A Comprehensive Guide to Understanding, Programming, Playing, and Recording the **Ultimate Electronic Music** Instrument

THE SYNTHESIZER

MARK VAIL

The Synthesizer

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ELECTRONIC MUSIC INSTRUMENT

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FOREWORD

When Bob Moog introduced the Moog modular synthesizer in the 1960s, it was the first new popularized instrument invented since Adolphe Sax created the saxophone in 1846. While almost a century separated these developments in musical technology, the efforts that led to the modern-day synthesizer were many. Pioneers such as Thaddeus Cahill, Leon Theremin, Friedrich Trautwein, Raymond Scott, Vladimir Ussachevsky, Paul Ketoff, Harald Bode, and many more each made important steps toward exploring the possibilities of sound sculpting by electronic means. Bob Moog's work, and the work of every other synth manufacturer, is built on the shoulders of those giants.

Even prior to formal education in the fields of engineering and physics, Bob devoted his time in his father's basement workshop educating himself about the history and technology of electronic music. This early passion led to his double undergraduate degrees and to his PhD from Cornell University in Engineering Physics. He remained a student of both the technical rigors of engineering and the rich and varied history of electronic music throughout his career. His intertwined understanding informed his professional path; his path informed an industry.

At the Bob Moog Foundation we embrace the ultimate importance of music, science, and history education as a force to inspire children to blaze new paths. With Bob's life and career—and those of so many other synthesizer pioneers—as our inspiration, we created *Dr. Bob's SoundSchool* to teach kids the science of sound. Waveforms, vibrations, pitch, amplitude, and the components of sound creation and transmission inform the students' knowledge of basic physics. The concepts are also used to ignite their sense of curiosity, exploration, and creativity.

Through this book, Mark Vail is echoing Bob's very own sentiments of the importance of both technical and historical information as forces to true understanding of the vast and glorious world of sound synthesis. The thorough and methodical exploration laid forth in the following pages provides for an inspired path of learning, understanding, and creating. In particular, the section on controllers is something Bob would have felt to be of utmost importance. From the magical elegance of the Theremin to the then-unprecedented touch sensitivity of the little-known Eaton-Moog MTS keyboard to the touchpad on the Moog Voyager synthesizer, he was impassioned about the creation of new control interfaces for musicians; he saw them as the most viable means to provide musicians with increased means of access and creativity in synthesis. On one of his last days at work he said to a colleague, "The keyboard is an antiquated interface. It's time to move on."

Moving on, or looking toward the future, we will see a continuation of the ever expanding offerings in synthesis. It's an exciting time for unprecedented creativity, should people be bold enough to explore it to that end. With Mark Vail as our guide, we have the tools to do so.

Michelle Moog-Koussa
Bob Moog Foundation
Asheville, NC
moogfoundation.org
May 1, 2013

PREFACE

Shop via the Internet or enter a good music instrument store and you can find a huge assortment of synthesizers for sale. They come in many forms: analog, digital, hybrid, hardware, software, modular, patchable, fixed-architecture, programmable, brand new, quite old, and handmade from scratch or a kit. Lucky me, I've had the opportunity to play with almost every kind.

How did I get here? Wendy Carlos's astute "On Synthesizers" article for the May 1973 printing of *The Last Whole Earth Catalog: Access to Tools* instilled in me a great interest in these instruments. I bought my first synth—a Minimoog—in 1976, soon after I'd discovered *Keyboard* magazine. After moving to the San Francisco Bay Area in 1977, I earned an MFA in electronic music at Mills College in Oakland in 1983 and got married the same year. Toward the end of 1987 my wife, Christy, found an alluring ad in the *San Francisco Chronicle*: *Keyboard* was in search of an editor. I was very fortunate to land the position—thanks, Dominic—and worked on *Keyboard*'s editorial staff from January 1988 until April 2001.

My goal with this book is to inspire existing and potential synthesists to get the most out of and make the kinds of music they most enjoy with synthesizers of as many types as possible. I wanted to create a book that I haven't seen elsewhere. I dedicate it to the dreamers, designers, developers, programmers, performers, users, artists, technicians, fixers, modifiers, and owners of synthesizers of all sorts.

