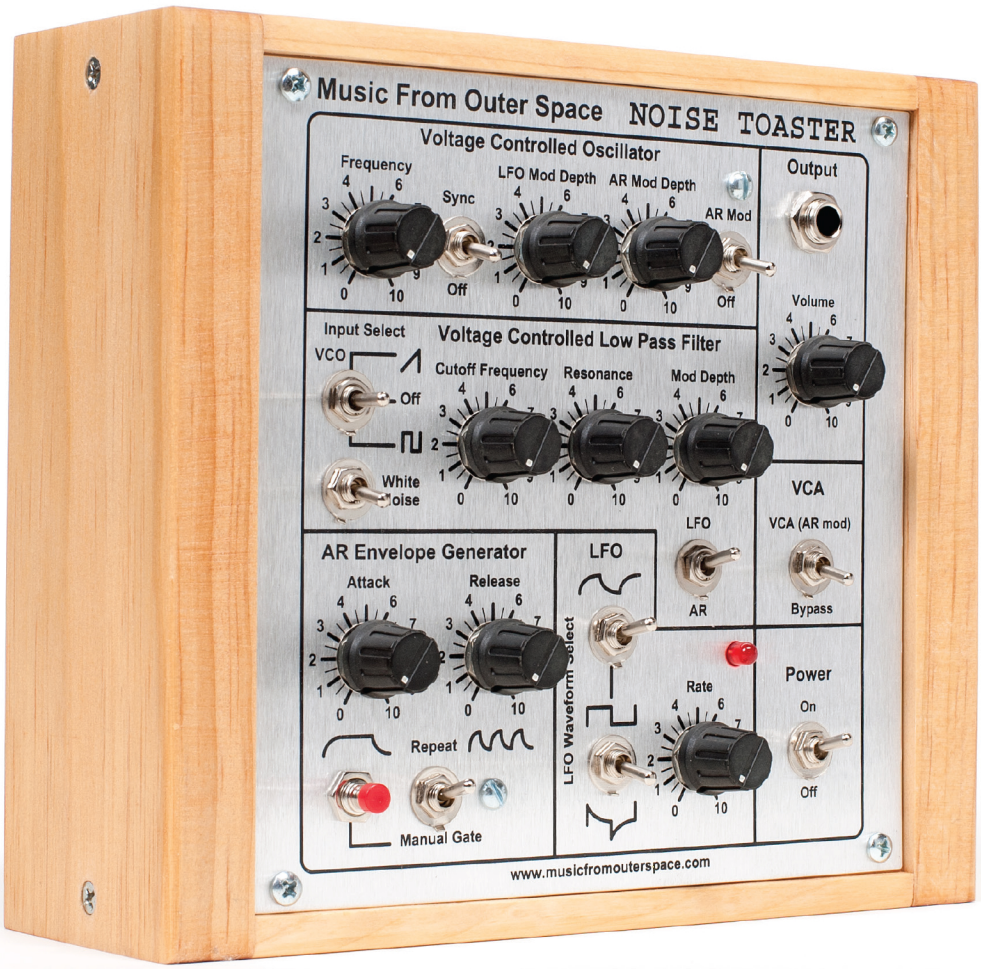
Make: Analog Synthesizers



A modern approach to old-school sound synthesis

Ray Wilson

Make: Analog Synthesizers

Ray Wilson

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Make: Analog Synthesizers

by Ray Wilson

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[TI]

For Debra Lee, whose love and kindness sustain me; Jonathan and Arielle, the lights of my life; and my parents, Charles and Elia Wilson, who always encouraged me to be inventive.

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Preface

I hope this book becomes tattered from use and is kept close at hand on your desk or work bench. We're going to cover a lot of information about analog synthesizers and how to get started in the fun and engaging hobby of *synth-DIY*. You'll need some electronics knowledge to fully benefit, but I think you'll find what's here interesting and informative regardless of your experience. Be forewarned that this is one of those hobbies that can become consuming, with ideas building on other ideas and inspiration coming at all hours of the day and night. You may find yourself soldering in your skivvies from time to time because you come up with an idea that simply can't wait for tomorrow to try out.

