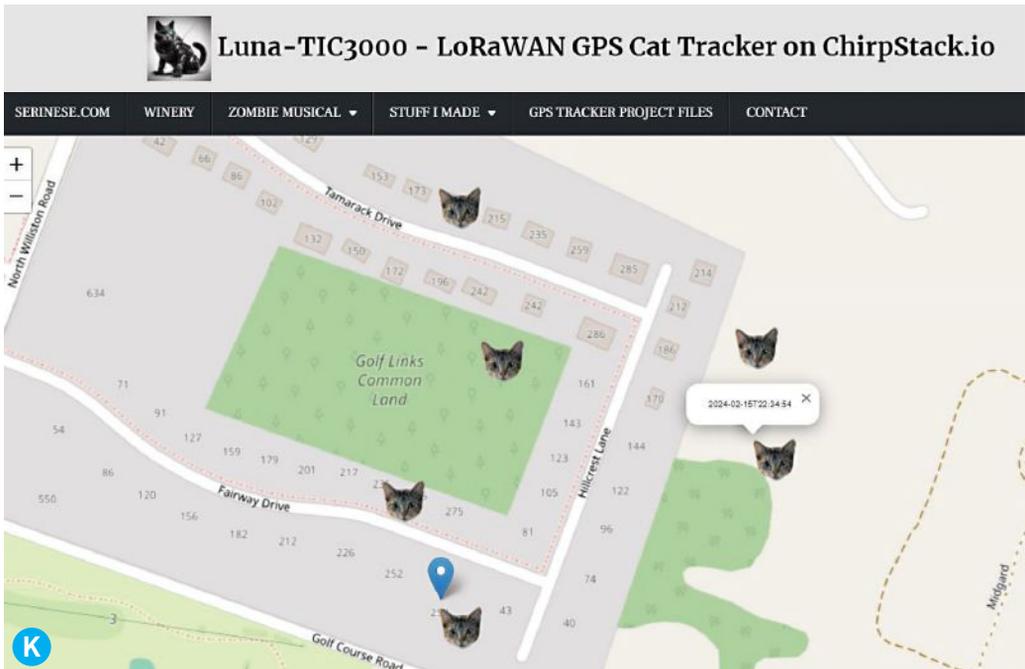
7. BROADCASTING ON THE WEB

With the tracker powered up and the network in place, I was ready to let the world know I was on patrol. Since BS's web skills haven't been updated since the 90s, he enlisted his son Hugo to build out the website that would track my movements around the neighborhood. Scratching Post (my name for Hugo) kept with the open-source motif and used OpenStreetMap and the lightweight JavaScript from Leaflet to serve up my location on a webpage hosted on my website,



serinese.com/luna (Figure K).

First, he created a simple HTML index page to display the OpenStreetMap coordinates of my stomping grounds and set the zoom to 17 by modifying the JavaScript *leafletscript.js* file:





```
const map = L.map('map').setView([44.4  
439, -73.0586], 17);
```

Next, he was able to dynamically add the markers of my movement by using the Uplink packets sent by ChirpStack to the JSON file. He wrote his own JavaScript to extract the **date**, **lat**, and **long** values from the JSON:

```
import locations from './locations.  
json' assert {type: 'json'};  
const points = locations.points;
```

and then passed it to the Leaflet script to be displayed on the map:

```
for (var i = 0; i < points.length; i++) {  
  let marker = new L.marker([points[i].  
latitude, points[i].longitude],{icon:  
greenIcon})  
  .bindPopup(points[i].time)  
  .addTo(map);  
}
```

The custom marker of my face was my idea; just another way of marking my turf without having to empty my bladder. SP just needed a transparent PNG image and this simple code from Leaflet:

```
const CatIcon = L.Icon.extend({
```

```
options: {  
  iconSize: [40, 39],  
  iconAnchor: [0, 0],  
  popupAnchor: [0, 0]  
}  
});
```

```
const greenIcon = new  
CatIcon({iconUrl: 'cat.png'});
```

ENVISIONING LUNA-TIC3000

While I don't mind stalking the woods with the tracker on my back, I did ask the hairballs to see about making a smaller one. There are some smaller boards and GPS modules like the Adafruit Mini GPS PA1010D that should work if they connect it to a LoRa module. BS has his eye on the Loko on CrowdSupply, which is tiny, and future updates will allow it to run on any LoRaWAN network.

I also want them to fix the map on the website so it will draw out my path and calculate the distance I travel for each mission. I don't trust those small human brains to connect the dots.

With those improvements and retractable adamantium claws, I can take on the rest of my neighborhood enemies and have the world witness my conquests. 🐾

YOUR NEXT PET PROJECT

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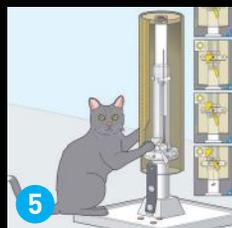
- 1 Double Pendulum Cat Toy**
Simple rig creates chaotic mouse motion.
makezine.com/projects/string-up-simple-chaotic-double-pendulum-cat-toy
- 2 Nvidia Jetson Cat Laser Teaser**
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Spinner hurls ball, dog returns to hopper, repeat!
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- 8 Tweed Dog Coat**
Sew a style fit for field, stream, or sidewalk.
makezine.com/projects/country-gent-tweed-coat
- 9 DIY Dog Collar**
Punch and rivet a great beginner project in leatherworking.
makezine.com/projects/diy-dog-collar
- 10 Dog Collar LEDs**
Bright lights for night walks or dog parties.
makezine.com/projects/illuminate-a-dog-collar-with-leds
- 11 Custom Canine Wheelchair**
3D print a new ride to restore Poochie's mobility.
makezine.com/projects/custom-canine-wheelchair



The Clue Coffee Scale

Load cell + microcontroller = precision weight measurement for superior espresso

Written and photographed by John Park and Jan Goolsbey



JOHN PARK is a professional maker who creates projects, videos, and tutorials for Adafruit Industries and designs and builds robots, illusions, and contraptions. He's the former host and co-writer of the Emmy-nominated *Make: television* show on PBS, and a 20-year CG animation veteran at Walt Disney Animation Studios, Disneytoon Studios, and Sony Pictures Imageworks.



JAN GOOLSBEBY, after a long and varied career in IT for a large research laboratory, refocused on his first love, electronics hardware design. He is an active member of the CircuitPython community where he enjoys learning new ideas and concepts. He's currently into music and sound synthesis, but is easily distracted by robotics, sensors, and anything noisy that blinks.

Achieving the ultimate cup of coffee involves the detailed preparation of ingredients and a concise choreography with your espresso machine. Part of this ritual is controlling the brew ratio, precisely matching the volume of beans to the amount of heated water. Exact measurements will help to make the entire process consistent, ensuring tasty success with each brew.

The Clue Coffee Scale is designed to weigh both ground coffee beans and the espresso machine's extraction output to achieve repeatable results — and it mounts right on your machine's drip tray. The scale uses a **load cell** sensor that employs a **strain gauge**, a sensitive resistance bridge array that is attached to the load cell's bendable metal beam. The slight changes in the bridge's resistance when the beam is deflected are measured by a special **analog-to-digital converter (ADC)**. The NAU7802 24-bit ADC breakout board connects to the load cell, provides an excitation current, and measures the bridge's differential voltage, which is then used to calculate the weight of the mass placed on the load cell.

The CircuitPython software running on the Clue interfaces with the ADC board to automatically update the display's animated linear scale as well as showing numerical results in both grams and ounces. To measure the contents of a container, the scale can be zeroed with a push of a button to subtract the container's tare weight. And to top it off, the flexibility of using CircuitPython makes it easy to customize the display and add features to the scale.

This guide will show how to build, calibrate, and code the scale. Your perfect cup awaits!

NOTE: A load cell is a precision device particularly when paired with a sensitive high-resolution ADC such as the NAU7802. However, because of component variations and software accuracy limitations, the scale is not recommended for safety, health, scientific, or commercial weight measurement applications — just amazing coffee.

BUILD THE COFFEE SCALE

This is one specific implementation of the scale for use on an espresso machine. Your build will vary depending on the target machine.

TIME REQUIRED: 4 Hours

DIFFICULTY: Easy

COST: \$95–\$100

MATERIALS

- » **Adafruit Clue microcontroller, nRF52840 Express with Bluetooth LE** Adafruit 4500
- » **Clear acrylic enclosure kit** Adafruit 4675
- » **ADC breakout board, NAU7802** Adafruit 4538 or SparkFun SEN-15242
- » **Strain gauge load cell, 1kg** Adafruit 4540 or equivalent
- » **Corner brace** for 2020 aluminum extrusion, Adafruit 1155
- » **Coupling plate, 3 holes** for 2020 extrusion, Adafruit 1216
- » **Cross-plate** for 2020, Adafruit 1220
- » **Cable, JST-SH 4-pin (Stemma QT / Qwiic), 100mm** Adafruit 4210
- » **Battery holder, 3xAAA** with on/off switch and 2-pin JST, Adafruit 727
- » **Cable, USB A to Micro-B, 36"** Adafruit 592 or equivalent
- » **Clear adhesive squares** Adafruit 4813
- » **Wire ferrules, 22AWG (4)**
- » **Various hardware including M2.5, M3, M4, and M5 screws, nuts, and washers**
- » **Heat-shrink tubing (optional)**

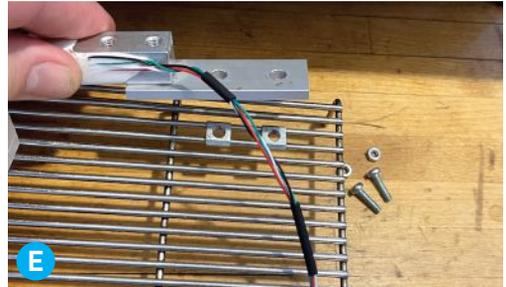
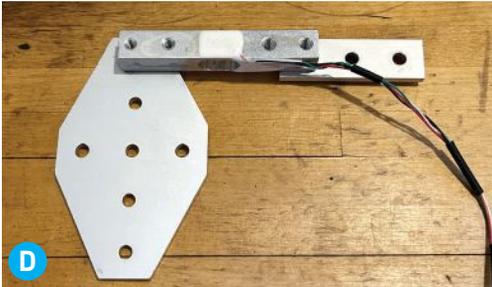
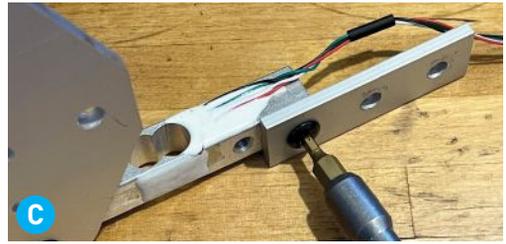
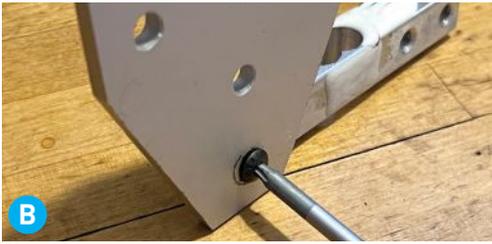
TOOLS

- » **Screwdriver** to fit screws
- » **Soldering iron and solder**



1. ATTACH PLATES TO LOAD CELL

To minimize the size and weight of the scale that will be attached to espresso machine's drip tray, only two aluminum brackets, the load cell, and a few fasteners are used (Figure A).



The fixed arm of the load cell (the end with the wires) is already tapped with M5 screw threads, while the weighing arm that can flex is tapped with M4 threads (the end with the yellow arrow sticker and load rating).

Attach the large cross-plate to the underside of the load cell on the weighing arm, using an M4 screw (Figure **B**).

Attach the 3-hole coupling plate with an M5 screw to the underside of the load cell at the fixed end (Figures **C** and **D**), being careful not to pinch any of the wires.

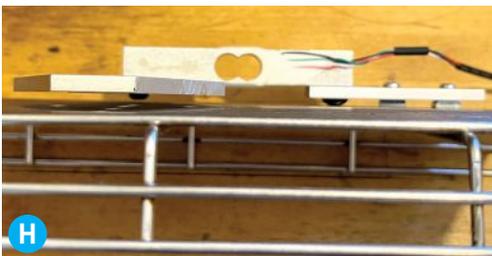
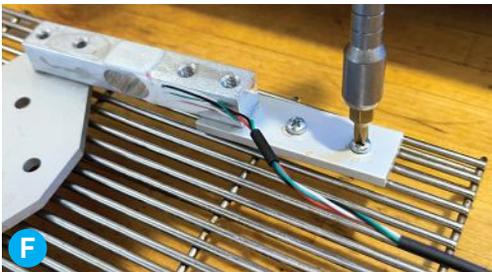
2. MOUNT SCALE TO DRIP TRAY

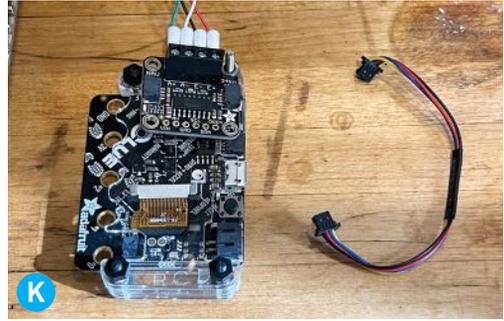
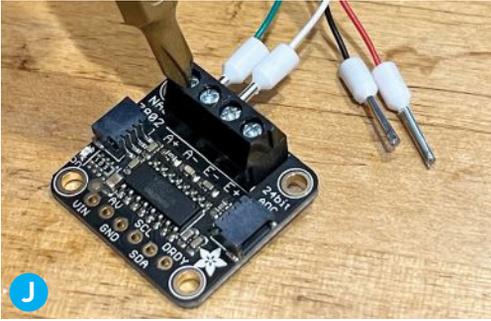
Use M3 screws, spacers, and nuts to attach the coupling plate to your drip tray grid as shown in Figures **E**, **F**, and **G**. Spacers can be M3 washers or nuts as long as they're large enough to span the drip tray grid wires.

The spacers are necessary to give the load cell enough clearance to flex under load as shown in Figure **H**.

3. PREP WIRES

If you like, you can add short lengths of heat-





shrink tubing to collect the four load cell wires into a cable (Figure **I**).

Add four small wire ferrules to the ends of the wires to make it easier to connect them to the screw terminals on the ADC board (Figure **J**).

TIP: These wires are so thin that the standard method of crimping the ferrules isn't recommended. Instead, solder the wire to the inside of the ferrules at the tip.

4. CONNECT THE CLUE

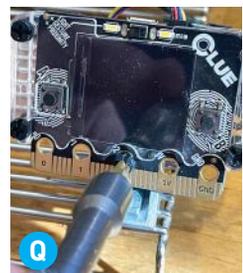
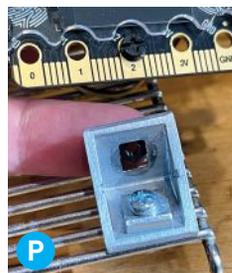
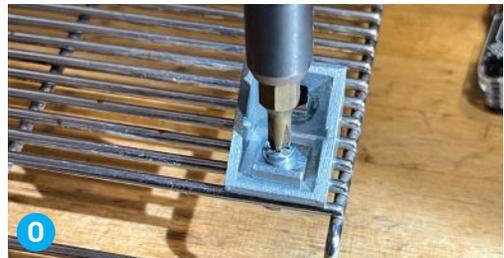
Attach the clear acrylic case to the Clue board, but leave off one screw in the upper right corner. Use a longer M2.5 screw and nut to connect the ADC board to the backside of the Clue (Figures **K** and **L**).

Connect the Clue and ADC with a Stemma QT cable (Figure **M**).

5. MOUNT CLUE TO DRIP TRAY

Mount the 2020 corner brace to the front of the drip tray grid using an M3 screw, nut, and washer (Figures **N** and **O**).

Attach the Clue to the corner brace using the remaining M3 nylon screw and nut from the acrylic case kit (Figures **P** and **Q**).



PROJECTS: Built-In Espresso Scale

6. CONNECT BATTERY PACK

Connect the AAA battery pack's wire connector to the Clue's 3V–6V battery jack (Figure **R**). Use an adhesive square to attach the battery pack lid to the drip tray's side (Figure **S**). Be certain to attach it so that the pack can be easily opened to replace batteries.

That's it, the scale is built!

7. GET THE PROJECT CODE

First be certain that you're running the latest version of Adafruit CircuitPython for the Clue board. Update it from the Downloads section of circuitpython.org if necessary.

Connect your Clue to your computer via a known-good data + power cable. The *CIRCUITPY* drive will appear in your Finder or File Explorer (depending on your operating system).

The Clue Coffee Scale project will require a specific set of CircuitPython libraries, a bitmap image, fonts, a calibration method, and the main *code.py* file. They're all in the bundle folder of the code repository at github.com/CedarGroveStudios/Clue_Coffee_Scale. Download the bundle and place those files in the root directory of the USB-attached Clue board.

The Clue board's root directory should now contain the following folders and files (Figure **T**):

clue_scale_bkg.bmp — background bitmap image
clue_scale_calibrator.py — load cell calibration program code

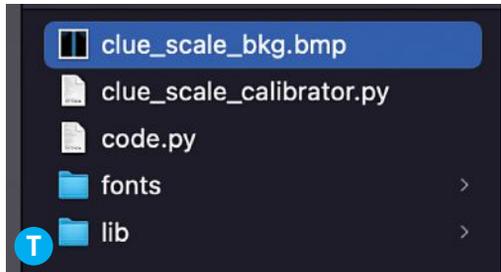
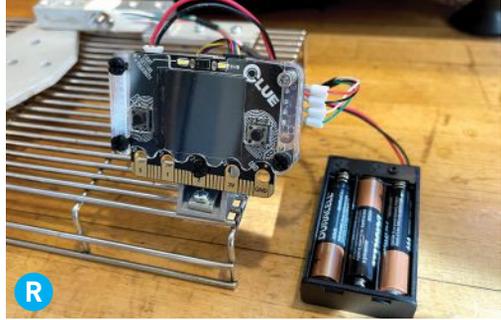
code.py — main project program code

fonts folder containing:

helvB24.bdf Helvetica font file

lib folder containing these required libraries:

adafruit_apds9960
adafruit_bitmap_font
adafruit_bmp280
adafruit_clue
adafruit_display_shapes
adafruit_display_text
adafruit_lis3mdl
adafruit_lsm6ds
adafruit_register
adafruit_sht31d
cedargrove_nau7802
neopixel
simpleio



NOTE: In the future, the project's *lib* folder may need to be updated to maintain compatibility with new releases of CircuitPython. You can either copy newer library file versions the Adafruit CircuitPython Library Bundle (circuitpython.org/libraries) or use the Adafruit **circup** command-line utility (github.com/adafruit/circup) to update the libraries.

8. CODE WALKTHROUGH

The main CircuitPython code module, *code.py*, prepares and operates the Clue Coffee Scale. Before using the scale, you'll need to update *code.py* with a calibration ratio that's unique to the load cell you attached to the NAU7802 breakout. First let's take a walk through the code and look at how each section works.