I extend my utmost thanks to my parents, Chuck and Jean (aka Kemosabe and Bubbles), who nurtured my interest in music and afforded me lessons and instruments; David Brodie for helping me find and purchase a Minimoog; Ellie Latz, who introduced me to her daughter Christy; Gordon Mumma, Lou Harrison, David Rosenboom, Maggi Payne, and Ed Tywoniak for their tutelage at Mills College; everyone at *Keyboard*, GPI, Miller Freeman Publications, and Backbeat Books, including Dominic Milano, Jim Aikin, Bob Doerschuk, Jim Crockett, Tom Darter, Ted Greenwald, Brent Hurtig, Andy Ellis, Michael Marans, Kyle Kevorkian, Debbie Greenberg, David Battino, Ken Hughes, Mitch Gallagher, Tom Wheeler, Art Thompson, Joe Gore, Jas Obrecht, Tom "Ferd" Mulhern, Richard Johnston, Bill Leigh, Matt Kelsey, Marty Cutler, Phil Hood, Sanford Forte, Jay Kahn, Mark Hanson, Andy Doerschuk, Jeff Burger, Kent Carmical, Jim Hatlo, Jim Roberts, Scott Malandrone, Ernie Rideout, Greg Rule, Karl Coryat, Pat Cameron, Charlie Bach, Michael Gallant, Marvin Sanders, Stephen Fortner, David Leytze, Amy Miller, Randy Alberts, Ned Torney, Rich Leeds, Linda Jacobsen, David Williamson, Ed Sengstack, Paul Haggard, Valerie Pippin, Gabe Echeverria and Chandra Lynn, Xandria Duncan, Perry Fotos, Jon Sievert, Robbie Gennet, Chris and Liz Ledgerwood, Sam Miranda, Cynthia Smith, Chris Eaton, Ricc Sandoval, Joanne McGowan, Matt Gallagher, Anthony Comisso, Rick Eberly and Margaret Anderson, Vicki Hartung, Dave "Feeney" Arnold, Pete Sembler, Diane Gurshuny, and Dan Brown, plus the many editors, authors, and publishers with whom I've had the pleasure of working, including Craig Anderton, Marvin Jones, Steve Oppenheimer, Gino Robair, Julian Colbeck, Tim Tully, Peter Forrest,

Peter Gorges, Matthias Becker, Ralf Kleinermanns, Gerald Dellmann, Ian Gilby, Paul White, Gordon Reid, and Jörg Sunderkötter; Dave Stewart, for sharing his keen British wit and expert contractual consultations; Dave Amels and Tom Rhea, who assisted me with the historical chapter content; and all of my very good friends in the music industry, namely Jerry Kovarsky, Jack Hotop, Amin Bhatia, Drew Neumann, Starr Parodi and Jeff Fair, Dave Smith, Bob Moog, Barbara Gaskin, Avery Burdette, Chris Martirano, Phil Clendeninn, Dale Ockerman, David Rosenthal, Laurie Spiegel, Don and Julie Lewis, Ikutaro Kakehashi, Roger Linn, Wendy Carlos, Don Muro, Mike Kovins, Charlie Bright, John "Skippy" Lehmkuhl, Suzanne Ciani, George Mattson, Hans Nordelius, Christoph Kemper, Dan Phillips, Chris Meyer, Andrew Lubman, Mike Groh, Roger Powell, James Grunke, J.L. Leimseider, Keith Emerson, Brian Kehew, Ben Dowling, Keiichi Goto, John L. Rice, Jordan Rudess, Jan Hammer, Malcolm Doak, John Bowen, Frédéric Brun, Colin McDowell, Herb Deutsch, Ernst Nathorst-Böös, Timothy Self, Morton Subotnick, Tom Coster, Kevin Lightner, David Zicarelli, Darwin Grosse, Alan R. Pearlman, Philip Dodds, Tina "Bean" Blaine, Ray Kurzweil, Candice Pacheco, Tage Widsell, Jennifer Hruska, Tim Ryan, Patti Clemens, Paul Wiffen, Marc Doty, Christopher Franke, Serge Tcherepnin, Rex Probe, Larry Fast, Kevin Braheny Fortune, Scott Kinsey, Dieter Doepfer, Tim Caswell, Eric Persing, Don Buchla, John Loffink, Mary, Greg and Marc St. Regis, Rick Smith, John Medeski, Bryan Bell, David Mash, Matt Traum, Geoff Farr, Gary Chang, Greg Kurstin, Pamelia Kurstin, Peter "Ski" Schwartz, Paul Lehrman, Andrew Schlesinger, Axel Hartmann, Moe Denham, Robert Bond, Tom Oberheim, Denis Labrecque, Tom White, Bill Mauchly, Milton Babbitt, Max Mathews, Lance Abair, Dave Rossum, John Chowning, Doug Curtis, Marcus Ryle, Kristoffer Wallman, Curtis Roads, Robert Rich, Dan Del Fiorentino, Robbie Clyne, Bob Yannes, Dave Bristow, Jeff Rona, Roy Elkins, Paul de Benedictis, Gerry Basserman, Scott and Kellie Wilkie, Dennis Houlihan, Jean-Jacques Perrey, Kevin Monahan and Denise Gallant, David Kean, TJ Martin, Tony Karavidas, Andrew McGowan, Paul Schreiber, Marsha Vdovin, James Bernard, David Van Koevering, Bryan Lanser, Philippe Chatiliez, Don Leslie, Alan Young, Mike McRoberts, James and Elisabeth Lewin, Paul Sommer, Kevin Jarvis, David Vogel, Barry Gould, Francis Preve, Keith McMillen, Virgil Franklin, John Eaton, Terry Riley, Lee Sebel, Gene Radzik, Gary Nester, Erik Norlander, Emile Tobenfeld, Bruno Spoerri, Geary Yelton, Bob Williams, Chester Smith, Alain Seghir, Dan Armandy, Felix Visser, Howard Massey, Pea Hicks, Timothy Smith, Jon Appleton, Jonathan Sa'adah, David Abernethy, and David Gross for their friendship and contributions to my synth knowledge and to the synth industry.