How I Got Started

I've had a consuming interest in analog synthesizers since the first time I heard *Switched-On Bach* back in the spring of 1968. Back then, the only thing that separated me from one of those analog beauties was cash, and lots of it. Those early synthesizers were way out of my financial reach, as in thousands of dollars out of my reach. However, I had an excellent opportunity to at least check them out and play them. My window into the world of analog synthesizers was provided by a music store in McKees Rocks, Pennsylvania, that has been there since 1965.

I haunted the keyboard room at *Hollowood Music and Sound* just about every day of my adolescence, and I can still remember being able to try out any of the amazing units on display. Looking back, I really appreciate how cool Mr. Hollowood was for allowing a skinny kid with long, curly hair and a penchant for trying to imitate Keith Emerson (I said trying…) to jam on any synth in the store while he was well aware that I couldn't possibly afford any of them (Figure P-1). The person who ran the keyboard room was an amazing keyboard player named John Bartel. John was one of my heroes because not only was he an outstanding keyboardist, but he actually knew how to get an awesome sound out of any synth in the place, including the ARP 2600.

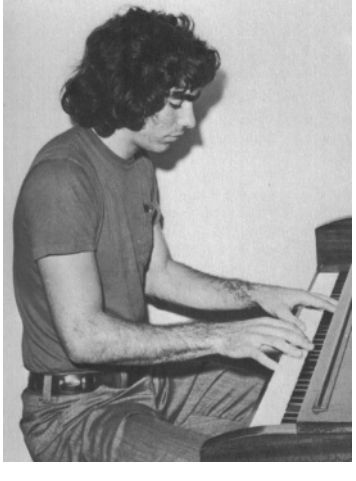

Figure P-1. *Would you let this character try out your ARP 2600?*

In those days I didn't know an ADSR from the business end of my alimentary canal. Eventually, after I started to work at U.S. Steel (as in an actual steel mill), I had some money in my pocket, and you can probably guess where I spent it. I went through a litany of analog synthesizers, buying, selling, and trading mainly Korgs, Mini-Moogs,

and a variety of the patchable semimodular Roland units. I'm ashamed to say that often I didn't fully explore the nuances of a synth before trading it off for a newer, shinier one.

Analog synth greed got a hold on me, oh lordy it got a hold on me. Playing and recording with them on my Tascam 4-track with 10-inch reels was a blast, but I wanted something more. I wanted to be able to make an electronic device that would allow me to interact with the synthesizer somehow. I had grandiose visions of someday making my own synthesizer. Little did I know that one day I *would* be building my own modular analog synthesizers that could do anything any synthesizer in that keyboard room could do (and more). And *you can too*.

My Electronic Roots

When my father, who was a remarkable mechanical engineer, used his influence to get me a job at the U.S. Steel Wheel & Axle Works in McKees Rocks, Pennsylvania, as a laborer in the "labor gang," I couldn't have guessed what was in store. To this day it surprises me that the mill would eventually be my ticket to receiving electronics training and in time (OK a *lot* of time) lead to me starting my own small electronics business, *Music From Outer Space LLC*, which I run to this day.

After a year or so of shoveling, sweeping, and jackhammering—and way more than likely at the behest of my father—I got into an electronic repairman apprenticeship program. This meant that I was freed from the labor gang! Not that jackhammering scale (the drossy crust that falls from steel billets as they are being heat-treated) out of furnaces that had been heat-treating train wheels the day before wasn't fun, but the apprenticeship was a godsend (well actually a *dadsend*). The apprenticeship meant that I got to go to the Homestead Works in Homestead, Pennsylvania (where they used to produce those giant buckets full of molten steel) and get paid more than I did as a laborer to learn electronics!