8a. Import and set defaults

This section imports all the needed modules and libraries, including the NAU7802 sensor driver. After importing, the first visible task of this section

is to turn the Clue board's NeoPixel LED yellow to indicate that the Coffee Scale is initializing. During operation, the indicator LED will glow green when operating normally or red when zeroing the scale.

Next, the scale defaults are specified. These are constants with names that are capitalized to help identify them as constants. You can change these values to alter the operation of the scale:

MAX_GR is the full-scale value of the scale in grams. The tick mark values adjacent to the graduated scale graphic are automatically derived from **MAX_GR** which can be any positive integer value. Since the graduated scale graphic is divided into tenths of full-scale, with five numbered tick marks, it's best to choose an integer **MAX_GR** value that will display nicely such as **1000**, **500**, **250**, **100**, **50**, **25**, **10**, or **5**.

DEFAULT_GAIN is the gain setting of the NAU7802 internal ADC's incoming signal pre-amplifier. Normally, this is set to the highest value of **128**.

SAMPLE_AVG specifies the number of measurements that are averaged when the load cell is measured. The measurement value will be more stable with a high **SAMPLE_AVG** value. The display will update more slowly with a higher value; it's a trade-off between stability and speed.

8b. Load cell calibration ratio

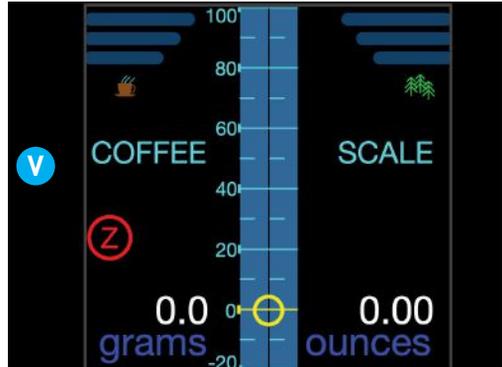
CALIB_RATIO is the factor that is used to convert the NAU7802's raw measurement value into grams. This ratio will need to be updated after running the calibrator method for your particular load cell in Step 9 below. You should only have to measure and record this calibration ratio once.

8c. Instantiate the sensor and display

The NAU7802 board is connected to the Clue's I²C bus and lives at address **42** (hexadecimal **2A**).

The NAU7802 24-bit ADC chip is capable of supporting two load cell channels, but only the first channel is available on the Adafruit Stemma breakout board; **active_channels** is therefore set to **1**.

Next, the Clue's integrated display is instantiated along with the primary **displayio** graphics group layer, **scale_group**, which will



contain the background bitmap image and other display layers.

Font objects for displaying measurement values and the tick mark labels are defined next.

8d. Display the background bitmap image

The display background file that includes the graduated scale (Figure **U**) is read from the Clue root directory and is appended as the first item in the primary **displayio** group layer. All other graphics objects will be put on layers over this background.

8e. Define and display text and graphics

This section defines the graphic elements that will be placed in front of the background graphic. First, the zeroing button graphic is appended to the primary **displayio** group.

The subsection that starts with **for i in range...** is the code that steps through the graduated scale's tick marks, creating a value label that's calculated using the **MAX_GR** constant and appending each label to the **displayio** group. Measurement values and units labels are added next.

Lastly, the **indicator_group** with its floating indicator bubble is created and added to the primary **displayio** group. The **indicator_group** layer is now the front-most graphics layer of the display (Figure **V**).

PROJECTS: Built-In Espresso Scale

The indicator bubble is a yellow circle that travels up and down the graduated scale, pointing to the measured value. The center of the circle will normally be transparent, but will appear yellow or red depending on the scale's current status; yellow when initializing, red when zeroing.

8f. Helpers

Two helper functions work with the NAU7802 driver class to zero the scale and to read the load cell's current raw value:

The `zero_channel1()` helper sets up and zeros the NAU7802's internal amplifiers and ADC (analog to digital converter) to prepare it to receive signals. This function is used when the scale is first powered up, and when it's manually zeroed by pressing the Clue board's A button.

The load cell's raw measurement value is obtained by the `read()` helper. This helper accepts an integer parameter that specifies the number of samples to be averaged each time the helper is called, defaulting to one sample (no averaging). The helper returns the averaged raw measurement value. Averaging the raw value can help reduce the jitter of the displayed value.

8g. Activate sensor and prepare to loop

This is where the NAU7802 ADC is enabled and calibrated for use. Before calibrating and zeroing, the internal sensor amplifier's gain is set to the default value. Once completed, the Clue will chirp some welcoming notes.

8h. The primary code loop

The primary loop is the main operational process of the scale. The loop indicates the scale's status on the Clue board's NeoPixel; green when the scale is operating, red when it's busy zeroing.

After setting the NeoPixel color, the load cell raw value is measured and converted to grams and ounces. The converted values are formatted and placed into the corresponding on-screen display labels and are also printed in the REPL.

The grams measurement value is used to position the on-screen indicator bubble along the graduated scale graphic using the `map_range()` function. Also, if the grams measurement value falls outside of the minimum or maximum range, the bubble is "parked" at the extreme position

and its interior color is changed from transparent to red.

Finally, the Clue board's A button is watched to see if it was pressed. When pressed, the Clue plays a sound and will begin zeroing the scale. During the zeroing process, the NeoPixel, the zeroing button graphic, and the center of the bubble are all set to a red color. After zeroing has completed, the code waits until the button is released before playing a completion sound, setting the bubble and zeroing button graphic interiors to transparent, and returning the Clue Coffee Scale to normal operation.

```
# The Primary Code Loop
# Read sensor, move bubble, display values
while True:
    clue.pixel[0] = clue.GREEN # Set status
    indicator to green (ready)

    # Read the raw scale value and scale for
    grams and ounces
    value = read(SAMPLE_AVG)
    mass_grams = round(value * CALIB_RATIO, 1)
    mass_ounces = round(mass_grams * 0.03527, 2)
    grams_value.text = f"{mass_grams:5.1f}"
    ounces_value.text = f"{mass_ounces:5.2f}"
    print(f" {grams_value.text} grams
    {ounces_value.text} ounces")

    # Reposition the indicator bubble based
    on grams value
    min_gr = (MAX_GR // 5) * -1 # Minimum
    display value
    bubble.y = int(map_range(mass_grams,
    min_gr, MAX_GR, 240, 0)) - 10
    if mass_grams > MAX_GR or mass_grams <
    min_gr:
        bubble.fill = clue.RED
    else:
        bubble.fill = None

    # Check to see if zeroing button is pressed
    if clue.button_a:
        # Zero the sensor
        clue.pixel[0] = clue.RED # Set
        status indicator to red (stopped)
        bubble.fill = clue.RED # Set bubble
        center to red (stopped)
```

```

    zero_button_circle.fill = clue.RED #
Set to red (stopped)
    clue.play_tone(1660, 0.3) # Play
“button pressed” tone

zero_channel()

while clue.button_a:
    # Wait until button is released
    time.sleep(0.1)

    clue.play_tone(1440, 0.5) # Play
“reset completed” tone
    zero_button_circle.fill = None # Set
to transparent (ready)
    bubble.fill = None # Set bubble
center to transparent (ready)

```

9. CALIBRATE THE LOAD CELL

Before putting the scale to use at your coffee-making station, use an accurate known weight to record the unique resistance characteristics of your particular load cell sensor (Figure **W**). This calibration should only need to be performed once unless the load cell is replaced.

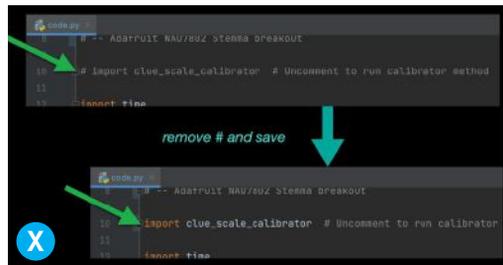
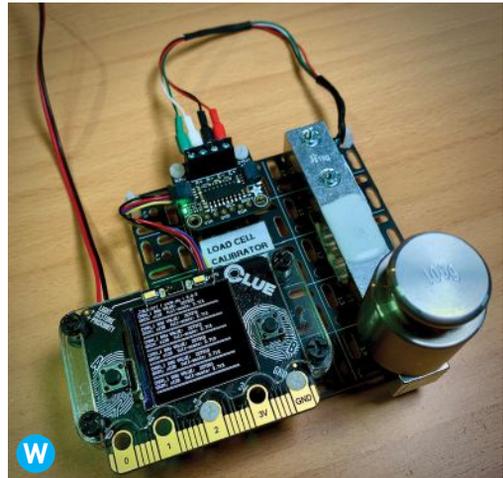
The calibration process reads and averages a handful of raw measurement samples, then prints the averaged value in the serial output window. The printed raw measurement value that corresponds to a reference weight will be used in the CircuitPython code to calculate the grams and ounces displayed on the screen.

Remember to mount the load cell so that the fixed end is securely fastened and the weighing end is free to flex with no restrictions.

9a. To begin the calibration process, remove all weights from the load cell.

9b. Edit *code.py* to activate the calibrator method. Using Mu or your favorite text editor (PyCharm is shown here), open the *code.py* file stored in the root directory of the Clue board and also open a serial output window. Remove the left-most comment hashmark and the following space character from line 10 of the file (Figure **X**).

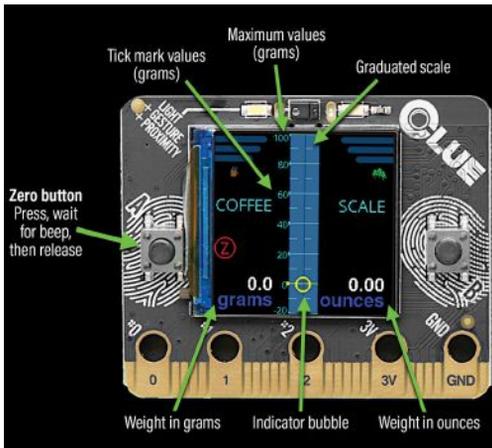
9c. After making the change to line 10, save the file. The calibration method will automatically run



when the *code.py* file is saved in the Clue board’s root directory. A notice that the calibrator is ready will print in the serial output window. See learn.adafruit.com/welcome-to-circuitpython for info on connecting to the serial console.

9d. Place a reference weight on the measurement end of the load cell. Once a few **RAW VALUE** measurements are taken, choose one that looks typically like a median value. In Figure **Y**, the 100g reference weight is producing a raw measurement value of approximately **215300**.

If you need to re-zero the load cell to get a



FEATURES AND OPERATION

The Clue Coffee Scale continuously displays the load cell weight measurement in both grams and ounces. The animated five-division graduated scale in the center of the display is calibrated in grams and shows the measured weight relative to the default maximum value of 100 grams.

An indicator bubble travels along the graduated scale, pointing to the currently measured value in grams. The interior of the bubble will turn red if the value falls outside the graduated scale range.

The Clue board's A button is used to zero or tare the scale. Press the button until a beep is heard, then release. The interior of the bubble and the Clue's NeoPixel will turn red while zeroing the scale. A second beep is heard when the scale completes the zeroing process.

YOUR FIRST PERFECT SHOT

You're now instrumented to take your espresso preparation to the next level. A great starting recipe is to pull a 30g shot in 30 seconds using a 20g dose of ground coffee beans — this is known as a *1:1.5 brew ratio* recipe.

- Zero your scale (tare) with an empty container
- Weigh again with 20g ground coffee in it
- Zero your scale again (tare) with the cup
- Pull the shot
- Weigh the cup again with brewed coffee in it.

You can then fine-tune your grind to increase or decrease the time to pull that same yield in order to accentuate different aspects of the coffee. The Clue Coffee Scale will help you dial in your espresso to perfection. ☑

BEAN THERE, MADE THAT

Try more great coffee projects from the pages of *Make*: — you can find all of these at makezine.com/projects/!



DIY COFFEE MAKERS

- makezine.com/projects/build-a-behemoth-cold-brew-coffee-drip-tower
- [/the-florence-siphon](#) (pictured above)
- [/cnc-drip-coffee-stand](#)

ESPRESSO HACKS

- [/hydraulic-espresso-tamper](#)
- [/the-bottomless-portafilter](#)
- [/xanthan-faux-caffe-latte](#)

WEIRD SCIENCE

- [/mobius-strip-coffee-cup-carrier](#)

BEAN ROASTERS

- [/simple-sifter-coffee-roaster](#)
- [/upgrade-your-coffee-roasting-setup-with-this-wobbling-disk](#)

And don't miss inventor Larry Cotton's saga at makezine.com/my-15-year-quest-to-make-the-ultimate-diy-coffee-roaster. Rumor has it there's a new improved roaster coming soon!

Scary Sconce

Fabricate a favorite enemy
for this fun bedside lamp

Written and photographed by Jeff Stein



JEFF STEIN is a hobby maker/artist, specializing in digital fabrication. He works out of his basement shop, about an hour north of Minneapolis, Minnesota.

I wanted to make a lamp. I didn't really need a lamp, but one of my favorite maker podcasts, *Because We Make* (since renamed to *Digitally Creative*), was having a lamp contest. The rules of the "Enlighten Us Challenge" were basic: make a lamp or something that uses lighting. It was stated clearly that entries with a "wow factor" would be the finalists.

Since I didn't need a lamp, I asked our son if he wanted one. He said "Yes, I want a Chain Chomp lamp." This might sound odd to some parents, but this child is obsessed with Mario Bros., so it was pretty on-brand for him.

For anyone who may not know, a Chain Chomp is an enemy from the *Super Mario Bros.* game series. It is always attached to an anchor block and when you come near, it jumps toward you and strains at the end of its chain, barking as it tries to eat you. I wanted to re-create that behavior accurately with my lamp, so I designed it with that in mind. Building it required all kinds of (non-digital) fabrication: welding, sheet metal work, cutting plastic, and woodworking.

1. FABRICATE THE WALL BRACKET

I used an angle grinder to cut out the pieces of steel (Figure A). Then I welded them together to make the wall bracket (Figure B). Nice clean welds are optional, as very little of the bracket will be visible. It just needs to anchor to the wall and support the weight of the lamp.

2. WELD THE CHAIN

I stretched the chain out straight, holding it in place with magnets. I welded each link to the next, flipped it over, and welded the backs of each link as well. At the top, I added an offset bar of links, so it has two points of contact to maintain the desired angle of "out and down" (Figure C). The bolt will go through the holes in the front of the wall bracket, and through two links of chain. The chain can pivot easily on the bolt to aim the light left or right. As the welded chain was ugly with burn marks, I painted it with chrome spray paint to cover that up.

CAUTION: Welding chromed metal can cause toxic fumes! Either use proper ventilation and protective gear, or strip the chrome before welding.

TIME REQUIRED: 10 Hours

DIFFICULTY: Moderate

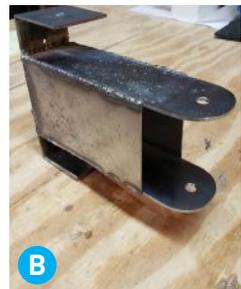
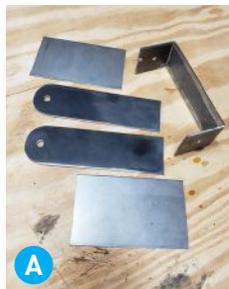
COST: \$70

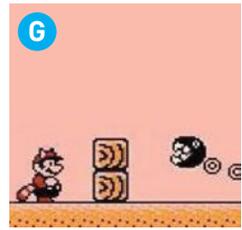
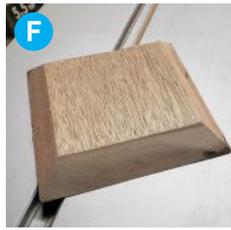
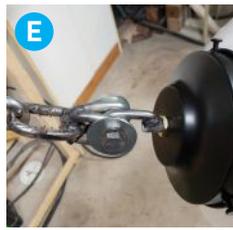
MATERIALS

- » Steel chain, 2" links, 4' length
- » Hardwood board, 1×6, 36" long | used mahogany. Nominal 1×6 lumber measures 5½" wide.
- » Sheet steel, 16 gauge
- » Scrap of thin plywood
- » Lamp cord
- » Lamp bulb socket
- » Plastic light globe, 10" diameter, approx. 4" fitter neck
- » Light globe fitter, approx. 4"
- » Threaded rod, hollow a few inches
- » Bolt, ¾"×6" long, with nut
- » Painter's tape
- » Spray paint: black, red, and chrome

TOOLS

- » Angle grinder
- » Drill
- » Welder
- » Magnets
- » Rotary tool with cutoff wheel e.g., Dremel
- » Table saw
- » Router with pattern bit
- » Small hand file
- » Sander or sanding block





3. FABRICATE THE NECK CONNECTOR

I needed a way to connect the chain to the back of the light socket, so I hacked up a link of the chain, and welded 1" of hollow threaded rod to it (Figure D). This link bolts to the end of the chain and allows the head's angle to be adjusted up or down with a wrench. The threaded rod screws through the globe holder into the back of the bulb socket (Figure E).

4. MAKE A 5-SIDED BOX

I cut off five pieces of the 1×6 mahogany board, each 5½"×5½". Tilting the table saw blade to 45 degrees, I beveled all four sides of each piece (Figure F). Then I assembled them into a faux box without a back. Finally, I used the drill and the file to cut two slots into the front of the box where the rounded ends of the bracket need to poke through.

5. ROUT THE PATTERN ON THE BOX

The box looked too plain as it was. I noticed the pattern on the original chomp anchor block (in *SMB3*) and decided to use it (Figure G). I printed out a screenshot of the block to scale, traced the design onto a scrap of plywood, then used a drill and palm router to cut the pattern in the plywood (Figure H).

Next I used the plywood as a template to carve the pattern into the two sides of the box, using a pattern bit in the router (Figure I).

After spraying black paint into the pattern (Figure J) and sanding off the surface (Figure K), the wood was protected with Simple Finish, which is boiled linseed oil with wax (Figure L).

6. CUT OUT THE TEETH

The Chomp head started as a 10" plastic globe. I used painter's tape to mark off the mouth area and define the teeth (Figure M), moving the lines around until it looked right to me. I used my Dremel with a cutoff wheel to remove the material from the mouth (Figure N), then used a hand file to smooth out and straighten the edges.

7. PAINT THE HEAD

I masked off the teeth and the eyes, both inside and out (Figure O). Then the inside of the globe was painted a dark red.

Next I taped off the mouth and neck holes completely and painted the outside black. When that was dry I removed all the tape (Figure P).

Finally, I made a small circle mask to paint the eyeball (Figure Q). After hitting both eyeballs, the painting is done (Figure R)! The teeth and whites of the eyes have no paint at all and are bare plastic.

8. INSTALLATION

I mounted the bracket on the wall, making sure it was level and screwed securely into a stud.

The box pushes on over the bracket and is a tight enough fit to stay in place snugly (Figure S). The chain is attached to the bracket with the bolt (Figure T).

Finally, the neck bracket is attached to the end of the chain (Figure U) and the head is mounted (Figure V).