My sincere gratitude also goes to Stephen Masucci for sharing his knowledge and experience of restoring vintage modular synthesizers, preparing state-of-the-art synth-based systems for recording and performance, and introducing me to the graphic artist extraordinaire and synthesizer aficionado John Blackford; and to John Blackford for creating the astounding and beautiful cover of this book.

Thank you, Michelle Moog-Koussa, for filling the enormous gap left after your father and my friend Bob passed, for determinedly directing the Bob Moog Foundation under extremely adverse and distressing conditions, and for contributing the foreword to this book.

Thank you as well, Norm Hirschy, editor of Music Books at Oxford University Press, for the opportunity to complete this book and for caring guidance, enthusiastic encouragement, and utmost patience throughout the process.

Finally, thank you especially, Christy, for decades of love, support, devotion, forgiveness, singing with me, immense knowledge of grammar, acute editing-with-a-hatchet approach when needed, and letting me buy so many wonderful music-making toys.

Mark Vail

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ABOUT THE COMPANION WEBSITE

www.oup.com/us/thesynthesizer

Oxford University Press has created a password-protected companion website for *The Synthesizer,* and I urge readers to take full advantage of it. The site features contributions from synthesists Drew Neumann and Niklas Winde to supplement material in the book. While Drew provided screenshots and audio using Digidesign Turbosynth and U&I MetaSynth to create specific sounds described in the book, Niklas produced three video examples of the Buchla 296e Spectral Processor in action, demonstrating possibilities afforded by a special module from synthesizer pioneer Don Buchla. Oxford's and symbols respectively indicate these audio and video examples in chapters 1 and 2.

In addition, the companion website includes lists of synthesizer books, films, museums, manufacturers, forums, blogs, dealers, and stores combined with links to immediately transport you to most of those sites. Finally, you'll find an extensive discography of synthesizer music from past to present.

You may access the site using the username **Music2** and the password **Book4416.**

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The Synthesizer

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Trendsetting All-Stars

The lineage of purely electronic musical instruments dates back to 1919. It's fascinating to consider important developments and innovative ideas that have occurred since then, and a good way to lay a foundation for understanding the wide variety of synths currently available and where they came from.

The use of electricity for musical purposes actually dates back to 1759, when Parisian Jean-Baptiste de La Borde made the *Clavecin Electrique*, or Electric Harpsichord. Its static electricity–charged clappers under keyboard control struck bells, much like a carillon, except that carillons are purely mechanical. By the turn of the twentieth century, Thaddeus Cahill had developed the Telharmonium, comprised of spinning electric generators called alternators or dynamos to produce musical tones, along with organ-style keyboard consoles from which to play the enormous device that was so big it required several railroad cars to be transported. Cahill intended the Telharmonium to transmit music through phone lines to paying subscribers, but the venture failed. Cahill's designs eventually influenced Laurens Hammond in the development of tonewheel organs beginning in the early 1930s and subsequently led to such instruments as the popular Hammond B-3.