I had found my passion. I supplemented my classroom training with breadboard experimentation, a Heathkit microprocessor trainer kit, and reading, reading, and then… more reading. I did the practice math problems and experiments in the books, and I'd encourage you to do the same if you're just getting started. Through it all I learned enough to spend the next 15 years in the medical electronics industry, finally landing in the biomedical engineering department of Siemens Pacesetter. Interestingly, I was able to do this without an engineering degree, but I think those days are over, so get in college and stay there until you're armed and dangerous with a degree in something useful.

Equipped with enough electronics training to be dangerous, a friend and I started a small electronics kit sideline called *Waveform Processing*. We were located in Crafton, Pennsylvania, and were in business from the late 1970s into the early 1980s. I designed some simple sound-making boxes (Figure P-2 shows the construction book and PC board that came with the Waveform Processing Mini-Synth), etched boards, kitted parts, and advertised in the much revered and renowned *Radio Electronics* magazine.

Figure P-2. *The Waveform Processing Mini-Synth*

To this day, I still cringe when I think of what we used to pay for a 15-word classified ad buried among hundreds of others in the back of that magazine: $500. Needless to say, the brand "Waveform Processing" is not rolling off of anybody's tongue today.

My interest in electronics didn't wane by any means; I kept on researching and breadboarding and developed some very cool mono- and polyphonic synths. I remember the excitement of discovering the Curtis Electromusic Specialties chips designed by Doug R. Curtis. They were simply the coolest chips ever. You could easily build voltage-controlled filters and voltage-controlled oscillators that tracked one volt per octave perfectly and were completely temperature compensated. I was in heaven. Eventually, however, family and job responsibilities caused me to pay less and less attention to synth-DIY.

I was getting my electronics design fix at Intec Systems in Blawnox, Pennsylvania, and eventually Siemens Pacesetter in Sylmar, California, so my focus shifted to designing electronic test equipment and writing software. In 1994, an earthquake of magnitude 6.7 chased us out of California and on to Aurora, Colorado. I can still remember throwing my first attempt at a modular into a huge dumpster as we hurriedly cleaned house and prepared to move. *(Man I wish I still had that thing.)*

After my work focus shifted entirely to software development, my *need* to work with electronics brought me full circle and back to synth-DIY with a vengeance. I started a website called Ray-Land (perhaps I'm a tad bit narcissistic) and began to publish the circuits, PC layouts, and circuit descriptions I was coming up with. I developed a simple, battery-powered mini-synthesizer called the *Sound Lab Mini-Synth* and published that as well, and it started to attract attention (Figure P-3 shows the very first Sound Lab Mini-Synth prototype).

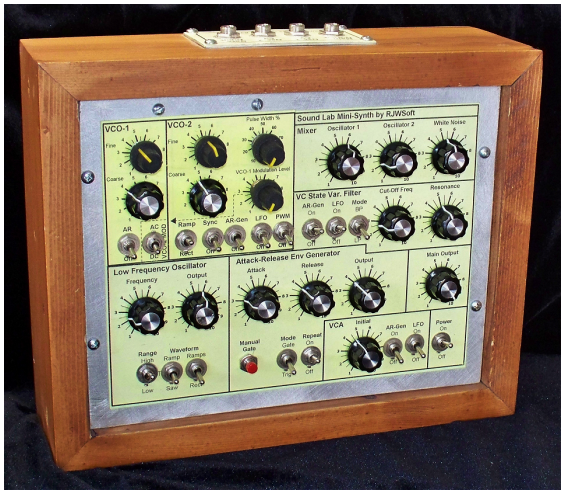

Figure P-3. *The Music From Outer Space Sound Lab Mini-Synth prototype*

Music From Outer Space

A fellow DIYer suggested I start selling the PC board for the Sound Lab Mini-Synth, and before you knew it, my current business, *Music From Outer Space LLC*, was born. I had the privilege of writing a 10-page article about the Sound Lab Mini-Synth for the March 2006 edition of the magazine *NUTS AND VOLTS, Everything For Electronics*. They even paid me half-decently to write it, to boot. I get a kick out of it to this day.