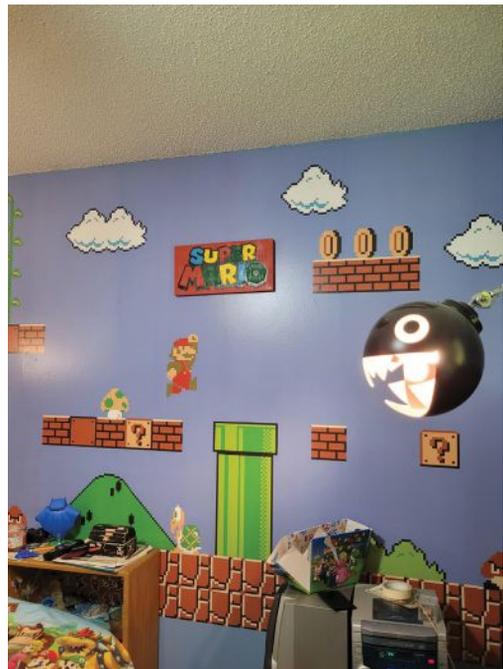


POWER UP!

Chain Chomp is best admired while keeping out of his reach. He does have quite the set of teeth, and is constantly straining to reach you!

With a smart LED bulb installed, my kid is super thrilled with his lamp. He tells his Alexa to change the color all the time, and dims it to use as a nightlight. As you can see, it really fits in with his room decor.

Unfortunately I didn't win the podcast challenge, although they did absolutely love it — I received tons of compliments, and made a bunch of new friends in the process! 🎧



Silicone Haptic Prosthetics

Make stretchy, wearable haptic devices — for a tactile virtual reality

Written and photographed by Lee Wilkins



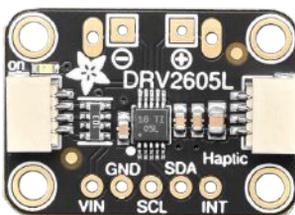
LEE WILKINS is an artist, cyborg, technologist, and educator based in Montreal, Quebec, a board member of the Open Source Hardware Association, and the author of this column on technology and the body and how they intertwine. Follow them on Instagram @leeborg_

This spring I did a residency about virtual reality and the body called **Bodies in Residency**, part of the **Bodies in Play** project at OCAD University in Toronto, Ontario, Canada. My goal was to explore different ways of thinking about what it means to exist in virtual reality that don't focus only on vision, but explore other senses. My guiding notion was: How can you know the difference between two objects in virtual reality without looking at them? This is possible in real life, why not in virtual life? How can you *feel* the difference?

There are a few haptic contraptions that exist currently. One of my favorites is the SoundShirt by CuteCircuit, which uses 28 high-resolution haptic actuators to make the wearer feel the music. Many VR controllers also have haptic motors in them, but they aren't designed for anything detailed or nuanced, they'll buzz lightly or more intensely, but nothing complex, and certainly nothing that you couldn't perceive visually.

I also wanted to explore some new squishy materials, so I worked with silicone rubber. In this project, I created what I call **haptic prosthetics**, which are like extensions of the body that can parse haptic information while leaving the hands free to do other things. I'm not too sure what those other things are — maybe engaging with more virtual/physical objects — but I really think hands are under-explored in VR!

To build this project, the main parts I used were the Adafruit DRV2605L haptic motor driver and a TCA9548A multiplexer. The DRV2605L is really neat because it has a whole bunch of different effects built in — for example clicking or ramping up and down — and other pre-programmed wave forms. You can use these together to give the wearer a whole range of sensations. Without using much code, you can access them all, and combining them together gives you an almost infinite range of possibilities. I used to code haptic patterns myself, but this board really saved me a ton of time.



MULTIPLEXING I2C DEVICES

The DRV2605L uses a protocol called **I²C** or **I2C**, aka **Inter-Integrated Circuit**. Many people use I²C in projects without really understanding it, but learning how it works can help you build more complex projects with much simpler wiring! I²C uses only two wires to communicate with multiple sensors, so you can attach many sensors to your microcontroller and not use up all your pins. Check your microcontroller for the I²C pins labeled **serial data line (SDA)** and **serial clock line (SCL)**. These are both used to communicate with your device: SCL is a clock pin that pulses at a regular rate, while the data is sent over SDA.

Each I²C device has an **address**, which is how you can chain them together in parallel and control them individually. The addresses start with **0x** followed by two numbers or letters, for example **0x11** or **0x3F**. While some I²C devices let you change their addresses, others are fixed. Adafruit's list of device addresses (learn.adafruit.com/i2c-addresses/the-list) is a great reference.

The problem here is that all of the same type of device have the same address, which makes it hard, for example, to use multiple haptic drivers at the same time. We can't chain them together in the normal I²C way because we can't distinguish them.

To fix this, we can use a TCA9548A **multiplexer** chip. This breaks out your single SCL and SDA pins into eight sets of SCL and SDA pins, which you can iterate through in code and address manually. Connect your multiplexer breakout board to your microcontroller's I²C pins, then connect each of your haptic drivers to the labeled multiplexed pins. The *Wire.h* library is used for I²C; once you've imported it, create a function like this:

```
void selectPort(int i) {  
  Wire.beginTransmission(TCAADDR);  
  Wire.write(1 << i);  
  Wire.endTransmission();  
}
```

Then you can select each I²C port in code, and write to it like you'd normally write to the pin:

```
selectPort(2);
```

That will get you started with haptic motors. Now let's attach them to your body!

MAKING A HAPTIC PROSTHETIC

We're going to make a silicone housing for a haptic driver board. I used these to attach haptic motors to the body in random places for my art piece, but you could make a silicone enclosure for any electronics! I really like it because it gets you away from typically boring electronics casings and gives a more organic feeling. I'm always looking to answer the eternal Wearables question: How can we make electronics feel like a part of the body?

My favorite silicone brand is Smooth-On, which has a variety of body-safe options. Body-safe silicone is usually a bit more expensive, so I used a cheaper silicone, Limino, for the molds. Silicone has a "Shore hardness" rating that lets you know how soft your part will be (Figure A). I wanted this prosthetic to be pretty squishy so I used a 00-50 Shore hardness silicone.

1. CHOOSE AND TEST YOUR TECH

Before you make a silicone casing, you need to be sure your circuit is working. Because it takes so many steps to make silicone molds, it's best to be really sure before you begin, otherwise you might make the entire mold and have it not actually fit your circuit! So I suggest wiring up your entire circuit and testing it before even starting.

I wired up an Adafruit Feather with a TCA9548A multiplexer and three DRV2605L haptic drivers. I attached haptic motors and purple LEDs to the DRV2605Ls, and powered it all with a 3.3V 500mAh battery. Figure B is the circuit diagram. Make sure to test it out before moving forward; I iterated through each haptic driver to make sure.

Then take a look at how much wiring you'll need and where you want the wires to come from.

TIME REQUIRED: A Weekend

DIFFICULTY: Moderate

COST: \$125-\$150

MATERIALS

- » **Modeling clay, oil/wax based** e.g. Monster Clay
- » **Casting silicone rubber, platinum cure type**
I used super soft Smooth-On 00-50 body-safe silicone for the prosthetic, and cheaper, harder Limino 15A for the mold.
- » **Mold release spray** for silicone molds
- » **Adafruit DRV2605L haptic motor controller**
Adafruit 2305, adafruit.com
- » **TCA9548A multiplexer module** Adafruit 2717
- » **Microcontroller** of your choice. I used an Adafruit Feather.
- » **LEDs, 3mm, through-hole**
- » **Small haptic motors** type 316040001 or similar
- » **Mixing tools, cups, popsicle sticks**

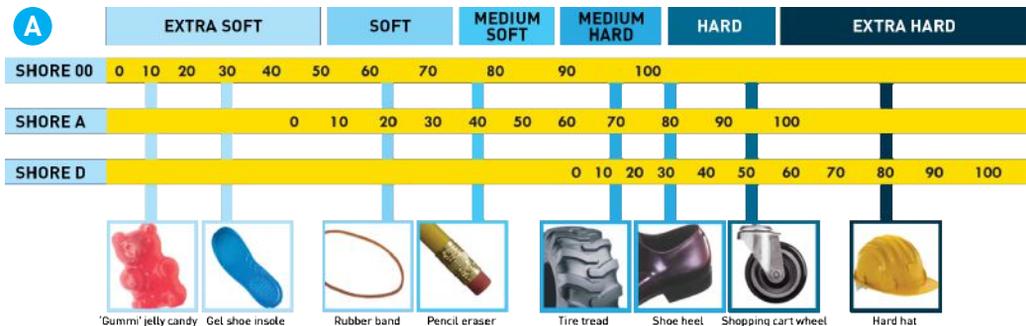
TOOLS

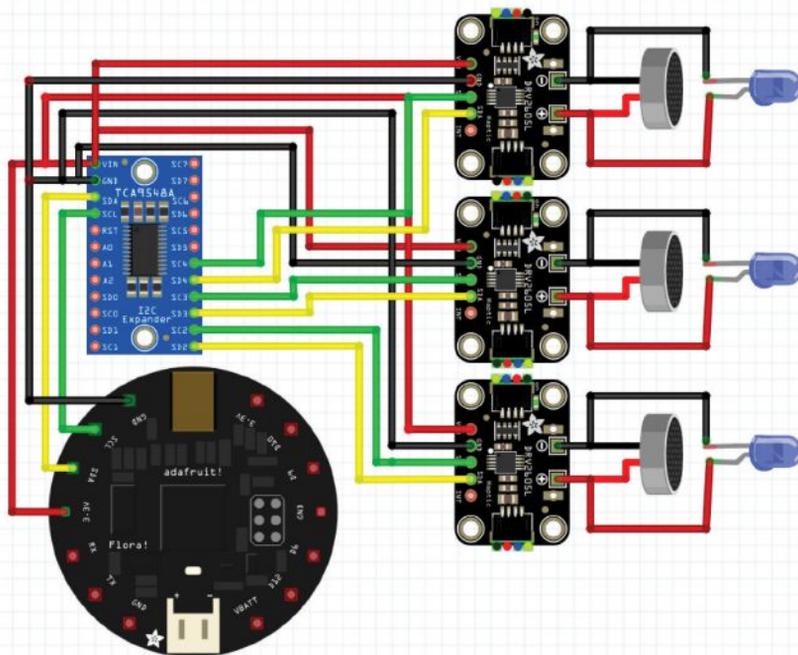
- » **Clay sculpting tools**
- » **Soldering iron and solder**
- » **Small Tupperware, box, or boards** such as wood, foamcore, etc., for mold walls
- » **Clamps**

I wanted mine to come out the top, but I wanted the LEDs to be facing into the silicone.

2. SCULPT WITH WAX-BASED CLAY

Once your circuit is set, you can start to make your silicone housing. First, you'll need to create a wax model which you'll use to make a silicone copy. You can use any type of clay to make this original object, but I really like a wax-based clay like Monster Clay because you can warm it in the microwave, and it is endlessly reusable. I used



B

a variety of tools to carve it, and I really took my time with it. Spending a bit of time making sure the edges are all smooth can really help you get a polished-looking result.

I pressed the DRV2605L into the clay, then carved out a spot for the LED and the motor. I left a bit of space for wiring, because that always takes up more space than I imagined. I wanted mine to look organic, so I also sculpted some gooey relief patterns (Figure **C**).

Mold-making is an entire art in itself (see makezine.com/projects/primer-moldmaking), so I'll keep it simple here. We're making a single-part mold, so the bottom should be flat, and you should avoid any overhangs (like in 3D printing!). Keep in mind that you'll need to extract this object from a mold later, so no loops that will be impossible to extract either. Keep it simple for your first try.

3. CREATE A SILICONE MOLD

Once you're happy with your driver holder, you can start to make a mold, so you can make a copy of it in silicone. To make a mold you'll need to first create a box around your model. You can use anything — like a Tupperware or box of any kind — as long as it's watertight. I used L-shaped wooden mold making barriers to make a box, and used more Monster Clay to plug the sides so it didn't leak (Figure **D**). This is key — I've poured



PROJECTS: Squishy Tech

silicone all over my kitchen table more than once. It's a huge waste of money and time! Keep the mold housing small so you don't use much silicone, because it can be expensive.

TIP: If you don't have wood boards handy, you can use a foamcore board. Mark where your box corners are on a piece of foamcore, then score them so that they fold but don't break. That way, you have three watertight corners and only need to seal the fourth one. I used more Monster Clay and some vinyl tape to seal this up (Figure E).

Spray both your mold housing and the part with mold release. Mix up your silicone according to the instructions, pour it in, and let it set. Make sure it's set fully before you try and extract it.

Once your mold has set, you can pull out the wax clay original and you'll be left with a negative mold for casting your prosthetics (Figure F).

4. CAST YOUR SILICONE PROSTHETIC

Spray your mold with mold release (Figure G), mix up a batch of body-safe silicone, and pour it in (Figure H). Let it cure and then, ta-da! You have your final silicone version of your wax clay board holder (Figure I).

I made mine using translucent, no-color silicone so that the LED would shine through and illuminate the material (Figure J), but you can add all kinds of colors. You can make as many of these as you want once you have the mold, which is pretty rad!

5. ASSEMBLE AND APPLY!

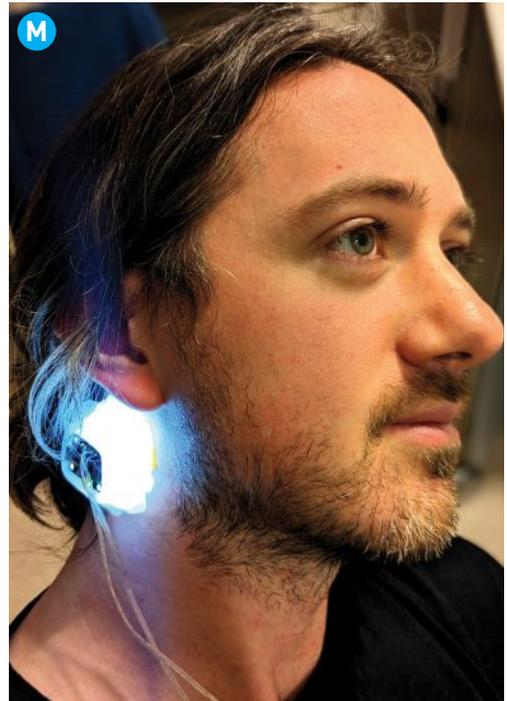
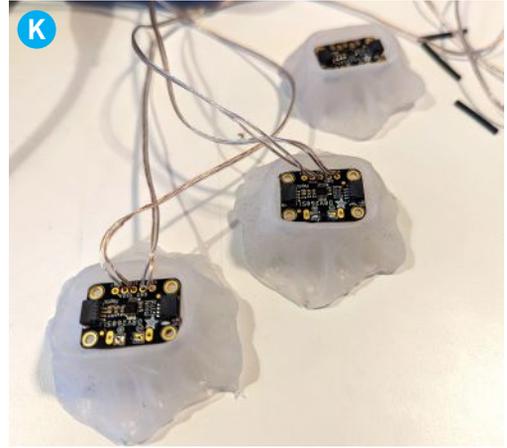
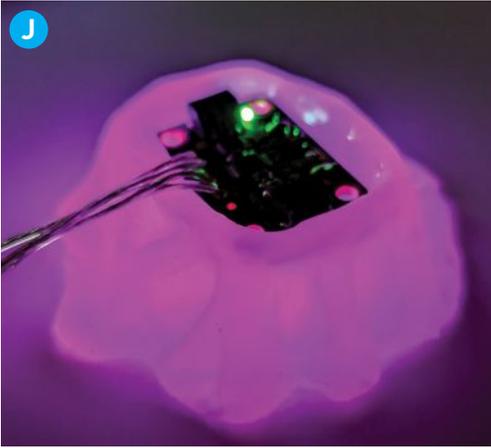
Press the driver board into place in the prosthetic (Figure K). I made a hole in the bottom of my silicone models so I could attach my haptic motors close to the skin.

I chose areas on the body that were sensitive — so wrists and neck (Figures L and M). I attached them using eyelash glue, but I think silicone prosthetic glue might work as well.

FEEL THE FANTASY

I'm hoping these haptic prosthetics can help us imagine what a virtual world might feel like, rather than just look like! Can we program new





textures, sensations, feelings, and other tactile experiences? What would a game “look” like that didn’t even require a visual environment?

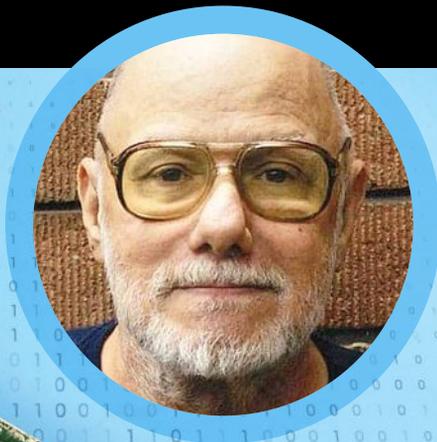
Naturally there’s the option to hook up something like this to a game engine like Unity, but we could also use it in conjunction with visual elements to make a more complex experience in various other arts and media. Next, I’m working on creating a variety of these prosthetics that fit specifically on different parts of the body, like the chest, neck, and feet! 🎧

BODIES IN PLAY (bodiesinplay.org) is a collaboration between OCAD University’s Social Body Lab (socialbodylab.com) and game:play Lab (gameplaylab.ca), and DMG/Dames Making Games (dmg.to). Together they create a unique partnership of academic and community spaces focused on different ways to think about tech, games, and bodies. You should check out their work!