To limit the focus of this synthesizer history so that it's a manageable universe, we'll avoid electro-mechanical instruments and instead concentrate on those that generate(d) sound electronically, whether it be via analog and/or digital circuitry, magnetic tape, optical disc, software, or some other means. Among the following instruments are many that you're familiar with and others of which you've never heard. In no way is this intended to be a complete catalog of every electronic instrument or synthesizer. Instead, I've chosen those that are important because they introduced novel capabilities or implemented existing concepts in significant new ways.

The instruments are organized by what their makers intended them to do, or what they turned out to be best at doing. I've arranged them in five categories: Control, Sound, Performance, Interface, and Composition. *Control* features instruments that offered new and/or advanced methods of controlling sound. *Sound* highlights instruments that advanced the art of electronic sound generation. You'll find instruments optimal for use in live situations under *Performance*. The *Interface* section touts instruments with highly developed and conceptualized methods of interaction between the user and the synthesizer. And synthesizers that delivered extensively improved or extraordinary methods of creating music appear in the *Composition* area.

This is not to imply an instrument that winds up in the Interface section couldn't, for instance, produce exceptional timbres or provide outstanding features for composing new music. In such cases where any synth excels at other functions, I'll share this information.

Control

One of the major limitations suffered by many electronic instruments has been a lack of the musician's expressive control. An instrument's tone may be astounding, but if the timbre remains static and unchanging throughout a note's duration—and if every note exhibits the same **attack**, **release**, and **amplitude** characteristics—the listeners' emotional involvement and interest will quickly fade. A performance that lacks expression can quickly become tedious, but the performer can also become bored and the performance itself dull.

attack: the audible onset of a sound, which may occur quickly as with a note or chord played on a piano, or more slowly like a softly blown flute
release: how a sound ends, whether it disappears abruptly or fades slowly until it's inaudible
amplitude: the loudness of a sound, normally quantified in terms of the logarithmic decibel (dB) scale, where 0dB is the threshold of hearing, a quiet whisper at three feet is 30dB, a normal conversation 60dB, loud singing at three feet 75dB, inside a subway 94dB, and amplified rock 'n' roll at six feet 120dB

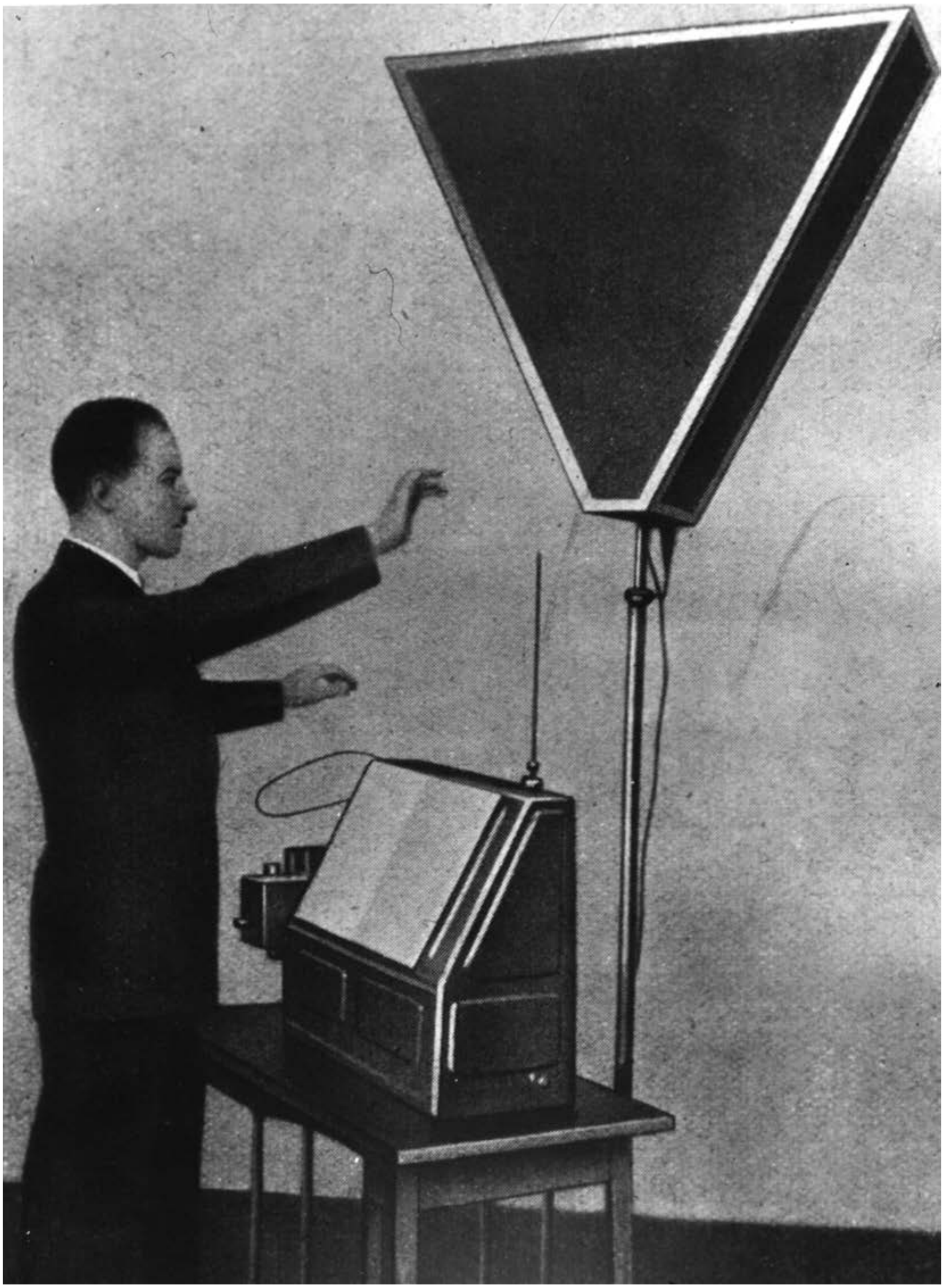
Since the introductions of the earliest electronic instruments, musicians have challenged makers to address control issues so they can add expression to their performances. Thankfully, many inventors rose to the challenge.