Figure P-4. *The Music From Outer Space website*

The name *Music From Outer Space* (also known as MFOS) was inspired by the fact that space program–related research was instrumental to the successful development of transistor and integrated circuit (IC) technology. Eventually, the technology trickle-down brought highly reliable, reasonably priced electronic components, transistors, and ICs to the masses. Today, MFOS is a popular website visited by synth-DIYers the world over (Figure P-4 is a screenshot from the website).

It's a great feeling to receive email from visitors expressing appreciation for the information and resources the site provides. I never forget how I learned from and was inspired by the work and invention of the synthesizer pioneers, many of whom are sadly gone now. The site's *Acknowledgments* page pays homage to my synthesizer heroes: the analog synthesizer inventors and electronics book authors who have inspired and taught so many of us. I'm convinced that synth-DIYers are some of the most creative and clever people around today, and I'm happy to say that many of the emails I receive from people asking questions or kindly thanking me are from some of the world's most prestigious learning institutions.

What You Should Know

If you have no electronics knowledge or training but still have a burning desire to get into analog synth-DIY, you have a bit of work ahead. You'll need to understand basic electronic principles such as:

- Reading a schematic

- Ohm's law
- How passive components work: resistors, capacitors, coils, transformers, switches, and relays
- How active components work: diodes, transistors, integrated circuits, and LEDs I heartily recommend the book *Make: Electronics* by Charles Platt (O'Reilly/MAKE). Don't think you have to completely understand the quantum mechanical level of operation before you can even get started, or you may *never* get started. The quantum community is still duking it all out.

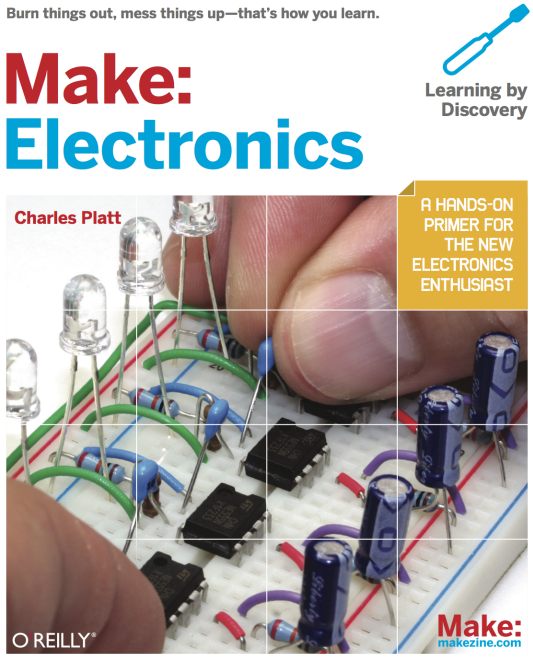

Figure P-5. *Make: Electronics is an excellent kickstarter for your basic electronics knowledge*

Purchase one of those 75-in-one electronic experimenter kits that have the components connected to springs or clips that facilitate building up and tearing down circuits quickly. The kits normally come with a book that takes the user through scores of experiments that often build on one another and clearly present the principles of operation for each circuit presented. I suggest you discipline yourself to simply step through *every* experiment and maybe even do each one *twice* for good measure! Yes, the kits look a little cheesy in their colorful cardboard boxes, but you can bet that Bobby Moog himself went through a number of these in his youth, and believe me, if you apply yourself, you *will* learn quite a bit.

The material presented in this book assumes a basic level of electronics knowledge and experience, including schematic reading, recognizing electronic components and how to read their values, soldering, and constructing electronic projects, including PC board population and front panel wiring. And no matter if you've been building for years or if you've just started, you'll need to know some troubleshooting techniques.