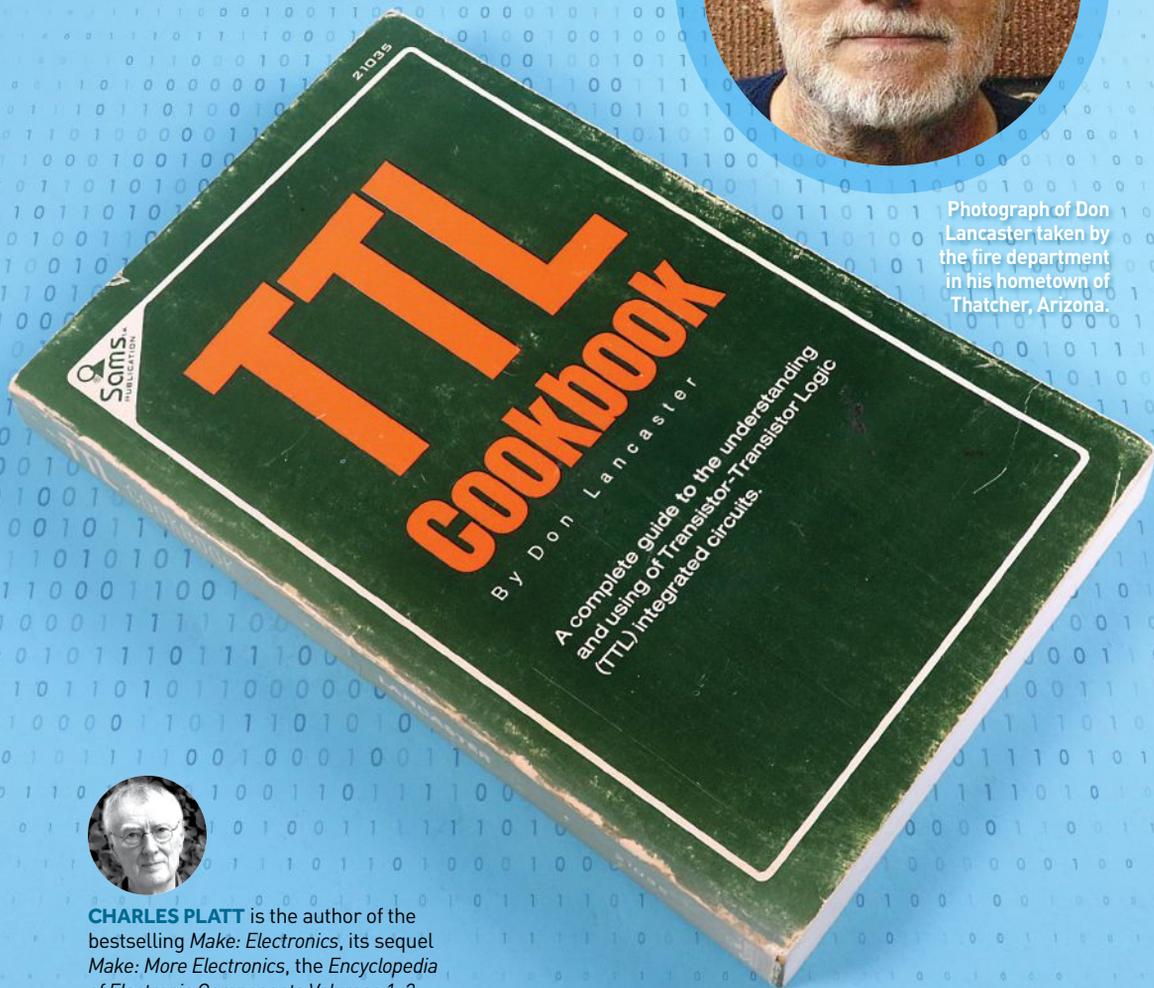
The First Digital Maker

Don Lancaster explained the mysteries of logic chips for generations of DIY hobbyists

Written by Charles Platt



Photograph of Don Lancaster taken by the fire department in his hometown of Thatcher, Arizona.



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

In the early 1960s, integrated circuit chips had military and aerospace applications such as the Minuteman missile. By the 1970s, the situation had changed radically: Ads in *Popular Electronics* offered individual 7400 quad 2-input NANDs for less than \$1 each.

Now the question was — how could hobbyists use them?

In 1974 Don Lancaster's *TTL Cookbook* told us how. It was an amazing repository of information that had been almost impossible to find, written by a man who worked for an aerospace contractor. Lancaster showed pinouts for almost a hundred chips using transistor-transistor logic (TTL), and then walked you through the process of combining them in circuits. When I first ran across it in a Radio Shack store, I felt stunned — disoriented — to have all this information in my hands. It was like the key to a world-changing secret society. (That's my well-worn copy of the first edition shown on the opposite page.)

I had never enjoyed analog projects such as audio amplifiers, requiring resistors and capacitors with values that had to be exactly calculated to preserve the subtle nuances of a signal. Lancaster told me that logic chips were not like that. The output from one chip went straight into the input of another, with no messing around.

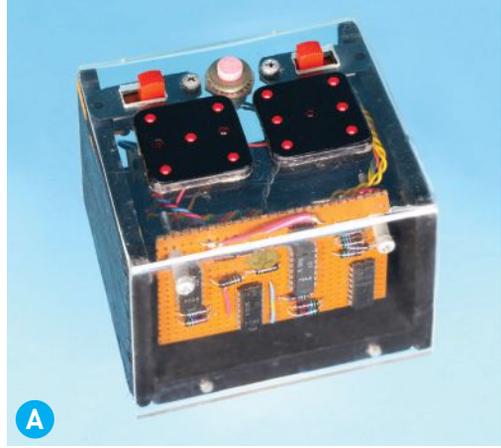
His book required patience and concentration — he had a relentlessly factual style, which was not reader-friendly — but it taught me something profoundly important:

You can do this. It's not as hard as you think.

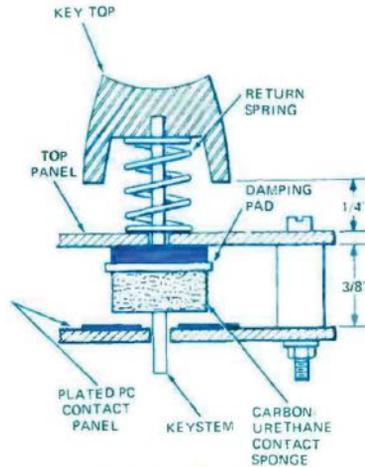
For my first project, I decided to build electronic dice. The Cookbook included a dice circuit, but it used D-type flip-flops, which were hard to understand. With the arrogance of ignorance, I decided to create a simpler version. The circuit required some decoding logic to convert binary output from a counter chip into the spot patterns for two dice, and I had to figure out how to make each counter roll over after counting from binary 000 to binary 101. But it worked, and it still works, almost 50 years later. You can see it in Figure A.

DAWN OF THE KEYBOARD

Don Lancaster was a quintessential maker, before that term existed. But beyond that, he was a true visionary, writing his book when personal



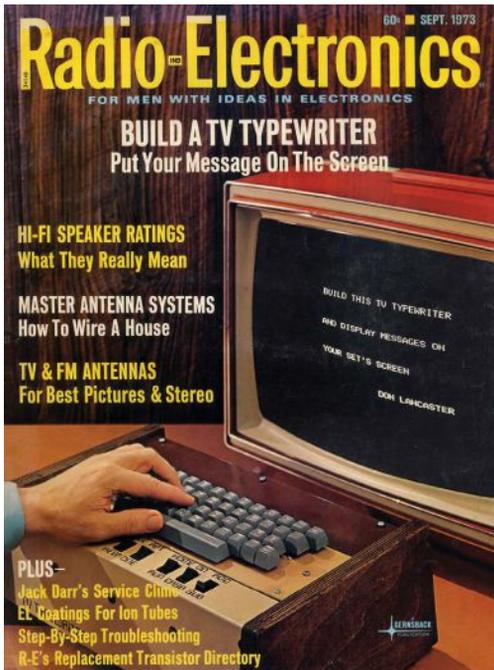
Digital dice, my first logic circuit, in a box fabricated from Lucite and plywood on my kitchen table, 50 years ago.



Don Lancaster's plan for building your own keys in a keyboard.

computers did not yet exist. You couldn't even buy a keyboard; they were only sold for serious money, for gadgets such as teletype machines. But Don foresaw the need for keyboards to control digital devices, and if we couldn't buy them, we'd have to fabricate them ourselves. In February 1973, his article "Build Your Own Low-Cost Keyboards" appeared in *Radio Electronics* magazine.

This was not a trivial project. It listed a source for the plastic key caps, but everything else was up to you. Etching circuit boards in your garage was the easy part; you also had to make your own momentary switches. He suggested mounting a disc of carbon-urethane sponge on a plunger beneath each key, so that the sponge pressed against two contacts. Carbon particles in the sponge caused it to become more conductive as it was squashed. His engineering drawing of the key structure is reproduced in Figure B.



C The TV Typewriter was Lancaster’s most famous project.

To protect the copper contacts from oxidation, “Gold, nickel, or tin plating is ideal,” he wrote, “but you can use ordinary silver-ink ‘PC Repair’ paint, provided you thin it properly and bake it on.” He recommended an oven at 200 degrees Fahrenheit.

Eventually Southwest Technical Products, widely known as SWTP, started selling a keyboard kit that was Don’s design, and they paid him royalties. But he had already gone further, developing the “TV Typewriter,” a video terminal which could be used with one of his keyboards to display two pages of 16 lines of 32 uppercase characters on a standard television set (see Figure **C**). This became his best-known project.

No one had ever made something which enabled you to type on a keyboard and see text on a TV screen. You couldn’t print the text, or save it, because there were no affordable printers or data storage devices. But the project established prerequisites for the personal computer revolution, which began 18 months later, when the Apple I was announced. Even then, keyboards were still difficult to obtain, so the Apple was sold without one, and a lot of buyers used Don’s SWTP kit to build their own. At the Computer History Museum in Mountain View, an Apple I has a Lancaster keyboard, shown in Figure **D**.

ON HIS OWN PATH

So who was this radical innovator? In an autobiographical summary Don described himself as an “archetypical computer nerd.” He was physically small while growing up in Pittsburgh, and recalled being frequently “thrown into trash cans or belittled by gym teachers.” But by the time he graduated, he had become a radio ham and was building projects such as walkie-talkies, a theremin, and a Van de Graaff generator.

He published his first feature in *Electronics World* in 1963, which paid him \$150. At the time, he saw this as “lots of money.”

To avoid being drafted into the military he took a job at Goodyear Aerospace, developing high-resolution CRT displays. In his spare time, he wrote for all the electronics magazines, describing fun devices such as a random audio tone generator, a color organ, color TV testers, and — yes — electronic dice. But after his *TTL Cookbook* became a best-seller, he became self-



D One of Don Lancaster’s handmade keyboards with an Apple I motherboard.

Charles Platt

employed. According to Don, the book eventually sold more than 1 million copies.

The advent of the Web was a gift for him; he retrieved the rights to many of his books and made them into PDFs, using his own PostScript code to create the layouts. He gave away the PDFs on his website, which he named “The Guru’s Lair;” and he lived partly on income from banner ads.

Don once characterized himself as “leading the way but missing out on the longer term rewards.” This was true; he ended up writing software patches for Apple, which were implemented on the Apple IIe, instead of joining the other engineers in Silicon Valley. Evidently he preferred living in the Arizona desert with his wife and daughter.

DEMOCRATIZING DIGITAL DIY

I never met Don Lancaster and I never will because, I was sad to learn, he died on June 7, 2023, aged 83. Still, his daughter Cathy is preserving his memory. She is maintaining “The Guru’s Lair,” which is a classic example of hand-coded HTML, as you can see from its homepage in Figure E. The site is a huge, sprawling repository reflecting Don’s numerous interests, from PostScript programming to exploring the desert near the Gila River.

When I learned he had died, I contacted Cathy, who was kind enough to share some memories of her father. Always thrifty, Don used to get her to duplicate floppies for his software mail-order business, and paid her 10 cents per disk.

She said he wrote his books because “he realized that the normal person didn’t have access to the information. He wanted to make it so that anyone could sit down and build something using his book.” Which I did.

Cathy doesn’t have many of the devices that Don made, but she does still have his electronic dice (Figure F), which of course preceded mine.

Before he died, her father wrote more than 40 books — including some that he self-published — on topics from Apple II assembly language to making enough money to survive as a self-employed person. But the message was always basically the same:

You can do this. It’s not as hard as you think.

free ebooks	bajada canals	on site stuff	off site stuff
gila hikes	usb classics	fast access	video links
more help	marcia swamp	auction secrets	magic sineWave
hydrogen stupidity	Post Script	patent bashing	blatant opportunt
cubic splines	hardware hacker	tech musings	resource bin
energy tutorials	gurugram library	unauth autobio	pseudo science
classic reprints	PS insider secrets	beginner stuff	tech innovation
simply marbelous	magsin calculator	third party	whatnu blogs
book to ebook	math stuff	Santa Claus	flutter wumpers
gonzo utilities	gonzo tutorial	avuncular sleezoids	low digital sinewaves
ps writes shtml	tri-mode PostScript	circle approx	student papers
powerpt emulation	nonlinear graphics	magic lamp	pixel interpolat
hanging images	enameled groundswill	architect perspect	vignette bkground
explore bitmaps	awful puns	build this TVT	trashing auto electr
tinaja questing	logfile analysis	all web files	all web ".psl" files
home	email	new	rss
eBay	xml	top	bot

E Screen capture of the home page of “The Guru’s Lair.”



- Cathy invites people who have memories of Don Lancaster to contact her via email at memoriesofdon@tinaja.com
- You can visit “The Guru’s Lair” at www.tinaja.com
- On YouTube you can find videos by a maker who built his own copy of the TV Typewriter using mostly period components: youtu.be/b-bFV8fHekk
youtu.be/Gil2ayNVDQg



Build “The Groaner”

An old-school circuit to prank your friends

Written and photographed by Charles Platt

One thing I learned from Don Lancaster’s many writings is that you can use a 555 timer for almost anything. Another thing I learned is that the original version of this very old chip is difficult to damage, even if you do weird things to it.

Many years ago, when my understanding of the 555 was still rudimentary, I wanted to make it generate the kind of groaning noise you hear from an audience when someone on a TV game show gives a wrong answer. I planned to mock my friends if we were playing a board game and one of them made a fatal error. Press the button, and — “Ohhhhh!”

I guessed that if I used a large capacitor to siphon current away from the 555 through an appropriate resistor, it could achieve the desired effect. But how and where to place the capacitor? I tried various locations on a hit-and-miss basis, finally applying it to Pin 5, the control pin.

This is a very nonstandard configuration, but the odd thing is, it works. The ultra-simple circuit in Figure G produces just the groaning effect that I was hoping for, especially if you mount it in a piece of PVC water pipe which resonates at a low frequency.

But *why* does this circuit work? Don Lancaster used to avoid questions like that. In his introduction to *TTL Cookbook*, he wrote: “The projects are introduced in such a way that considerable design effort by the builder is needed.” Yes, he wanted us to work hard! His attitude seemed to be, “Here’s the schematic. Now you figure it out.”

I’m not like that. I tend to be an explainer by nature, but just this once and just for fun, I’m going to follow Don’s example. Why does the groaner groan? If you track down a diagram showing the comparators inside a 555 timer chip, you may find the answer.

FABRICATION

To test the circuit, twist the trimmer to adjust the pitch from a deep groan to a whine. You can substitute a lower value for the 68Ω resistor to get a louder sound, or a higher value for longer battery life.

To immortalize the Groaner, solder the components onto perforated board using point-to-point wiring, as shown in Figure H. The underside of the board is shown at the top of the

BREADBOARDED VERSION

TIME REQUIRED: **1 Hour**

COST: **About \$10**

MATERIALS

- » 9V battery
- » Snap connector for 9V battery
- » Breadboard
- » 555 timer chip original TTL version, not a 7555
- » Capacitors, electrolytic: 22 μ F (1) and 100 μ F (1)
- » Capacitor, ceramic, 0.1 μ F
- » Resistors: 68 Ω , 2.2k Ω , 10k Ω , 22k Ω (1 of each)
- » Trimmer, 50k Ω
- » Speaker, 2" diameter, 8 Ω
- » Pushbutton with pins suitable for breadboard
- » Hookup wire

FINISHED VERSION

TIME REQUIRED: **5 Hours**

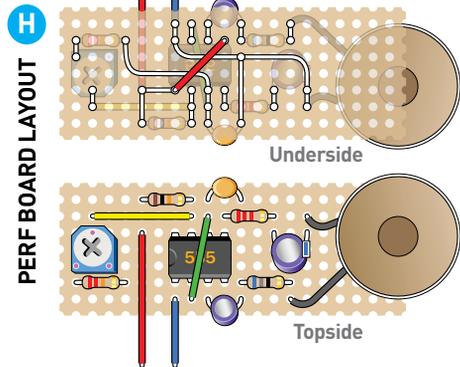
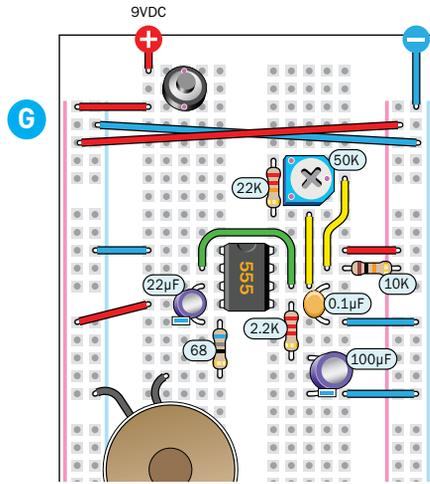
COST: **About \$15**

MATERIALS

- » Same components as for breadboarded version, plus:
- » Pushbutton suitable for panel mount
- » PVC water pipe, 1.5" internal diameter, 6" length
- » ABS plastic or plywood, 1/4" or thicker, approx. 6" x 6"
- » Perforated board, 1" x 2"
- » 5-minute epoxy glue

TOOLS

- » Pliers
- » Wire strippers
- » Miniature screwdriver for trimmer
- » Soldering iron, solder, and flux (optional) for finished version only



The speaker is protected behind a perforated circle of ABS plastic.



The components fit easily into PVC water pipe 1 1/2" in diameter.



Holes in the top enhance the sound.

diagram, and the topside is shown at the bottom (flipped on the long edge).

If you mount the circuit in a piece of 1 1/2"-diameter PVC pipe with a speaker glued into one end, the Groaner will acquire a hollow, mocking resonance. You'll need to protect the speaker with a piece of perforated plywood or plastic, as shown in Figure I.

If you mount the pushbutton on a disc that push-fits into the opposite end of the pipe, drill some holes in it so that the pipe works like a small bass-reflex enclosure, as shown in Figures

J and K.

Photo Roboto

Make a thermal printing robot out of a vintage camera Written and photographed by Sam Freeman



TIME REQUIRED: A Weekend

DIFFICULTY: Intermediate

COST: \$200–\$350

MATERIALS

- » Raspberry Pi mini computer with SD card and USB power
- » Raspberry Pi camera
- » Epson TM-T20ii thermal printer with USB cable
- » Vintage twin-lens reflex (TLR) camera
Find an old junky one on eBay for under \$100.
- » Magnets, 1/2" round (4) such as McMaster-Carr 5862K922
- » 3D-printed Pi case (optional)
- » Steel plumbing pipe nipples, 1/2" diameter, with fittings: cross, tee, elbows, flanges, and 1/2"-to-1/4" hex bushing
- » Bolt, 1/4-20, 1" long, with nut
- » Resistor, 150Ω
- » Arcade button, 100mm
- » Multi-outlet extension cord
- » Hookup wire, 20 AWG
- » Female header connectors
- » Female spade crimps, 22–16 AWG (6)
- » Wood screws, #8×3/4" (8)

TOOLS

- » 3D printer (optional)
- » Wire crimpers/cutters
- » Drill
- » Soldering Iron
- » Saw
- » Router (optional) but helpful



SAM FREEMAN is a product designer based in California. Formerly *Make*: lab manager, he enjoys making fun things and knows where his towel is. samtastic.co

There's something undeniably charming about old cameras, and there's something undeniably fun about photo booths. This build brings both together in a blend of low-fi prints, vintage hardware, and modern circuitry. A Raspberry Pi camera inside an old TLR (twin lens reflex) camera takes a user's photo and prints it instantly on receipt paper. Your guests will be able to snap a selfie and keep a thermally printed souvenir.

I built the original bot for my wedding, but today we're making an improved version that debuted at Maker Faire Bay Area 2023.

FINDING A CAMERA

I've tested a Graflex 22 (Figure A) and an Argoflex. Whatever you use, you'll want to make sure there's room for a Pi camera module and a path for the ribbon cable. Since the Pi camera can't see through the shutter, you'll need a vintage camera that supports *time mode*. We'll also be removing the lens, so it might be best not to start with a camera you're strongly attached to.