No Touch Required

In late 1919, the Russian inventor Lev Sergeyevich Termen (1896–1993) began concertizing with the Etherphone. Also known as the Termenvox, it generates tones within a frequency range of about four octaves—similar to that of a cello—by combining signals from two high-frequency **heterodyning oscillators** to output a pitch based on the difference of the oscillators' frequencies. You might know its inventor by his Gallicized name: Leon Theremin. Performers play his instrument, which eventually became known simply as the Theremin, without touching it.

heterodyning: frequencies generated by two sources are combined to create a third frequency, which equals the difference of the source frequencies
oscillator: a circuit that generates periodic fluctuations in voltage to produce an analog signal of frequency measured in Hertz (Hz), or cycles-per-second

The Theremin is monophonic, capable of producing only one pitch at a time. The proximity of one hand in relation to a vertical antenna determines pitch. Rather than offering a note scale with fixed frequencies such as a piano or organ, the Theremin's pitch



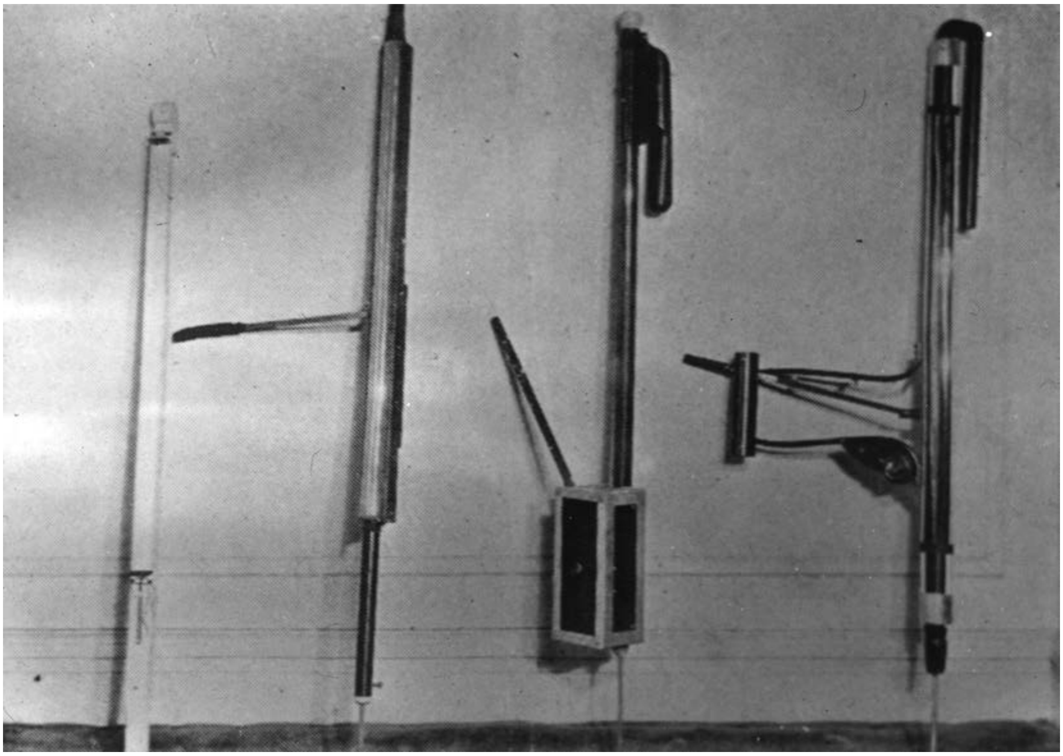
Leon Theremin ca. 1927 in performance with a Theremin amplified by one of his speaker systems of that era. (Courtesy of Tom Rhea)