Once you've got the electronic basics down, you're ready to start finding synth-DIY projects to experiment with. The Music From Outer Space website presents scores of fully documented synth-DIY projects for both newbies and advanced hobbyists. I think you'll find the Noise Toaster lo-fi noise box (see Chapter 4) to be a great starting project if you're a synth-DIY newbie—and just one of the coolest portable toys ever if you already have DIY skills. It makes a really wide variety of sounds, and it's a solid analog synthesizer through and through.

What's Next?

Chapter 1 gives some background and shows a few examples of what kinds of synthesizers are possible to build once you have some synth-DIY experience under your belt. Chapter 2 shows you what tools, test equipment, and electronic components you'll need in your work area or lab to succeed in your synth-DIY work. Chapter 2 also covers how to improve your soldering skills and presents some sage troubleshooting advice. In Chapter 3 I'll discuss the purpose and operation of the various analog synthesizer modules, what they do, and how they interconnect and interact. Chapter 4 describes the construction of the Noise Toaster analog noise box project. Chapter 5

presents an introduction to op amps that leads into an explanation of the circuitry behind the Noise Toaster in Chapter 6. Chapter 7 brings it all together with some useful information about how to record your next platinum synth music CD using your computer as a multitrack recording studio. The three appendixes dive deeper into several common electronic circuits found in analog synthesizer modules, how they function, and how you can use them in your own projects.

We've got a lot of material to cover, so let's get started.

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1 What Is Synth-DIY?

In the mid-1960s an electronics engineer with a Ph.D. from Cornell University in engineering physics was starting a musical revolution, and he didn't even know it. That engineer was Robert Moog. In a small factory in bucolic Trumansburg, New York, he was developing a series of unique electronic analog sound synthesizers that would take the musical world by storm.

At the same time, the muse of invention was striking a West Coast engineer named Don Buchla. Buchla was developing his own unique series of electronic analog sound synthesizers. Both Moog and Buchla's remarkable inventions were *voltage-controlled*; they both used a varying voltage to control the sound-shaping functions of the synthesizers' modules.

It wasn't long before analog synthesizer sounds and music were being heard everywhere all the time. They made their way into music studios, records, commercials, jingles, company sound logos, movies, every genre of music, video games: everything. Analog synthesizer sounds and music had become so widespread that scores of companies saw the potential market and dove headlong into the analog synthesizer business. Some popular manufacturers were Moog, ARP, Oberheim, Yamaha, Korg, Fairlight, E-mu Systems, Roland, and many others.

Although extremely popular for many years, the analog synthesizer's sales numbers eventually began to dip with the advent of less expensive, easier-to-manufacture, *and pretty darn snazzy* digital synthesizers. Instead of creating sounds using analog sound-producing circuitry, digital synthesizers use microprocessors to do the heavy lifting. Binary representations of various sound and instrument waveforms are stored in read-only memory (ROM). The microprocessor coordinates the synthesizer's real-time user interface activity, scans the polyphonic keyboard, and finally processes and streams the digital audio data to the synthesizer's output.

This was one of the digital synth's weaknesses. Instead of the completely continuous, organic, full sound of the analog synthesizer, the digital units often included digital conversion artifacts and lacked sonic character. Figure 1-1 highlights the difference between a waveform generated digitally and a continuous waveform generated by analog circuitry. The early digital units borrowed from analog synthesis for filtering and sound envelope shaping for a time, but the lower cost, manufacturing advantages, and technical advances of the digital units soon ended the analog synthesizer's dominant reign of many years.

Sadly, history also shows that while it takes an electronics genius to invent amazingly cool synthesizers, it also takes a great deal of business sense to keep a company in the black. Just about all of the major players in the synthesizer industry had an electronic genius or two on board, but only a few remembered to hire a chief financial officer (CFO). Many of the major players in the synthesizer business are now only a memory, a distant electronic wail in the breeze.