CHOOSING A THERMAL PRINTER

I chose this particular printer because I needed auto-cutting for a busy crowd, and it already had Pi support. If you trust your audience more than I do, you can find newer/cheaper options. Also, while receipt printers make charmingly lo-fi images, the thermal paper they use isn't very eco-friendly. Switching to an ink-based system would let you print on ordinary recyclable paper.

1. GRAB THE CODE

The program is a simple script that waits for a button press, then lights an LED and sends a photo from a Pi camera to the printer. Head to github.com/SamDIYFreeman/PhotoRoboto for the code, as well as installation instructions for printer drivers.

2. PREPARE THE TLR CAMERA

Don't tell anyone, but we won't be using the original lens. It might not be authentic, but keeping the original glass would open up a graduate-level optical engineering challenge, and at our resolution the difference would be entirely lost.

Unscrew the objective or *taking lens*, front and back. On some models, you may need a

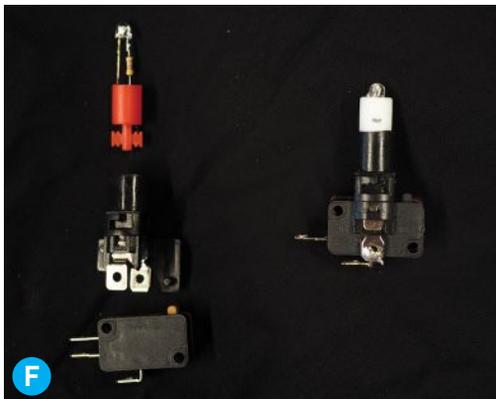


screwdriver to take apart the outer assembly. Proper disassembly could be its own tutorial, so go slow and keep track of everything so you can put it together without the glass. A thin piece of flat stock can work as a makeshift spanner for the rear lens. Note that the black coating scratches easily.

Open up the aperture to the widest setting unless you want the blades in the way. To set your camera to time mode, turn the dial to the T indicator (Figure B), wind the crank, and open the release lever.

3. PLACE THE PI CAM

Mount the Pi camera module behind the now-empty taking lens (not the viewfinder lens). Feel free to 3D print a custom mount, but I used cardboard and duct tape and it's held for 5 years and counting.



4. BUILD THE ROBOT BODY

Technically your camera could live anywhere, but a pipe robot gives this build maximum personality. Its form is up to you. A 1/2"-1/4" hex bushing with a 1/4"-20 nut jammed inside and a bolt through the neck provides mounting to the camera's tripod socket (Figure C).

A 3D-printed case and four hot-glued magnets hold the Pi securely on the back (Figure D).

5. WIRE IT UP

A four-wire harness with spade crimps on one end and header sockets on the other connects our buttons and LED to the Pi. You can solder your own harness or use cables off the shelf, as long as they're at least 30" long (Figure E). The ground (-) wire should have three connectors.

The big button's built-in LED runs on 12V. To make it run on 5V from the Pi, bust out your soldering iron and swap the resistor with one that's 150Ω (Figure F). Tying the LED (-) and button COM

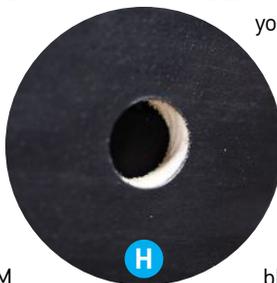
together will save you a crimp connector and prevent anyone (yourself included) from ever removing the LED again.

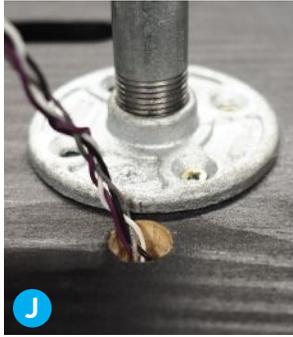
6. BUILD THE BASE

While the Pi and camera module live on the TLR, all the other components are housed in a wooden base. It needs enough room for the printer and power supply, a shutter button, power button, USB supply, and multi-outlet power cord. Mine's 14"×12"×8" (Figure G).

Cut a hole big enough for your power cord, and a 1 1/8" hole for the big arcade button in front (Figure H), and another for the power button in back. Make a hole on top wide enough for your wire harness and USB cables.

Cut out a 1"×4" slot for the printer. The prints don't shoot out very far, so you'll need to position the printer as close as possible to the face — this might require routing out the backside. The printer is held in place loosely with scrap blocks of wood.





Mount the big button in front and the little one in back. Connect your crimps to the buttons and LED (Figure **I**), then run all your cables through the base and up to the Pi (Figure **J**). The code uses GPIO pins 16 for LED, 20 for “Shutter,” and 21 for Shutdown. Physical pin 34 is common (-).

PI PICTURE PARTY!

Setup is simple. Plug your Pi and printer power into the multi-outlet. Then plug your bot into the wall and make sure the shutter’s open.

The script will automatically start on boot — the LED should turn on when it’s ready. Now hit the shutter button for your first test print (Figure **K**), and congratulations! You’re the proud owner of a bot who’ll free you up to enjoy the party.

UPGRADES

I recently upgraded to a V2 Pi camera, so I’m using the current library. Next I’m working on delicately shoving a Pi Zero inside a vintage TLR instead of mounting it on the back. You could also back up photos to the card or the cloud. 📸

VINTAGE PHOTOGRAPHY PROJECTS

OPENSX70

This open source, community project led by Joaquín de Prada in Barcelona is reverse-engineering the classic Polaroid SX-70 self-developing Land camera to replace its ancient PCB with Arduino-based hardware and software. The goal? Total manual control of shutter speed, double exposures, flash operation, timer, and more. Join in at opensx70.com.



OKTO35 3D-PRINTED MOVIE CAMERA

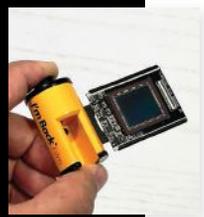
Movie film has become rare and expensive, so this brilliant bit of engineering shoots four Super 8 tracks on a roll of affordable 35mm film. It also takes stills and time-lapses, and can even scan old film to digital. Slovenian maker Blaž Semprimožnik is working on a MK3 version; follow along with his amazing builds at blazsemprimoznik.com/okto35.

Joshua Bird (“Wigglegram Lens,” *Make*: Volume 79) aimed for the same goal with his own “absurd and impractical” 3D-printed movie camera; enjoy his cautionary saga at joshuabird.com/blog.



ADAPT FILM CAMERA TO DIGITAL

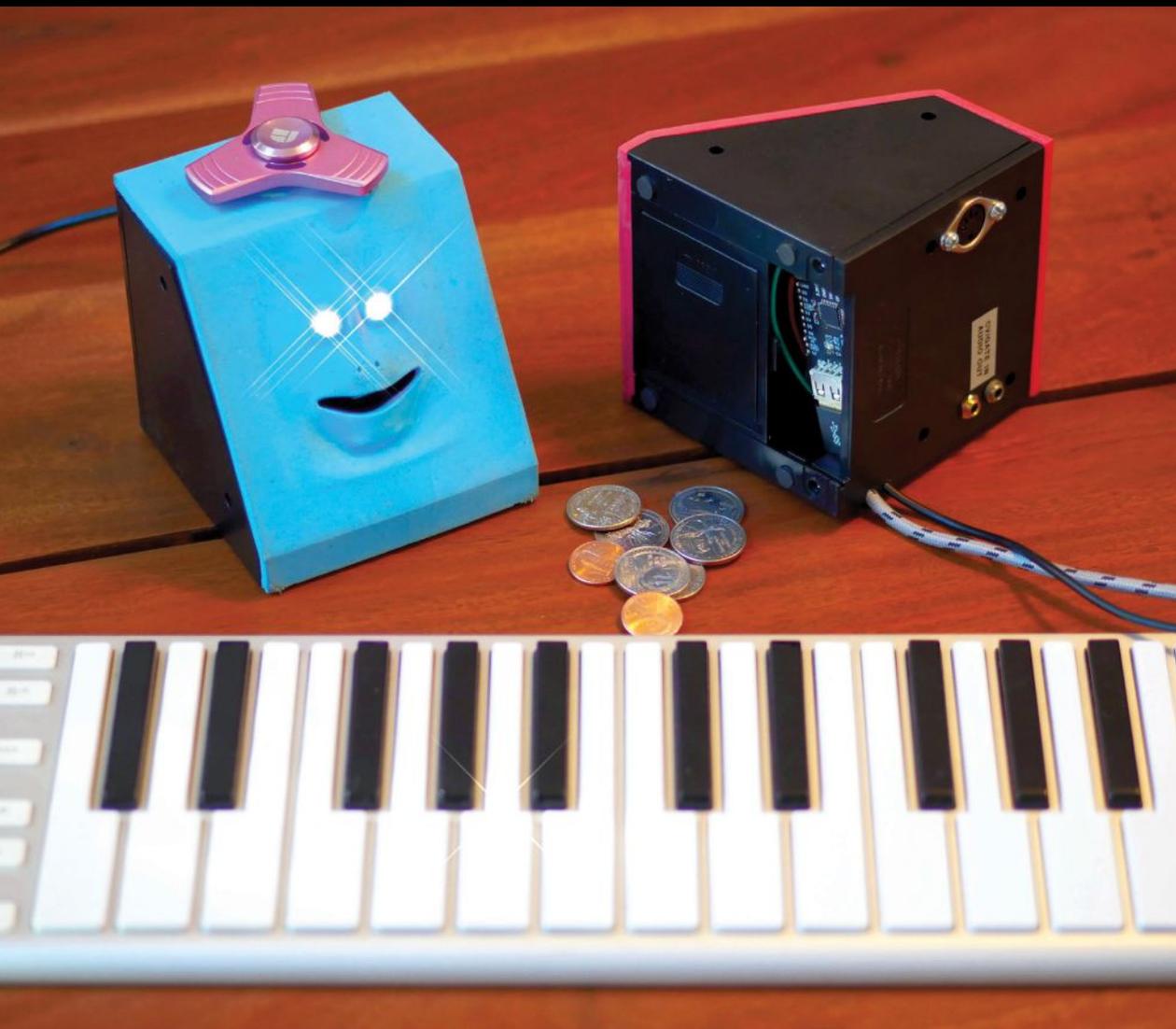
Can you convert a classic film camera to digital? DIYers have, but the drawbacks are severe: small sensors capture only a fraction of the standard 35mm frame. Finally some crowdfunded solutions are shipping: the DigiSwap adapter mates old SLRs to your iPhone optics, while I’m Back Film is a drop-in digital sensor in a film-cartridge form factor. Hype or hope, at least they’ll give camera hackers some new jumping-off points.



Wave Hello to WVR

The easy way to add polyphonic audio to your projects

Written by David Battino



DAVID BATTINO [batmosphere.com] is the co-author of *The Art of Digital Music* and writes the popular “Synth Hacks” column for *Waveform*. With his wife, Hazuki, he also self-publishes Japanese storytelling books, which they have performed at four Maker Faires.

If you've ever wanted to add interactive audio to your projects — or even make your own electronic musical instrument — WVR would like to speak to you. This thumb-size audio board requires no programming, no soldering, no external storage, and almost no extra hardware. Simply plug it into a breadboard, connect a stereo audio jack, and power it up with a USB cable. Within seconds, WVR ("waver") launches its own web server. Connect via Wi-Fi and you can wirelessly load (and trigger) thousands of sounds. WVR can store 12 hours of stereo audio onboard.

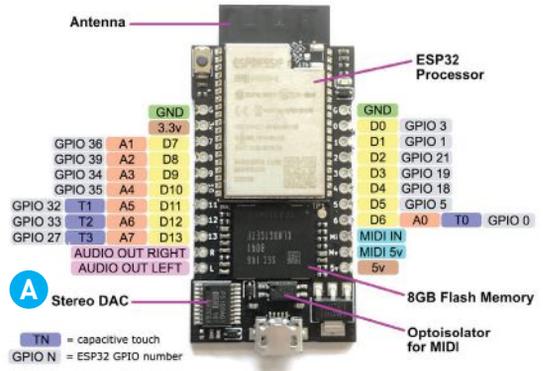
Add buttons, microcontrollers, or a MIDI jack; a built-in optoisolator lets you attach a standard MIDI keyboard (see Figure A). Unlike typical audio boards, WVR is *polyphonic*; you can play up to 18 stereo sounds at once. That means you can load it with samples of a choir singing individual notes and then play chords. Or set up evolving soundscapes by mixing loops of wind, rain, and frogs, and then trigger thunder sounds from a sensor.

A NEW WAVE

Speaking of evolution, what I like best about WVR is how cheerfully the developer, Andrew John March, adds features based on customer requests. Some of mine he's added include MIDI volume and pitch bend, variable attack and release times for fades, and a play/pause/resume trigger type. (When performing live, I like to load WVR with long speech recordings and then pause playback between words or sentences.) WVR is Arduino compatible and can store 10 sets of alternative firmware, making it easy to test new features.

Andrew is open to interface suggestions too (see Figure B). He added a few of mine within days, such as bulk file upload and the ability to change the parameters of multiple notes at once. That led to a feature that's almost unique on this type of board: pitch interpolation. On WVR, you can select a range of notes, load an audio file into one of them, and the system will automatically create transposed copies to fill the missing pitches.

That's a big advantage over the popular Robertsonics WAV Trigger and Tsunami boards, which require one audio file per note. Andrew wrote that his original intent was to recreate the WAV Trigger but add Wi-Fi and multisampling and make it open source. (By *multisampling*, he



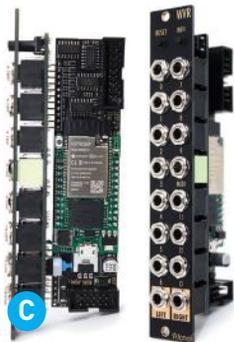
The WVR audio board features an ESP32 processor with Wi-Fi, 8GB flash memory, MIDI input, stereo output, and 14 I/O pins.



WVR's web interface lets you load sounds over Wi-Fi and set how they play back — looped, one-shot, velocity-switched, etc. You can even trigger sounds wirelessly.

WVR Specs

- **Size:** 26x55mm
- **Price:** \$40 (USB MIDI backpack \$10)
- **Distributors:** SparkFun sparkfun.com/products/21307, Tindie tindie.com/products/ultrapalace/wvr
- **Processor:** 240MHz ESP32 WROVER-B with Wi-Fi and Bluetooth
- **Firmware:** 10 slots; Arduino compatible
- **Storage:** 8MB internal RAM, 8GB flash (12 hours of 16-bit/44.1kHz stereo audio)
- **Audio output:** PCM5102 stereo DAC
- **Data I/O:** 14 GPIO pins (including 8 analog and 4 capacitive)
- **MIDI input:** Standard (3V or 5V); Wi-Fi; USB via optional backpack
- **Audio file format:** 16-bit/44.1kHz stereo WAV (converted on import)
- **Polyphony:** up to 18 stereo voices
- **Sample management:** 128 notes × 16 MIDI channels
- **Velocity switching:** 128 notes can have up to 32 layers
- **Playback modes:** One-shot, loop, partial loop, pause/resume (with optional looping)
- **Info:** github.com/marchingband/wvr



Atonal Circuits' Eurorack version of WVR, with jacks for control voltage input.



The Thames pedal, offered as a Kickstarter reward, packages a WVR in a foot-friendly format.



At just 2 inches long, the WVR and its USB MIDI backpack easily fit the coin chamber of my Takada Face Bank.

means **velocity switching** — WVR can assign up to 32 samples per note and switch among them as you play harder on a MIDI controller.)

Typically, sound designers use velocity switching to add realism, recording a progression of drum hits or piano notes from soft to loud and then using keyboard velocity to switch among them. I use it for randomization as well. On WVR, I'll load different sounds into a narrow range of velocity windows so that tiny changes in how I play surprise me with pseudo-random sounds. (WVR supports 128 velocity levels, so I might set one sound to respond to velocity 64–66, another to 67–70, and so on.) WVR calls these velocity groupings **racks**, and offers 128 of them.

SURF THE SOURCE

About that open-source feature: Surf to github.com/marchingband and you can not only try multiple variations of the WVR firmware, you can even download the hardware plans for making your own board. Robin Marsily of Atonal Circuits (atonal.be), who contributed the documentation, developed a Eurorack version of WVR (Figure C). He used the GPIO pins for control voltage input and added a button to turn off the Wi-Fi, saving power and potentially reducing noise. The GitHub site also links to a Discord forum where makers discuss project ideas.

WVR's compact size and wireless configurability make it an easy fit for a plethora of project enclosures. The original Kickstarter campaign offered a guitar pedal format (Figure D) with foot switches that trigger drum samples or sustain a piano sound. A rotary push encoder changes

volume or sound type.

I found that a WVR with the USB MIDI backpack fit perfectly in the 1"×1"×3½" coin chamber of a Takada Face Bank (Figure E). I simply soldered a MIDI jack to the WVR's MIDI pins and a stereo mini phone jack to its audio output, and then connected a USB extension cable to the backpack to provide USB MIDI input. A second USB cable powers the WVR and any connected USB controller. Cool bonus: Both MIDI inputs are active simultaneously, so you can connect two controllers and have them trigger different sound banks — a MIDI drum pad for percussion and a keyboard for melodic sounds, for example. For fun, I added color-changing LEDs behind the Face Bank's eyes and a circuit that flaps its rubbery lips when a 5V pulse arrives at another jack. (See it in action at [instagram.com/davidbattino](https://www.instagram.com/davidbattino).)

LEGO MY WVR

For a project that truly showcases WVR's size and features, see Robin's collaboration with artist Cole Blaq, a 2"×4" drum machine (Figure F; cole-blaq.com). Part of Cole's *Enter the Brick* series, this tiny instrument is made of unmodified Lego pieces. The eight studs on top are buttons that, in combination with two more buttons on the side, control 12 functions like pattern record, erase, volume, and tempo. Cleverly, the buttons also trigger speech recordings on the WVR to guide the performer.

A central concept of the *Brick* series is that all sculptures are scaled versions of original Lego components. That left Robin a volume of



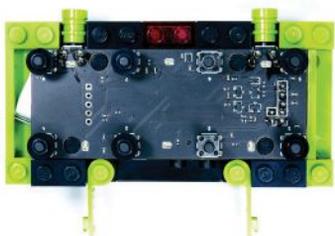
F Artist Cole Blaq collaborated with Atonal Circuits to build a tiny Lego drum machine powered by WVR.



G Atonal Circuits' custom WVR shield (bottom) is sized to fit Cole Blaq's Lego sculpture. The top board runs the drum machine functions.



H The bottom of Atonal Circuits' WVR shield adds a LiPo battery, audio output, MIDI input, and an amplified speaker.



I Both boards mounted in the Lego case. On top are the ten buttons and six status LEDs.

about 8×3×2cm for the electronics. He designed two circuit boards (Figure **G**): a breakout board for the WVR and a sequencer board. The breakout includes 3.5mm audio and MIDI jacks, a rechargeable battery, and an amplified speaker (Figure **H**). The sequencer board holds the buttons, six status LEDs, and a PIC microcontroller that sends MIDI to the WVR.

Two Lego doors open to reveal the USB charging port and audio/MIDI jacks. (The drum machine works independently but can also be connected to external gear.) That left room for only one speaker, so Robin used the second channel of the PAM8403 amplifier chip to animate another LED. He even added precision holes to the boards so they snap onto the Lego pieces (Figure **I**).