varies continuously. A performer controls the instrument's volume with his second hand, moving it nearer to a second antenna to quiet the Theremin's output and pulling it away to make the sound louder. While it may sound simple and easy to play, it's extremely difficult to master, but it is also one of the most expressive electronic instruments. On one hand, it's easy to mimic sirens and old science-fiction sound effects; on the other, it

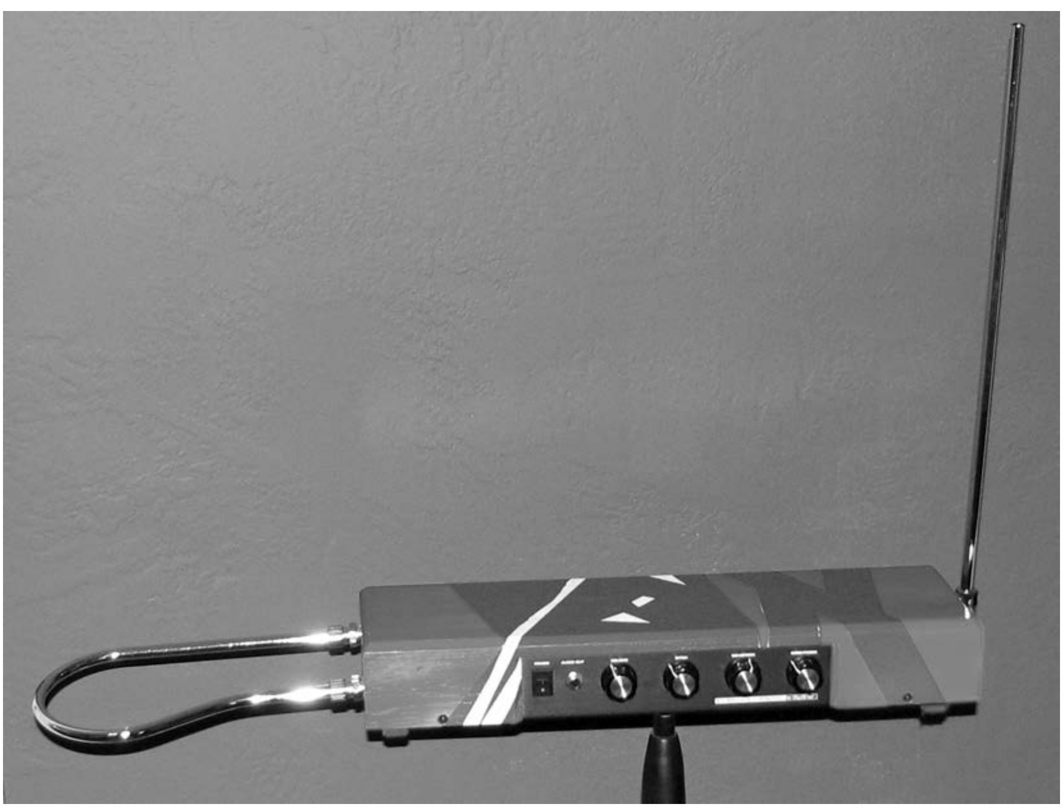
A dancer performs on Leon Theremin's Terpsitone during the early 1930s. (Courtesy of Tom Rhea)

may take years of concentrated study and practice before someone can confidently play melodies.