However, analog synthesizers were just too cool to stay gone forever. There has always been a small analog synth priesthood keeping the faith alive, but today, people all over the planet are

rediscovering the warm, inimitable analog synthesizer sound. They're finding that turning *real* knobs, flicking *real* switches, plugging in *real* patch cords to produce *real analog* sounds is way more interesting and engaging than scrolling through an LED parameter display or clicking virtual switches with a mouse. Today many musicians and hobbyists with an interest in electronics are discovering that with the right schematics, tools, printed circuit boards (PCBs) and ingenuity, making their own analog synthesizer is well within reach. The book you're holding in your hands right now has the information you need to put you squarely onto the road to *doing it yourself* when it comes to building your very own analog synthesizer.

A Bit of Analog Synthesizer Etymology

Before we move on, let's take a moment to consider what the term *analog synthesizer* really means. The word *analog* puts me in mind of *organic*, *living*, *real*, and *continuously variable*. A good definition of the word *analog* would be "of, relating to, or being a mechanism in which data is represented by continuously variable physical quantities." The key point we're interested in as far as describing an analog synthesizer is "continuously variable." An analog synthesizer creates sound by means of electronic circuit elements: resistors, capacitors, transistors, and integrated circuits. If you observed the output of an analog synthesizer with an oscilloscope, you would see that the waveform voltage is continous, as opposed to the characteristic stepped appearance of a digital signal source (Figure 1-1). This is one of the characteristics that give analog synthesizers their warm, fat, and much-sought-after sound.

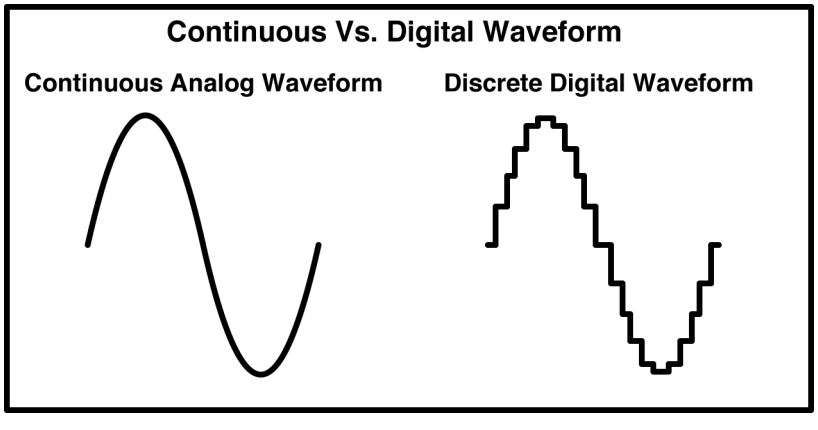

Figure 1-1. *Continuous waveform versus discretely stepped digital waveform*

Additionally, much of the circuitry found in an analog synthesizer has roots in the early analog computers. These were very early computers built from operational amplifiers and passive electronic components (resistors, capacitors, coils, etc.) that performed mathematical operations such as logarithms, multiplication, division, addition, subtraction, and even root finding. Analog computers were used by scientists and engineers to solve all manner of mathematical problems before modern digital computers were developed. Variables were entered using potentiometers (informally known as *pots*) to set voltages, which the analog computer would process in real time. Interestingly, the circuit used in an analog synthesizer to regulate the response of the voltage-controlled oscillator (VCO) to control voltage is a linear voltage to exponential current

converter that might well have been found in an electronic analog computer.

Now we turn to the term *synthesizer*. To synthesize is to take existing elements and combine them to produce something new. Anyone who has heard the incredible range and variety of sounds that come from an analog synthesizer would have to agree that its combination of unique electronic circuitry produces incredible sounds not heard before on this planet. Analog synthesizers are also perfect for producing convincing reproductions of just about any acoustic or electronic instrument.