CATCH THE WVR

I was one of WVR's original Kickstarter backers in 2021 and am continually delighted by what it can do. I immediately bought a second board and installed it in a Japanese action figure, Ultraman's nemesis Birdon (Figure **J**). BirdonGaku, as I call him, provided all the samples for a performance at Chicago Knobcon last year. With a small MIDI keyboard and a USB power bank, I could even practice on the tray table on the flight out.

Andrew March is already prototyping WVR 2, based on the ESP32-S3, which has integrated USB and more RAM. That should enable features like signal processing effects, integrated USB MIDI, and perhaps even USB mass storage and USB device mode for programming. But I'll probably pick up a few more original WVRs while I wait. This little board really speaks to me. 🎧



J Plug and play: BirdonGaku (left) has a traditional five-pin MIDI input on his back. SoundBite has both five-pin and USB MIDI input. It's powering the keyboard too.

Aureole Anniversary

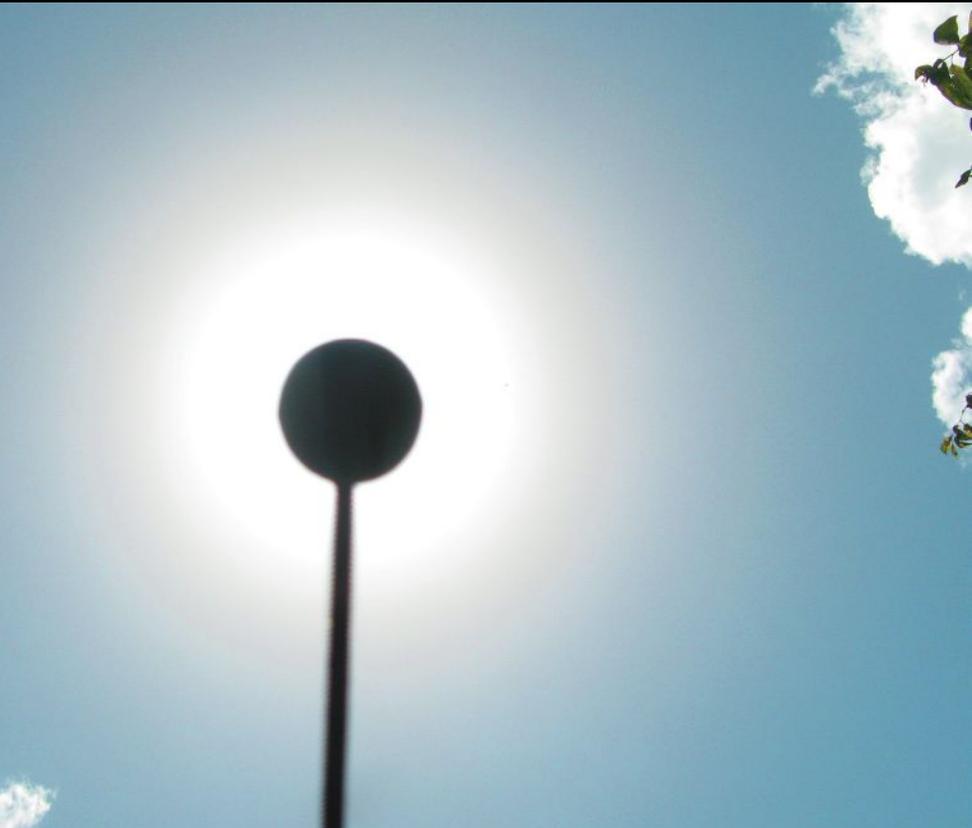
Photographing the solar aureole — this time with your cellphone

Written and photographed by Forrest M. Mims III



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



This column marks 15 years of writing about science for *Make*. Those columns have covered many kinds of DIY projects plus some history and adventures, and many of them are available online at makezine.com and in *Make: Forrest Mims' Science Experiments* (Maker Media, 2016, makershed.com/products/forrest-mims-science-experiments).

The columns have ranged from fun projects to serious science, including two columns on how to measure the altitude of smoke, dust, and other stuff in the air using a DIY twilight photometer (“Build a Twilight Photometer to Detect Stratospheric Particles,” *Make*: Volume 44, March 10, 2015). That project led to serious atmospheric science and an ongoing NASA assignment to

measure the height of atmospheric particles from the historic eruption of the giant Hunga Tonga volcano from under the South Pacific Ocean on January 15, 2022.

That enormous explosion sprayed the equivalent of 50,000 Olympic swimming pools into the stratosphere, where I have been able to measure the altitude of some of it based on that 2015 *Make*: column. Because water vapor is the leading greenhouse gas, the Hunga Tonga eruption may have contributed to a global temperature increase.

SOLAR AUREOLE PHOTOGRAPHS

Since 1998 I have used a variety of instruments to study the atmosphere. But I have also used a very simple device that visualizes stuff in the air without any electronics. This is a camera in which a small black ball called an **occluder** is placed in front of the lens. When the camera is pointed at the sun so that the black ball blocks the solar disk, aerosols from smoke, dust, and air pollution form a fuzzy glow around the black ball called the **solar aureole**.

I began doing this seriously in 1998, and from then until 2006 I made solar aureole photos with a 1.5-megapixel Fuji MX-700. This camera provided 4,465 images of the solar aureole and the sky over the north horizon. While the resolution (1,280×1,024 pixels) was considerably lower than today's digital cameras, it was more than adequate for aureole images.

The occluder was a 1/2" wood ball painted black and attached to a 6"-long, 1/16" steel rod like those used for survey flags. The camera was pointed at the sun and the occluder was held manually so that it shaded the camera's lens.

This brings us back to the 15th anniversary of this column, for in 2007 I began using a much better camera, a Canon G9. That's when I decided that an occluder mounted on a frame connected to the camera would be much better than a handheld occluder.

Besides being easier to use, a frame would keep the occluder the same distance from the camera lens during each photo. My first column in *Make*: described how to make that occluder frame for first-class aureole images.

TIME REQUIRED: 1–2 Hours

DIFFICULTY: Easy

COST: A Few Dollars

MATERIALS

- » **Wood ball, 1/2" diameter**
from a hobby shop; painted black
- » **Steel rod, 1/16" diameter, 6" length**
from a hardware store

TOOLS

- » **Mobile phone**

THE MAKE: SOLAR AUREOLE CAMERA

If you'd like to duplicate the solar aureole camera featured in my first column in *Make*:, that column was reprinted in *Make: Forrest Mims Science Experiments* (pages 119–124). Figure A shows the Canon G9 perched on the occluder frame described in that first column.

The Canon G9 was mounted on a bracket from a hardware store by means of the camera's threaded tripod receptacle. An 1 1/16" black ball mounted atop a 1/8"×3 1/2" threaded (6-32) steel post served as the sun occluder.

During use, the camera was slightly rotated until the occluder was in the center of the frame. The aureole was then photographed by pointing the camera so the shadow of the occluder was centered over the lens. This arrangement worked fine from December 17, 2007, to August 2023, when the G9's memory card slot failed.

That G9 provided approximately 3,400 solar aureole photos and a similar number of photos



The camera and solar aureole occluder featured in the first *Make*: column in this 15-year series.



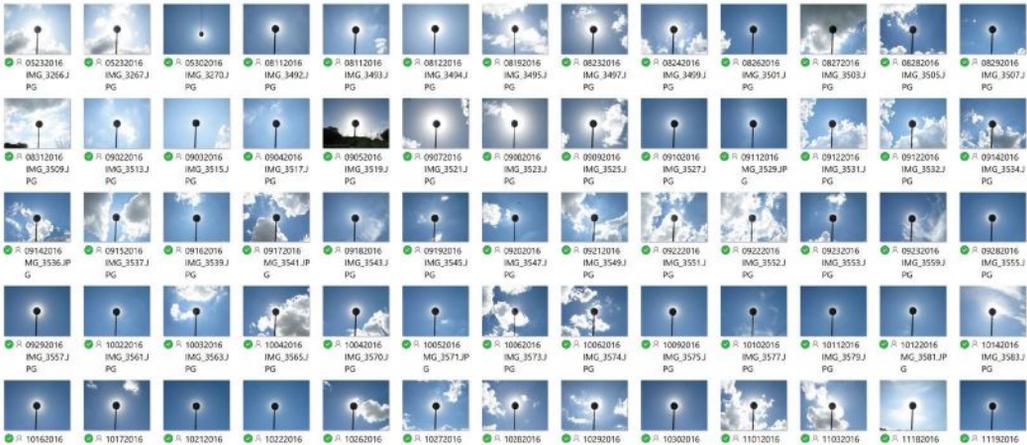
B Very small solar aureole during a clear spring day on May 6, 2016.



C Extraordinarily prominent solar aureole caused by thick biomass smoke from Mexico on May 20, 2016.



D Major solar aureole caused by Saharan dust arriving over Texas from Africa on September 7, 2016.



E Series of solar aureole images from May 23 to November 19, 2016.

of the sky over the north horizon during its 16 years of service. Those wonderful photos have significant scientific value, for they provide a much faster way to spot Saharan dust and smoke events than inspecting lengthy columns of optical depth data that I measure electronically.

SAMPLE SOLAR AUREOLE PHOTOGRAPHS

The cleanest days I have measured have always been at Hawaii's Mauna Loa Observatory (MLO). Those days are often so clear that there is no solar aureole.

At my Central Texas site, the clearest days occur during winter with occasional very clear days during fall and spring. Figure **B** shows a very small solar aureole during a clear spring day on May 6, 2016. It is not as clear as the MLO sky, but it's close.

During spring, thick smoke from agricultural fires in Mexico often drifts over Texas. Figure **C** shows an extraordinarily prominent solar aureole

caused by thick biomass smoke on May 20, 2016.

During late summer and fall, dust from Africa's Sahara Desert often arrives over Texas. Figure **D** shows a major solar aureole caused by Saharan dust that arrived over my site on September 7, 2016. The difference in the appearance of the smoke and dust aureoles is apparently caused by the size of the particles, with smoke being composed of much smaller particles than dust.

After you have been collecting solar aureole photos for a few months, you'll be able to display the results in a poster-like display like Figure **E**. This array of 65 images from May 23 to November 19, 2016, shows the wide variety of aureoles that occur from spring to fall.

You might be wondering why all these aureole images are from 2016. I could have selected any year from 2009 to 2023, for each year's seasonal differences are very similar.

After the G9's memory card slot failed in August 2023, on September 1 it was replaced with a Canon G12 — a more advanced camera

introduced in 2010, with higher resolution and an articulating screen. Initially the adjustable screen made acquiring the aureole photos awkward. But after a few weeks the G12 became easier to use than the fixed-screen G9.

USING A CELLPHONE TO MAKE SOLAR AUREOLE IMAGES

I am still using the original occluder mount and the G12 camera and hope to accumulate many more years of solar aureole imagery. Meanwhile, I miss the portability provided by my original MX-700 camera and handheld occluder. Only recently did I realize that a cellphone provides an ultra-simple means for acquiring solar aureole photos when the mounted Canon G12 is not available. An old, unused phone should work well.

I saved the handheld occluder that I used for thousands of aureole photos more than a decade ago (Figure F). It is ideal for cellphone aureole photos, since it slips into a shirt pocket where it can be instantly retrieved. Here's how I make cellphone aureole photos:

1. Place the phone in one hand in selfie mode, and the occluder in your other hand.
2. Adjust the phone until the sun is near the center of the screen. Do this rapidly to avoid damaging the sensor.
3. While watching the screen, adjust the occluder until the sun is blocked.
4. Gently press the photo button so the phone does not move.
5. Immediately point the phone away from the sun to protect its camera.

When the sun is high in the sky, your face might end up in the photos (Figure G). That's OK. Just make sure the aureole around the sun is fully visible. With practice, you can keep your face out of the photos (Figure H).

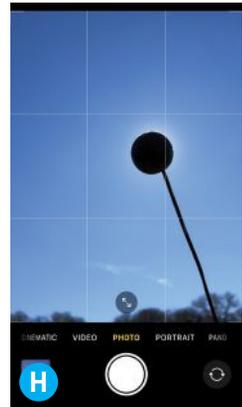
DOING SERIOUS SCIENCE WITH SOLAR AUREOLE PHOTOS

For serious scientific purposes, it is best to make solar aureole photos at the same manual settings. I use 1/1600 at f4. It's also best to make images at the same time each day the sun is visible.

You can use a larger occluder with your phone camera if you want to make serious aureole



Recent mobile phone selfie image of the solar aureole plus the author holding the occluder.



Mobile phone solar aureole image after the author learned how to stay out of the photo.

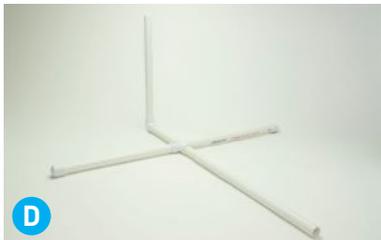
photos over a long period of time like I do. The simplest approach is to remove the top and bottom from a sturdy cardboard box like those used to package food. Use tape to attach the miniature occluder to one side of the box so that the black ball extends several inches from the edge of the box.

Place the phone inside the box with the selfie lens facing up. Then adjust the angle and direction of the box until the sun is centered behind the occluder's shadow and press the photo button. While this approach is less portable, the occluder will have the same size in every photo. ☑

CAUTION: Always wear sunglasses and a hat and never look at the sun while making aureole photographs! Work fast to avoid sunlight damage to your camera's image sensor. You may void the phone's warranty if you damage the camera by pointing it at the sun.

1+2+3 Stomp Rockets

By Maker Camp



TIME REQUIRED: 30–60 Minutes

DIFFICULTY: Easy

COST: \$5–\$10

MATERIALS

- » PVC pipe, 1/2" diameter, 5' length
- » PVC fittings, 1/2" diameter: end caps (2), 90° elbow (1), and cross (1)
- » 2-liter soda bottle empty and clean
- » Strong tape for launcher
- » Sheets of paper
- » Masking tape or invisible tape for rockets
- » Extra 1-foot length of 1/2" PVC pipe (optional)

TOOLS

- » PVC cutter or hand saw

Add the last 1' pipe (the launch tube) to the L connector, and the long pipe to the last opening of the + connector (Figure D). Make sure the L is facing up and perpendicular to the rest of the structure.

Finally, place the 2-liter bottle over the end of the long pipe (Figure E) and secure it with tape (Figure F). Make sure to use enough tape to hold it on well and seal the connection.

3. ROLL YOUR ROCKET

Using an extra piece of PVC pipe (or you can remove the upright launch tube from your launcher temporarily), roll a sheet of paper around it (Figure G), but not too tightly. Secure the seam with a strip of tape (Figure H).

Pinch one end of your paper tube closed and wrap it with more tape. Twist the end of the tape to make a pointy nose cone (Figure I).

BLAST OFF!

Now you can place your rocket onto the launch tube and stomp on the bottle to send it soaring into the sky!

Make an air-powered paper rocket launcher for a few bucks!

1. CUT THE PVC PIPE

Measure and mark three 1-foot sections of PVC pipe, and one 6-inch section.

Using a PVC cutter (great tool) or a saw, cut your PVC on your markings. You should now have three 1' sections, one 6" section, and a long remainder piece (Figure A).

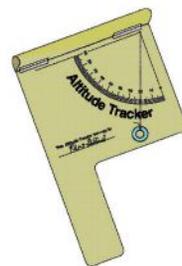
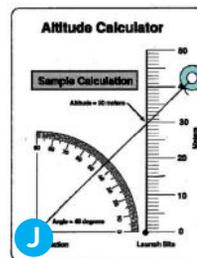
2. ASSEMBLE THE LAUNCHER

Press two of the 1' pipes tightly into opposite sides of the cross (+) connector (Figure B). Then add end caps to the open end of both of those pipes.

Plug the 6" pipe into the + connector and add the elbow (L) fitting to the other end of the pipe (Figure C).

WHAT'S NEXT?

- Try adding fins to your rockets. How does changing the angles of the fins change the flight?
- How does a bigger bottle (like a milk bottle) change the rocket's flight?
- Try building an altitude tracker (makezine.com/go/easy-altitude-tracker) (Figure J) to see how high the rockets fly! 🚀



MAKER CAMP is a free, do-it-yourself online resource to help leaders organize a summer camp that engages children in making. Our goal is to provide you and your campers with inspiration and helpful resources, including hundreds of projects to fit a wide range of interests and abilities. Making helps children become self-directed learners and good problem-solvers. For educators, Maker Camp project standards are provided based on Common Core and Next Generation Science Standards. Get started at makercamp.com!

Tilt & Tip Puzzle Rings

Fun to make, wear, and play!

Written and photographed by Bob Knetzger



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.



TIME REQUIRED: 1 Hour

DIFFICULTY: Easy

COST: \$5-\$10

MATERIALS

- » Acrylic sheet, 1/8" and 1/4" thick in clear and colors
- » Tiny balls such as BBs, ball bearings from your stash of bits and bobs, or even dragées, those silvery cake decorating balls
- » Thin chipboard or card stock
- » Acrylic solvent cement
- » Double-sided tape

TOOLS

- » Laser cutter (optional) or hand tools, hobby knife and small hole punch

This project combines retro fashion and fun in a tiny and easy-to-make format: puzzle rings. You can make them quickly with a laser cutter or with hand tools, and choose graphics to match your own nostalgic decade: groovy 60s, disco 70s, hi-tech 80s, and so on. Then have fun wearing and playing them!

PUZZLE DESIGN

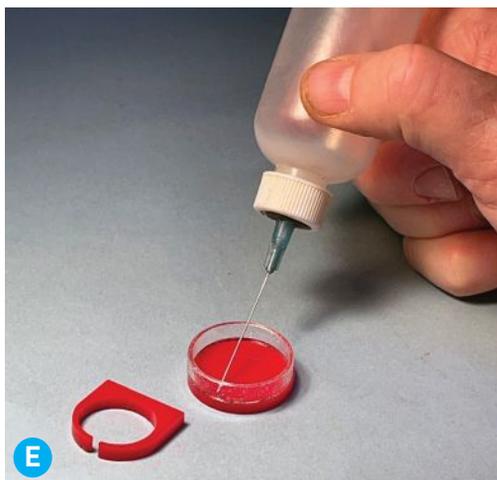
The design of the Tilt & Tip Puzzle Ring is simple: a stack of parts, with the middle part as a spacer ring to make a chamber for the balls to roll in (Figure A). Only one dimension is critical: Be sure the spacer layer is thick enough to provide clearance for the balls to roll around freely (don't forget to include the added chipboard thickness, too). You can change the size of the finger ring part to fit kids or adults.

Go online at makezine.com/go/tilt-tip-puzzle-rings to download the patterns and artwork (Figure B).

MAKE IT!

1. Print out the graphics on chipboard, trim to size with a hobby knife (Figure C), and punch the target holes. If you have a small 1/8" pliers-style hand punch, that'll work great (the usual 1/4" paper punch is too big). Or, use a hole punch and a hammer (Figure D).

TIP: Use a piece of end grain wood underneath when punching out parts. You'll get a cleaner hole.