Leon Theremin dabbled with many different instrument designs. One was the Terpsitone, also known as the Etherwave Dance Stage, a platform on which the performer controlled pitch with vertical movements of her body and volume by moving toward or away from the rear of the platform. Another series of Theremin's devices resembled the cello, except that no strings were involved. On one of these, the performer moved fingers up and down a touchplate surface—a fingerboard—to play one note at a time. The other hand rested on a lever that jutted out of the "fingerboard Theremin" to control note articulation and volume.



Three examples—to the right—of the fingerboard instruments Leon Theremin developed during the 1930s. On the left is an incomplete instrument. (Courtesy of Tom Rhea)



In early 2001, I painted and assembled this Etherwave Theremin, a kit from Big Briar—Bob Moog's company name before he recovered the legal rights to his name in 2002. Moog Music still offers the Etherwave in assembled and kit forms. (Mark Vail)

For *The Birds*

The German acoustician Friedrich Trautwein (1888–1956) introduced another innovative and expressive monophonic electronic instrument in 1928, the Trautonium. For pitch control, it incorporated a metal bar onto which the performer depressed a wire that closed a circuit and generated a tone. Protrusions extending above the bar indicated specific notes, but the pitch varied continuously. While earlier versions of his instrument produced every note with the same abrupt attack, Trautwein later equipped the instrument with a mechanism that allowed the performer to vary note attack by changing how hard or soft he depressed the wire onto the bar. Given enough practice, a performer could play the Trautonium very expressively.

Unlike the Theremin, the Trautonium incorporated a neon-tube oscillator to produce a rich-sounding **sawtooth waveform** replete with high **harmonics**, which could be filtered for timbral variation. Trautwein understood the nature of **formants** in acoustic instruments and equipped the Trautonium with a series of formant filters, or resonators, which the performer could tune over extended frequency ranges in real time, thus allowing a wide variety of tonal variations. This illustrates an important contrast between electronic and acoustic instruments: the physical attributes of an acoustic instrument—

A young Oskar Sala performs in concert on a Telefunken Trautonium. (Courtesy of Tom Rhea) including the shape of its body and resonance properties—force its formant to be fixed to a specific frequency range.

sawtooth: a **waveform** with a voltage that begins at a low value, climbs steadily to a high value, then drops immediately to the beginning value before repeating the shape; a *reverse sawtooth* does the opposite, jumping immediately from low to high, falling steadily to the low point, and so on

waveform: a signal generated by an oscillator with certain harmonic content

harmonics: overtones, or higher frequencies, in a tone that are integer multiples of the **fundamental**

fundamental: the root or lowest frequency of a note, typically perceived as its pitch

formant: one or more frequencies that are emphasized by the resonant qualities of an acoustic instrument's body or by filters in an electronic instrument

In the early 1930s, Trautwein's colleague Paul Hindemith (1895–1963) composed music such as Trio Pieces for Three Trautonia and Concerto for Solo Trautonium and Orchestra. Telefunken produced a limited run of Trautoniums beginning in 1932. Alfred Hitchcock's *The Birds* featured sounds produced by the instrument's descendant, the Mixtur Trautonium, to which the virtuoso Oskar Sala (1910–2002) made extensive enhancements.

Oskar Sala plays the Mixtur Trautonium in 1932. Sala made many contributions to this instrument beyond Friedrich Trautwein's original Trautonium. (Courtesy of Tom Rhea)

Waggling Keyboard

It's a bit of a stretch to fathom, but a monophonic keyboard, developed to enhance pianos and organs in the mid-twentieth-century home, offers more expressive control than many contemporary synthesizers. The thirty-seven-note keyboard for Georges Jenny's Ondioline—which he began developing in 1938, patented in 1941, and produced until 1974—mounts underneath a piano or organ keybed. Its keys are similar to those on an accordion, but the keyboard is spring-loaded to allow finger-generated **vibrato** with horizontal motions. The Ondioline's keyboard also responds to pressure: After you've played a note, you can vary its volume and timbre by changing how hard you depress the key. You can transpose the Ondioline to cover an eight-octave range. Its separate speaker