How do I define analog synthesizer-DIY, or synth-DIY, as I call it? It's people making their own electronic sound boxes, noise makers, and synthesizers; and modifying Speak & Spells and other vintage electronic sound toys to get weird and unusual sounds from them. It's conventions where from a few to as many as hundreds of people who share the synth-DIY passion get together to compare notes and see and hear one another's latest projects. It's learning about electronics and components, reading schematics, soldering PC boards, and wiring front panels. It's learning where to find the best prices and selection for electronic components. It's learning what tools and equipment you'll need to succeed and how to troubleshoot the projects you make. It's being creative, including learning how to set up a recording studio right on your computer so you can make multi-track recordings of your sound creations. And finally, its actually making your own analog synthesizer, from something as small as a lo-fi noise box to as huge as a modular monster that would have cost tens of thousands in the analog heydays.

What Can I Build?

What you can successfully build depends on the level of electronics knowledge you possess, the effort you put forth to learn and become proficient, and the passion you have to build your own analog synthesizer. Please rest assured that even if you are just getting started, the analog modular *sky* is the limit—if you really want to get there. I always suggest that newbies cut their teeth on solderless breadboard experimentation or one of those electronic experimenter kits. After you've gone through the experiments and know a bit more about resistors, capacitors, transistors, and ICs, step up to a kit with a PCB that requires soldering—because wielding a soldering iron is a fundamental skill you just can't do without. I'll go over the tools you'll need and how to set up your workbench in Chapter 2. But now, let's take a look into your possible DIY future and feast our eyes on some photos of analog synthesizer DIY projects people have contributed over the years. Many graphic artists are drawn to synth-DIY and express themselves not only audibly but visually as well.

Figure 1-2 shows the popular MFOS *Alien Screamer* built by DIYer Bernard Magnaval, of France. DIYers build their own cases and make their own faceplates. I love the creativity shown in this build: the bright colors and cool-looking knobs. The Alien Screamer has a VCO and a low-frequency oscillator (LFO) that can be used to both modulate and sync the VCO. The LFO provides a variety of waveforms with which to modulate the VCO's frequency. For its size and simplicity, this little guy makes some totally cool sounds.

Figure 1-2. *Music From Outer Space Alien Screamer*

This DIYer etched the circuit board for this eight-step sequencer in Figure 1-3 from a layout published on the MFOS website and then built up the entire project. Sequencers are used for repeating patterns of notes and creating arpeggiation effects.

Figure 1-3. *Music From Outer Space eight-step sequencer*

The Sound Lab Mini-Synth (Figure 1-4) is a favorite among DIYers, with its two VCOs and warm-state variable voltage-controller filter (VCF), as well as a normalized switching scheme that permits a *ton* of sonic variety. This is the project that put MFOS on the synth-DIY map and has been built by hundreds of people around the world.

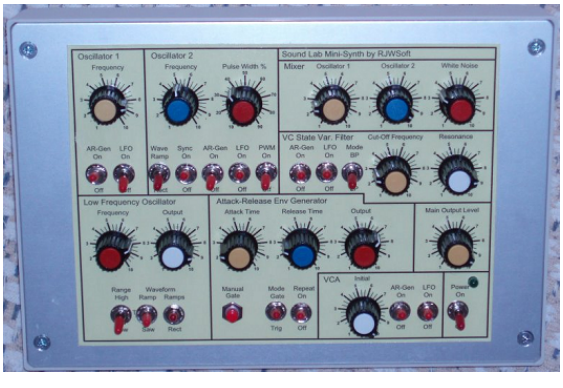

Figure 1-4. *Music From Outer Space Sound Lab Mini-Synth*

Some people go to great lengths to express themselves through synth-DIY. Figures 1-5 through 1-7 show some of the more unusual examples. If you plan to gut your Stradivarius for a synth case, I suggest you think it over calmly for a bit, but in the end, the decision is yours. Using parts of a human body is also up to you, but as you can see, it has been done. And finally, some folks like to wear their synthesizer and march through their neighborhood. Doing so is entirely up to you and perhaps your homeowners association.

Figure 1-5. *A Stradivarius made into a Weird Sound Generator*