2. Next, cut out the plastic parts. I used a Glowforge laser and Proofgrade acrylic sheets that come in the required thicknesses — and in fun colors, too! The Glowforge automatically sets the power and speed settings to match, but you'll have to adjust your own laser cutter's setting for each material.

Or you could cut out the parts with hand tools. Print out the .svg cutting file and use that as a pattern for hand fabrication.

TIP: For hand fabrication, you can use some 1" OD thin-wall clear acrylic tubing to make the spacer. Cut off a short piece to make a ring of the needed thickness.

3. Assemble the middle spacer ring to the base with acrylic solvent (Figure **E**). Avoid super glue — it might fog the clear parts.

4. Stick the graphic disk inside the ring using double-back tape or glue.

5. Add the balls and then bond the clear top to the middle layer. Let it dry.

6. Finally, bond the finger ring part to the bottom (Figure **F**).

WEAR 'EM — AND PLAY 'EM!

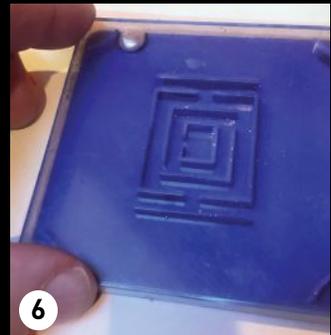
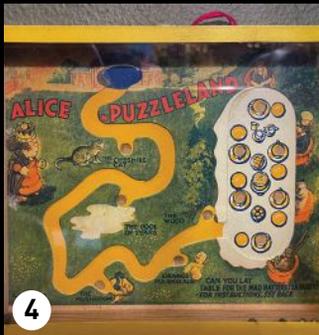
Tilt and tip your ring to get the balls in the holes (Figure **G**). Make up your own game variations: get only one ball in, while avoiding the other holes. Try it with your other hand — or wear it on your toes! How fast can you do it? Use your phone's timer and take turns: try to set a record among your friends. Or make two rings and have a race!

MAKE IT YOUR OWN!

"Up your game" and create your own puzzle ring design! Add your own personalized slogan, graphics, or a selfie image. Stack up multiple layers of clear mazes to build a 3D maze puzzle. Scale up the parts to make a larger locket or badge puzzle. Tilt & Tip Puzzle Rings are as much fun to make as they are to wear and play! 🎯

A TILTED HISTORY OF PUZZLE FUN

Tilt-and-tip dexterity puzzles have been around for a long time. The simplest ones are “ball-in-a-hole” games but there are many others.



1 This vintage design has tiny white balls for you to tip into position as teeth while the captive eyeballs wiggle in place.

2 Roll the “Golden Rods” into place, matching each length in order from shortest to longest.

3 “The Cog Wheel Puzzle” has an eyeleted center wheel. Roll the balls one by one into the spinning cog wheel.

4 “Alice in Puzzleland” asks: Can you roll the balls down the path and set the table while avoiding the hazards?

5 Help Geoffrey Giraffe blow some bubbles in this vintage Toys-R-Us birthday party favor.

6 “Squiggles” is a 1959 maze game from an earlier and less safety-conscious era. Instead of a rolling ball, it contains a hazardous blob of squiggly, liquid mercury!

BEST BURN FOR YOUR BUCK

JEN SCHACHTER

is a multimedia maker and artist, designing and fabricating everything from props and set pieces to dioramas of miniature worlds. A veteran of Adam Savage's workshop and longtime contributor to *Tested and Make*, she appeared on the cover of *Make*: Volume 86 in her towering Marie Antoinette wig made of EVA foam. Find her at jenschachter.com.



Making the most of your
laser projects with LightBurn

Written and photographed by Jen Schachter

In 2020, I launched a small laser-cut product business with a run of 150 diorama kits that I designed, cut, soldered, and packaged myself. I was confident in my artistic chops at the time, but had never manufactured anything at scale before — and it showed. Three years and several hundred kits later, I'm still finding better tools and ways to optimize my workflow.

Among those tools is LightBurn, a layout and control software for laser cutters with some powerful features to help streamline designs for production work.

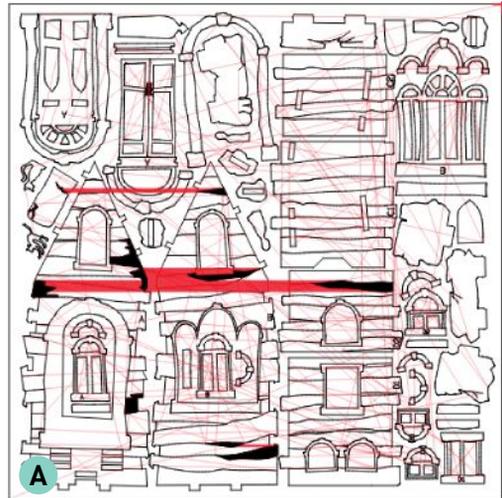
These are my top tips for getting the most out of your projects with LightBurn!

1. DESIGN WITH A “PRODUCTION MINDSET”

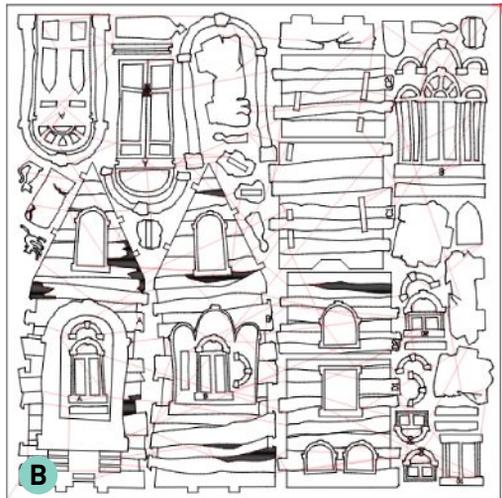
Whether you plan to make one or one hundred of something, consider the manufacturing process as you approach your design — this will set you up for success before even firing up your machine. For example, it takes a laser much longer to engrave or “fill” a raster shape than it does to simply outline the same shape with a light score or cut mark. The difference may be only a few minutes — no big deal for a few sets — but multiply that by several dozen and you've added hours or even days to your production time!

With this in mind, I use filled shapes sparingly in my projects, and instead **create details and texture with vector lines**. This can be done within LightBurn using their native drafting tools, or imported from another design software. I like to draw freehand with a digital pen and drawing tablet using the brush tool in Adobe Illustrator. This technique lends an illustrative quality to the designs, while still preserving their editability as vector paths.

Inside the LightBurn workspace, a thoughtfully created design can be fine-tuned even further for maximum efficiency. Clock the total time estimated in the Preview window (shortcut Alt+P on Windows, or Option+P on Mac) and then dig into the **Optimization Settings** (docs.lightburnsoftware.com/OptimizationSettings.html). Just a few adjustments can shave off minutes (Figures A and B) or even cut your production time in half!



Job preview, not optimized, time 21:06 per sheet.



Job preview, optimized, 14:47 per sheet — 30% faster!

2. THINK OUTSIDE THE DEFAULT SETTINGS BOX

When you first get started with LightBurn, you'll likely use the presets for your machine in the Material Library. But once you have a sense for what's legible and safe (as in, doesn't catch fire, or crash the laser head) you can begin to experiment, changing one variable at a time to see how it affects the output.

Laser speed, power, and interval settings are adjustable in the Cuts/Layers window. Double-click any layer to open the more advanced Cut Settings Editor where you can test other variables

like **scan angle**, **cross-hatching**, and **z-offset** to get different effects (Figure C). Here's how I use some of them in my projects:

- **Cross-Hatch:** engrave both horizontal and vertical patterns within a fill layer
- **Z Offset:** defocus the laser head by fractions of a millimeter to get broader, darker lines
- **Scan Angle:** change the direction in which the laser etches
- **Interval:** increase or decrease the line "resolution" of a fill layer.

To easily run a side-by-side comparison, try the handy **Material Test Generator** (youtu.be/pTx0RG_4Wbs) and **Interval Test Tool** (youtu.be/kpMunzp2NM8) under the new Laser Tools menu in LightBurn.

3. TAKE SOME ARTISTIC LICENSE

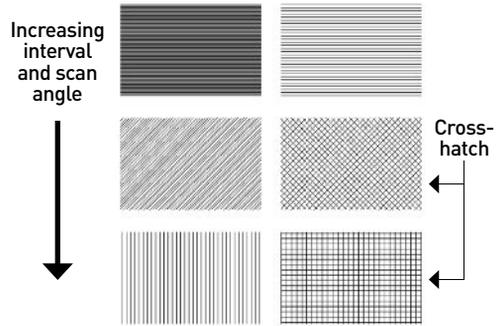
When a design does call for engraving, I have found a settings "sweet spot" that both etches quickly and reads well aesthetically. The finished effect is a sort of **hatch pattern with bold outlines** around the edges — almost like classic comic book art, which nicely complements my design style. Check out the details on this miniature house (Figure D) to see what I mean!

As you adjust values in the Cut Settings Editor, you may notice that interval and lines per inch (LPI) are inversely related: as the LPI goes up, the interval goes down, and vice versa. Low intervals result in deep, densely engraved fills with crisp edges. High intervals yield fewer lines per inch, so they will engrave much faster, but also appear lighter, shallower, and less-defined. This can work for quick "draft quality" samples, but it can also be used to your advantage for finished pieces by cranking up the power!

To get this effect for your project will require some testing, but here is the basic process, which you can set up in your original design file, or within LightBurn:

- Select all areas you want to engrave.
- Set them all to one color and Fill mode.
- Duplicate those shapes in place (Ctrl+D on Windows, or ⌘+D on Mac).
- Assign a new color to the duplicated shapes and set them to Line mode (or Stroke, in some design software).

FILL SETTINGS TEST



- C** Experiment with LightBurn's cut settings to change the interval (line "resolution"), scan angle, and cross-hatch patterns.



- D** I combine hatching with bold outlining for a comic-book style shading that engraves fast and reads well.

- In LightBurn, set the Fill color to a high interval, high speed, and high power setting.
- Set the Line color to a high speed and medium power. (You want a bold score mark that looks dark but doesn't cut fully through the material.)

CAUTION: Note that the values here are "low" or "high" in relation to the baseline settings for that material and your specific machine. Make sure you know the safe range first before experimenting!

You can take this a step further by assigning different fill settings to specific features to create varying hatch patterns within your design.

4. CONSIDER THE END USER EXPERIENCE

It's always a good idea to keep parts organized and labeled, but it's especially important if you won't be the one assembling the finished product! **Tabs**

and bridges, scored or perforated outlines, and part names/numbers go a long way to make final construction a breeze, and LightBurn has some useful features for creating them.

Tabs (also called **bridges**) in laser cutting are small sections of a cut path that are intentionally skipped or set to not cut fully through the material. This keeps parts attached to the sheet until they're needed, when they can be easily snapped free. Creating tabs in my kit designs used to be a painstaking process of clipping and deleting individual nodes, but LightBurn can generate tabs in a specified quantity, cut power, and width automatically in the Cut Settings Editor! Here are some of my tips for tabbing:

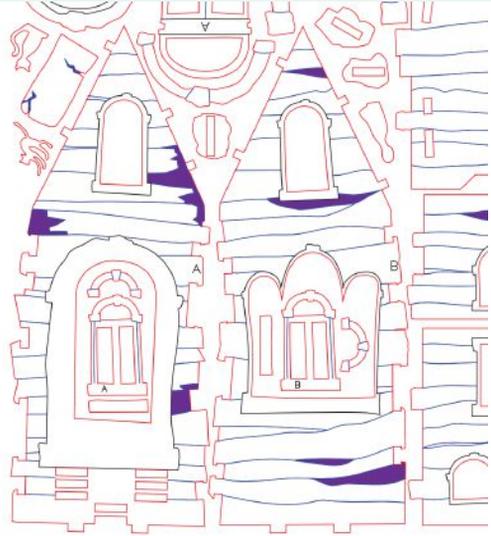
- Set the tab cut power to 20%–30% to prevent splintering when parts are removed.
- Manually reposition any tabs interfering with curves, corners, or delicate parts of the design.
- Save on material cost by nesting small parts inside the negative spaces of others and adding tabs to connect the inner shape.

When a design calls for multiple layers, it's helpful to indicate their placement with a faint **scored or perforated outline**. Any layer set to Line mode in LightBurn can be toggled to score or perforate instead of a through-cut:

- Duplicate the outline of the top layer part and assign it a new layer color.
- Position this outline where the part should be placed on the layer below.
- In the Cut Settings Editor, toggle on Perforation Mode to create a dotted line. Or, to make a faint score mark, set the power lower and the speed higher than the cut settings for that material.

Another feature your end users will thank you for is a clear **part labeling system**. This can be descriptive like “Right Door Panel,” or intuitive: window A clearly fits in the corresponding outline on panel A in this example (Figures **E** and **F**).

Engraving labels is time consuming, so why not use **single-line vector text**, aka **SHX typefaces**, which can fire off a whole set of part labels in no time. For a deep dive on single-line fonts (youtu.be/-Uj6Dz8g0ko) and tabs/bridges (youtu.be/R2tR9hLwVF0), check the LightBurn tutorials. 📌



E Help your end user by labeling parts that should fit together ...



F ... and by scoring faint outlines where parts should be placed, like this window.

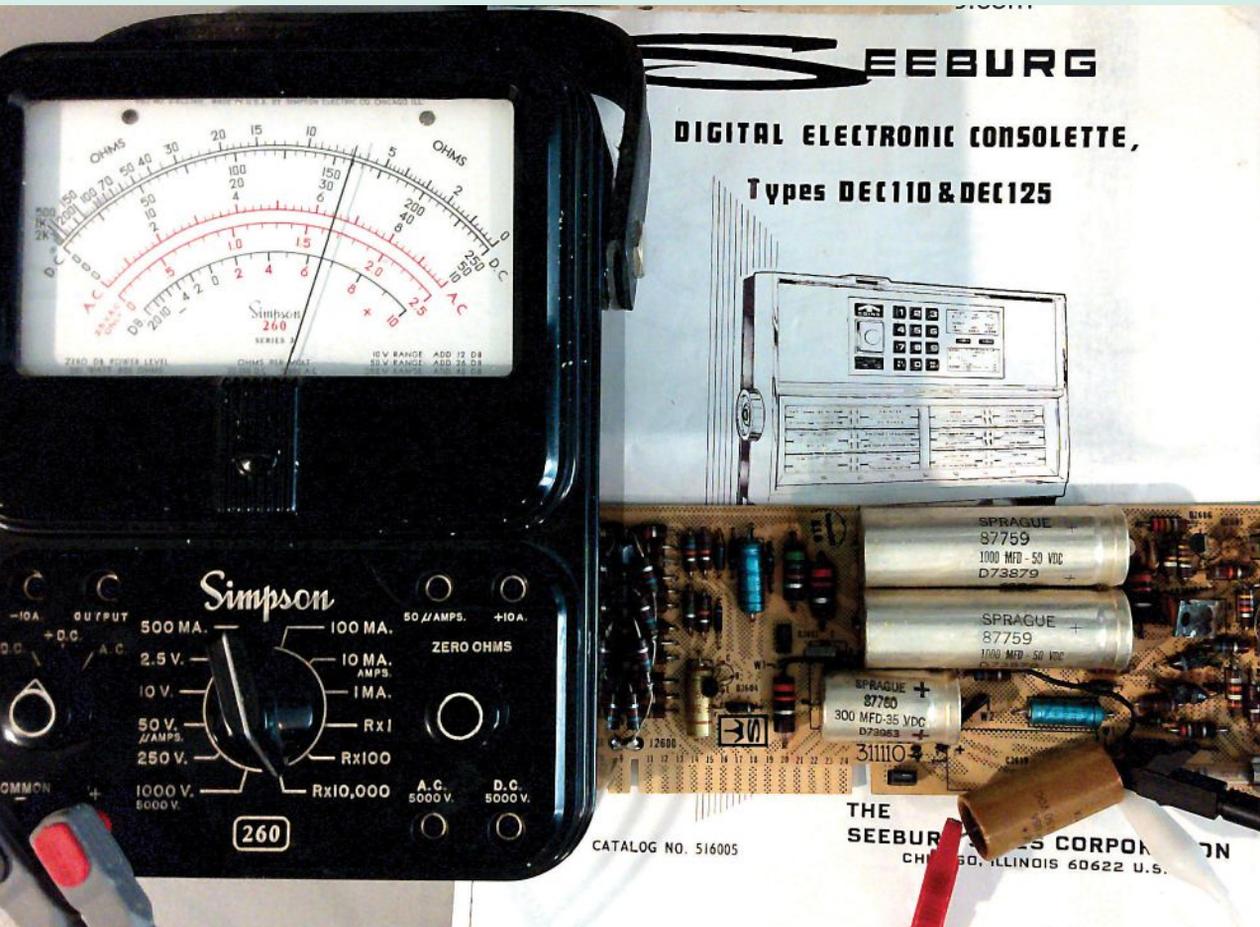


These LightBurn skills have helped me streamline production of my laser-cut kits like this Book Nook diorama — a miniature wardrobe with working doors that hides a portal to a snowy forest beyond. Kits and plans available at etsy.com/shop/JenSchachter.

GOOD CAP BAD CAP

Replacing old capacitors to restore vintage electronics

Written and photographed by Wayne Seltzer



WAYNE SELTZER is a retired electrical engineer and product manager, currently teaching creative technology and design at the University of Colorado's ATLAS Institute. He founded and manages the Boulder U-Fix-It Clinic, a volunteer organization that helps people fix their broken stuff at ongoing repair events. boulderfixitclinic.org

Replacing old capacitors is an easy fix for common failures around the house, like refrigerators, window A/C units, and stereo equipment. And if you've ever searched for repair advice on retro gear, you've probably seen more than a few forum postings and websites that advise you to "Replace all the capacitors! Buy this kit!" and all your problems will be solved. Even if the kit includes all the correct parts and you spend the time carefully replacing each capacitor, will it work? Maybe, maybe not.

Before you overdo it, here's some practical advice to identify the capacitors that you should consider replacing.

WHAT CAPACITORS DO

A capacitor is a passive electronic component that stores an electric charge. They're rated in **capacitance** values ranging from small, measured in picofarads (pF), to large, measured in thousands of microfarads (μ F). They also have a maximum voltage rating. High capacitance and high voltage typically imply a larger physical size.

You'll find large capacitors in the **AC-to-DC power supplies** of all sorts of gear. Capacitors are used to filter the DC voltage. So, for example, if you hear an AC hum in audio gear like radios and amplifiers, suspect a bad capacitor. If you have an oscilloscope, you can look at power supply outputs to see if there is a lot of ripple in the signal. Sometimes products have labeled test points for measuring power supply voltages.

Audio filter circuits such as treble/bass controls, equalizers, speaker cross-overs, and guitar effects pedals are likely to use capacitors to reduce or boost a range of audio frequencies.

Oscillator circuits that create periodic signals (sine wave, pulses, etc.) often use capacitors; the capacitance is related to the frequency.

The audio output stage of many **amplifiers** use capacitors to "decouple" the DC component of the signal to connect to a speaker. A faulty capacitor will prevent the signal from passing from one stage of the circuit to the next. An audio signal injector and oscilloscope are useful tools for tracing the signal path.

Whatever kind of troublesome gear you're troubleshooting, a service manual and schematic diagram will be very helpful. Good news: Retro



gear is much more likely to have such documents available.

HOW CAPACITORS FAIL

All types of capacitors consist of two metallic plates separated by a **dielectric** (non-conducting) material such as air, electrolytic paste, polymers, paper, and others. Wikipedia has a long list at en.wikipedia.org/wiki/Capacitor_types.

If the dielectric fails in some way, the plates could conduct current to each other, forming a low-resistance circuit; this is known as a "shorted" or "leaky" capacitor. Or the wires connecting to the plates, or the plates themselves, could fail, causing an "open" capacitor and incomplete circuit. High voltage spikes, heat, moisture, vibration, and the passing of time can cause these problems.

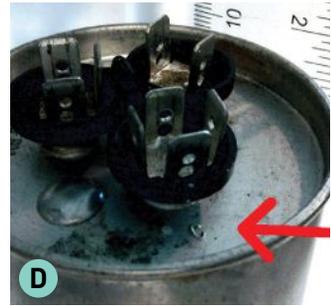
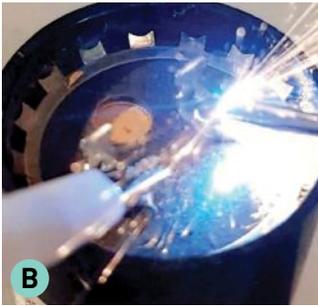
Old paper capacitors are particularly vulnerable to failure — they can dry out over time — but don't jump to conclusions if you see one. Many 50-year-old paper capacitors are perfectly fine.

You might come across some bulging electrolytic capacitors. This means they've been stressed beyond their voltage limits, or perhaps developed an internal short, and some of the liquid electrolyte has boiled into a gas, expanding the package. These are obvious candidates for testing and possible replacement.

Figure A shows an old 8 μ F "dry" electrolytic capacitor with paper and wax construction. Though it looks like some wax has melted, that doesn't necessarily mean it's defective. The best way to tell for sure is to test it with a reliable capacitance meter.

TESTING CAPACITORS

It's challenging to test a capacitor while it is connected to the rest of the circuit. It probably



CAUTION: Large-value capacitors may have significant stored charge even in an unpowered circuit. Don't shock yourself. Use a test lead and an insulated screwdriver to short out the capacitor before poking around. If you get a healthy spark, that's probably not the faulty capacitor you are looking for.

Figure B shows a large capacitor — the starting capacitor for an air conditioner compressor — that is being discharged. You can see the slow-motion video at youtu.be/wmVyfkg6ZCM.

has other components connected to it that will prevent measurement of the capacitance. If a multimeter shows zero ohms across the capacitor leads, it might be shorted — but it's possible that other components are responsible for the low resistance. Check the schematic if you have one.

You'll probably have to disconnect one lead of the capacitor to test it. It might be easy to desolder or clip the lead. Just be sure that you can easily reconnect it after testing.

MULTI-SECTION CAPACITORS

In your retro gear exploration, you might find some capacitors in a metal can with three (or more) terminals, labeled with two or more capacitance values. These are usually electrolytic capacitors sharing a package, almost always sharing a common negative terminal.

Figure C shows a two-section example, 35 μ F and 5 μ F, from an air conditioner compressor motor, labeled "35/5MFD." Testing the 35 μ F section shows only about 8 μ F capacitance, displayed as 8843nF (nanofarads). That's probably why this compressor wasn't running.

Figure D is a view of the terminals. Note the shared negative terminal marked "C" for "Common."

You might find it hard to obtain exact

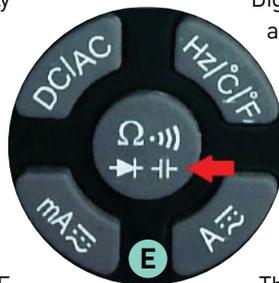
replacements for multi-section capacitors. One solution is to use multiple individual capacitors with the correct capacitance and voltage ratings, if you can find room to mount them. Or, if you want to preserve the look of your retro gear, you can carefully take apart a multi-section capacitor, remove the old capacitors from the can, and stuff new individual capacitors in. Because modern electrolytic capacitors are typically a smaller volume than their retro equivalents, you have a good chance of making this work.

USING A DIGITAL MULTIMETER

Your digital multimeter might have a capacitor test mode. Look for the capacitor symbol as shown in Figure E.

Digital multimeters test capacitors via a **resistor-capacitor (RC) circuit**. A low fixed voltage is connected to the capacitor being tested, and the meter looks at the voltage across the resistor. As the capacitor charges, it eventually reaches the input voltage, and the voltage across the resistor approaches zero.

The meter keeps track of the time required to charge the capacitor, does some math, and displays the capacitance value (Figure F). Note that the larger the capacitor, the longer it takes to charge. A 10,000 μ F cap could take minutes to charge, so be patient before declaring the capacitor as failed.



USING A LOW-COST MULTI-FUNCTION TESTER

If you're interested in a low-cost tester, you can find this TC1 Multi-Function Tester (seen in Figure C) on Amazon and eBay for about \$20. These automatically identify transistors, diodes, inductors, resistors, and capacitors and display their measured characteristics.

CAUTION: Again, make sure you discharge capacitors before testing! In this tester there isn't any protection to the input pins of the microcontroller, so a charged capacitor is likely to destroy the electronics. (Then you'll have something else to repair!)

USING AN ANALOG MULTIMETER

An "old school" analog multimeter with an electromagnetic pointer is an intuitive way to test a capacitor. Watching the meter move as the capacitor charges provides an intuitive sense of what's going on (Figure G). You can see a video of this process at youtu.be/h-ush_YG5Qc.

LEARN MORE ABOUT CAPACITORS

The RC circuit is part of any electronics education and it's helpful for understanding what capacitors do. In this circuit, a DC voltage source (like a battery), resistor, and capacitor are connected in series. When the circuit is turned on, the capacitor charges through the resistor until it reaches the voltage of the DC voltage source. Here's the equation:

$$V_c = V_s (1 - e^{-t/RC})$$

V_c = voltage across the capacitor

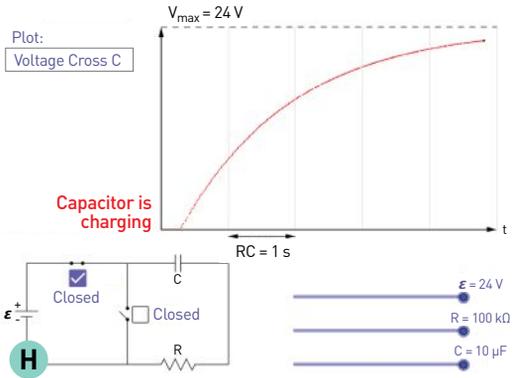
V_s = voltage source

$e = 2.71828...$ constant (Euler's number)

t = time elapsed since the circuit was connected

RC = resistor R in ohms (Ω) \times capacitor C in farads (F)

If you want to experiment, you can easily build your own RC circuit, or you can use one of the many online physics and electronics simulators available. Try one at geogebra.org/m/rFEV4HJx



— click the switches to charge and discharge the capacitor and watch the capacitor voltage change (Figure H). You can change the values of the resistor and capacitor to see how they affect the circuit's behavior.

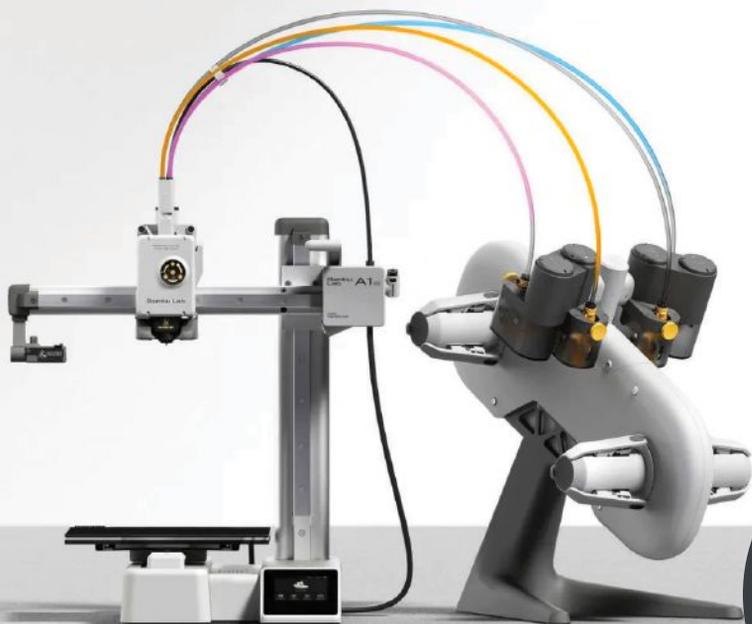
NEXT STEPS

Consider outfitting your workshop with a collection of **test equipment** including a multimeter, oscilloscope, and audio signal injector. There are lots of audio signal generators on the markets and some low-cost kits you can make yourself.

Build a **collection of capacitor types** and test them with your equipment so you are familiar with the process and components before you start troubleshooting your gear.

There are many resources on the web to help you with your projects. And, there may be a **fix-it clinic or repair cafe** in your area where volunteers are happy to give you a hand. Check out boulderufixitclinic.org → Repair Resources to find a clinic near you.

Have fun repairing and restoring your broken stuff! 🛠️



Bambu A1 Mini With AMS

\$459 combo us.store.bambulab.com/products/a1-mini

The A1 mini is Bambu's most affordable 3D printer. To enable multi-material printing at this price point, they've gone with a small build plate, but big features.

EASY AND FAST

Out of the box, it's almost completely ready to go. You do have to remove a shipping bracket, attach a filament holder, and plop the PTFE tubes into place but these things only took me about 30 seconds.

Printing is as easy as you'd expect from Bambu at this point. One thing I liked immediately: before it begins, the machine prompts you to select which filament from the AMS (automated material system) you'd like to use. Very convenient.

This little printer is surprisingly fast; you'll want to place it on a sturdy surface so it doesn't walk away. However, even on a wobbly table I didn't notice any print defects from the speed. Although the A1 mini is small, when paired with the AMS it still takes up considerable desk space, because the new version of the AMS is free-standing and sits next to the printer instead of on top.

NEW IMPROVED MULTI-MATERIAL SYSTEM

The new AMS system is quite nice. The open layout resolves some annoying issues with the previous version, such as broken filament getting stuck down inside the unit. I really like this implementation of a multi-material system. I rarely use it for multicolor prints, but rather as just a nice system for dispensing my filament. I have four different colors loaded at any time, and I can select them in the slicer or at print time on the machine. I can even set the machine to swap to another roll when the one I've selected runs out.

For multicolor printing, the AMS works great. As you can see in my Fat Shark model (printables.com/model/459165), colors are crisp and clear and the print quality is not affected. However, as with all filament swappers, there's a lot of waste.

This is a fantastic printer so far. The price is hard to beat; nothing on the market really competes with this if you're looking for multicolor. I would highly recommend the A1 mini for those starting out. So far, it's extremely easy to use and the quality it puts out is very nice. —*Caleb Kraft*



XTool S1 Enclosed Diode Laser Cutter

\$2,299–\$2,999 options xtool.com/products/xtool-s1-laser-cutter

The Xtool S1 is a diode-based laser cutter that fits right into the desktop laser market we've seen previously dominated by CO₂ lasers. It touts a 40W diode cutting/engraving tool, autofocus, curved surface compensation, and a rigid, well-designed enclosure. There's a host of accessories to expand the capabilities, such as a riser box for tall objects, a rotary tool, and even an auto pass-through for engraving objects larger than the standard 19"×12" bed.

I'm really impressed by this machine. It feels super solid and safe. I'm not worried about stray laser beams reflecting around the room, like I do with open gantry machines. It has an auto pause feature when you open the lid, as you'd expect.

The feature set is very competitive: the autofocus and curve compensation are strong winners here. Frankly, at this price I'd highly recommend this over the base model of some popular desktop CO₂ brands — with the caveat that you can accept the limitations of a diode, such as struggling with transparent items. This machine makes the diode laser feel like a serious tool. —CK



Creality K1C 3D Printer

\$559 creality.com/products/k1c-carbon-3d-printer

Creality's new flagship printer features a hardened steel quick-change nozzle, blazing fast speeds (powered by Klipper firmware), a fully enclosed environment, and an AI-enabled camera, all at a surprisingly low price. If only that were where our story ended!

My test prints came out great — fast and clean with smooth walls, no ringing, clean overhangs, and smooth top and bottom layers. Thanks to the nozzle-based auto-leveling, I had no issues with bed adherence, without tuning. The enclosure looks professional, something we're not used to seeing in a sub-\$700 3D printer. Sadly though, the K1C feels half baked, near-great but with simple things missed.

The most glaring issue? The cable chain, which guides the cables and filament to the extruder, bangs up against the lid, sometimes lifting and dropping it. Creality was obviously aware — they include a strip of rubber tape meant to muffle it and protect the lid — but it just seems silly to ship machines like this. Also, there are no load or unload scripts for changing the filament, and no instructions for it.

If you want a printer for advanced materials like carbon fiber, and can deal with its quirks, the K1C is a fast, low-cost option. If you're looking for your first printer, probably skip it until the next version works the kinks out. —Matt Stultz



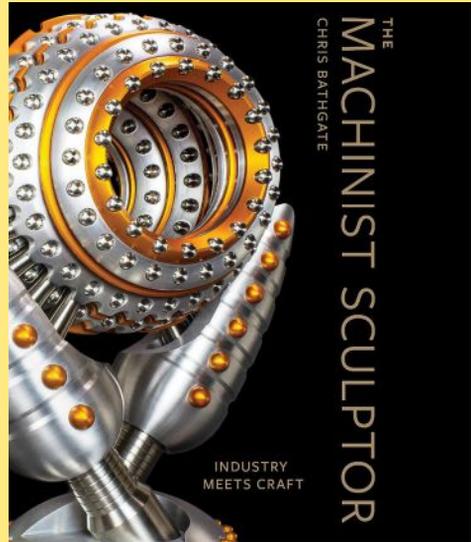
TwoTrees TTC 450 CNC Router

\$549 as tested twotrees3dofficial.com

This affordable CNC router from TwoTrees boasts a 460×460×80mm working area. It arrives partially assembled including a wasteboard, tools for assembly, and a small assortment of endmills. This machine is intended for soft materials like plastics, foam, and wood. You can also work in soft aluminum if you go slowly.

The TTC 450 is an interesting size and price point: it's almost as big as an X-Carve or Shapeoko, for less than half the cost. The savings come from how barebones this router is — it doesn't have the fancy software of the others, and it comes with a pretty tiny set of end mills.

Overall it's a pretty good option for someone on a very tight budget. If you're wanting to do more woodworking, I'd consider upping your budget to get something a little more rigid, but if you're just wanting to learn, this machine should work fine and you'll be able to produce things like cutting boards without issue. —CK



The Machinist Sculptor: Industry Meets Craft

by *Chris Bathgate*

\$65 schifferbooks.com/products/the-machinist-sculptor

A coffee table book is a well-established concept, but what would a “workbench book” look like? It would likely have all the components you'll find in Chris Bathgate's *The Machinist Sculptor*: blueprints, CNC machining, piles of steel chips, colorful anodized and polished materials, and stunning artwork.

Bathgate has been producing incredible artworks based on industrial methods that captivate and stun people whether they know how to work a knee mill or not — finely machined works that look like constructions from another civilization, machined to a beautiful fit and finish and assembled with great care. In this book, he dives into his past work and expounds on his process both physically in the workshop and mentally with his views of art.

Get this book for the maker in your life and they will thank you. —CK



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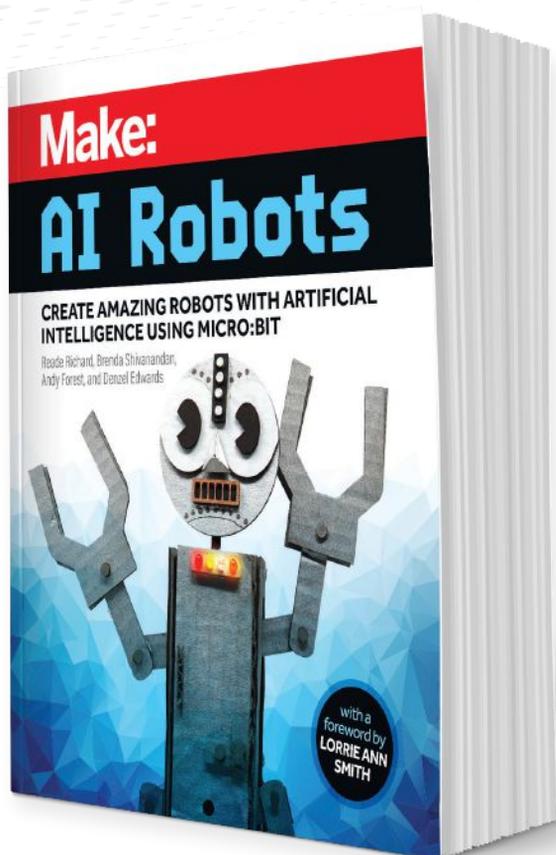
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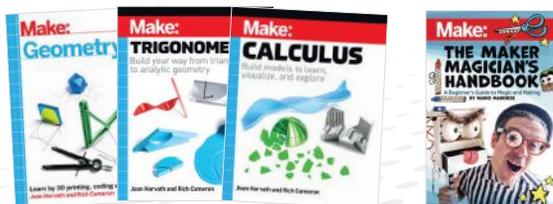
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OVER THE TOP



HOLY BIKE [INSTAGRAM.COM/BROOKDALEBADBOY](https://www.instagram.com/brookdalebadboy)

For some, there is nothing more beautiful than the sound of a motorcycle revving its engine in the distance. The raw power, the noise, and the sheer unadulterated *coolness* of a good motorcycle can seem almost heavenly to the bikers and gearheads of the world (as well as providing excellent canvases for making and customization). All of the motorcycle's power and potential can be seen in **Keith Young's** piece — the **Holy Bike**.

Young grew up in California's Bay Area surrounded by makers, and custom lowriders were a constant sight in his town. The Holy Bike, as he calls it, was born from his childhood memories of custom motorcycles and began life as the engine of a 1975 Honda 550 Super Sport motorcycle.

"When people build custom vehicles," Young said, "they always put the biggest and craziest engines they find with lots of chrome. I wanted something simple and easy, something old school with character."

Young specifically chose not to use any high-tech tools, machines, or programs — the bike was born from his imagination and hands alone, working with assorted hand tools, a drill press, a welder, and quite a lot of steel, copper, and brass. He describes the resulting motorcycle as a "rat bike," or a custom piece marked by its unfinished appearance and unconventional parts. "The term *rat* in this context is meant to convey a sense of ruggedness and individuality, as opposed to the polish and pristine look of other motorcycles. Specifically, this bike is a reflection of me growing up with my dad in the garage, building stuff with what we had, by hand."

In a figurative and literal nod to its origins, the Holy Bike has 550 holes drilled all across the frame, the swingarm, the front forks, and even the gas tank. It has no kickstand but instead uses a Level Ride Air Suspension system to raise itself up and down, taking cues from the lowriders of Young's youth. And yes, it is still a working motorcycle. —*Marshall Piro*s



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