Dana Countryman bought this blond Ondioline in 2000 and used it on several albums, including two with Jean-Jacques Perrey: *Destination Space* and *The Happy Electropop Music Machine!*. (Dana Countryman, © 2007 Dana Countryman) cabinet contains most of the electronics—all vacuum tubes originally, but solid-state transistor circuits appear in later models. Using switches at the top of the speaker cabinet, you can vary timbre by routing the audio signal through a variety of filter paths.

vibrato: a (hopefully) pleasant and periodic wavering or modulation of pitch produced manually or using automation, typically modulated in a synthesizer with a **sine** or **triangle waveform** oscillating at around 7Hz

sine waveform: a periodic, single-frequency, sinusoidal waveform; at audible frequencies, it consists only the fundamental frequency and no harmonics and is also known as a *pure tone*

triangle waveform: named for its triangular shape, a periodic signal that rises and falls in a linear fashion with sharp corners at the waveform's apex and lowest point; useful as an LFO (low-frequency oscillator) waveform for pitch modulation as a vibrato effect; at audible frequencies, a triangle wave contains the fundamental frequency and all of the odd-numbered harmonics whose ascending amplitudes decrease in ratios of 1:9, 1:25, 1:49, 1:64, 1:81, etc., sounding similar to a sine wave except with weak harmonics, whereas a sine wave has no harmonics, only the fundamental

Jean-Jacques Perrey is the best known Ondioline player. He left medical school to work with Jenny (d. 1976) in 1951 as a demonstrator and salesman, and continues to perform and record with the instrument well into the twenty-first century. Perrey proved that the Ondioline can produce unique and diverse timbres, and that the expression it affords can equal that of a violin.

Timbral Flowage

Borrowing the medieval moniker for what became the trombone—the "sackbut"—the Canadian Hugh Le Caine (1914–77) created an extremely expressive instrument with components and capabilities found on voltage-controlled synthesizers that it preceded by decades. Le Caine's monophonic Electronic Sackbut, which he developed between 1945 and 1948 and continued to redesign and improve until 1973, had a familiar-looking musical keyboard for note selection, but one that was quite unusual. For one thing, it was horizontally spring-loaded. Lateral movements to a key altered the pitch, allowing a gradual bend up or down to a different note—even one "between the cracks" of a scale. Wobbling a key back and forth imparted vibrato to the pitch. Not only was the bend range adjustable up to a whole octave, but pitch could also be controlled via a touch-sensitive ribbon.

The Electronic Sackbut's four-octave keyboard also provided **velocity response** for variations in note attack: playing softly resulted in a note with a slow entrance, and hitting a key harder made the response more immediate. Continuous pressure sensing allowed real-time variation in note volume for producing crescendos and diminuendos after a note began playing.

Hugh Le Caine with a prototype of his Electronic Sackbut in 1954. (Courtesy of Gustav Ciamaga, the Institute of Radio Engineers, and the Electronic Music Foundation)

To address timbre, Le Caine equipped the Electronic Sackbut with a lefthand control section for precise parameter manipulation using fingertip pressure. The performer's left index finger varied among basic waveforms, some of which were evocative replications of clarinet, flute, oboe, trumpet, and organ. Other waveforms stressed the fundamental or certain harmonic intervals. As a note sounded, the player could morph through different timbres. In addition, the left thumb and remaining fingers shaped the Electronic Sackbut's tone: while the performer used his or her thumb to control **filter resonance** and the formant, or peak in the frequency spectrum, he or she could modulate amplitude and frequency and add noise or periodic voltages using other fingers.

velocity response: a touch sensitivity that detects the force or speed with which the instrument has been struck
filter resonance: an emphasized peak of a narrow band of frequencies

Le Caine was striving for an electronic instrument that would play as expressively as an acoustic instrument such as the violin, but with the extended timbral opportunities afforded by electronics. Continuous variation of the harmonic content of the Electronic Sackbut's tone made the instrument much more expressive than it otherwise would have been. Unfortunately, it never went into production due to Le Caine's inability to finalize its design.

Tape-to-Electronics Transition

During the late 1950s and early '60s, *musique concrète* was the most familiar method of creating electro-acoustic music by recording acoustic sounds—sometimes electronically processed—and timbres output by electronic test equipment onto 1/4″ magnetic reel-to-reel tape, which the composer then cut into snippets and meticulously spliced together to create astounding and often rhythmic sequences of unrelated sounds. Creating a few minutes of taped music could take weeks or even months.

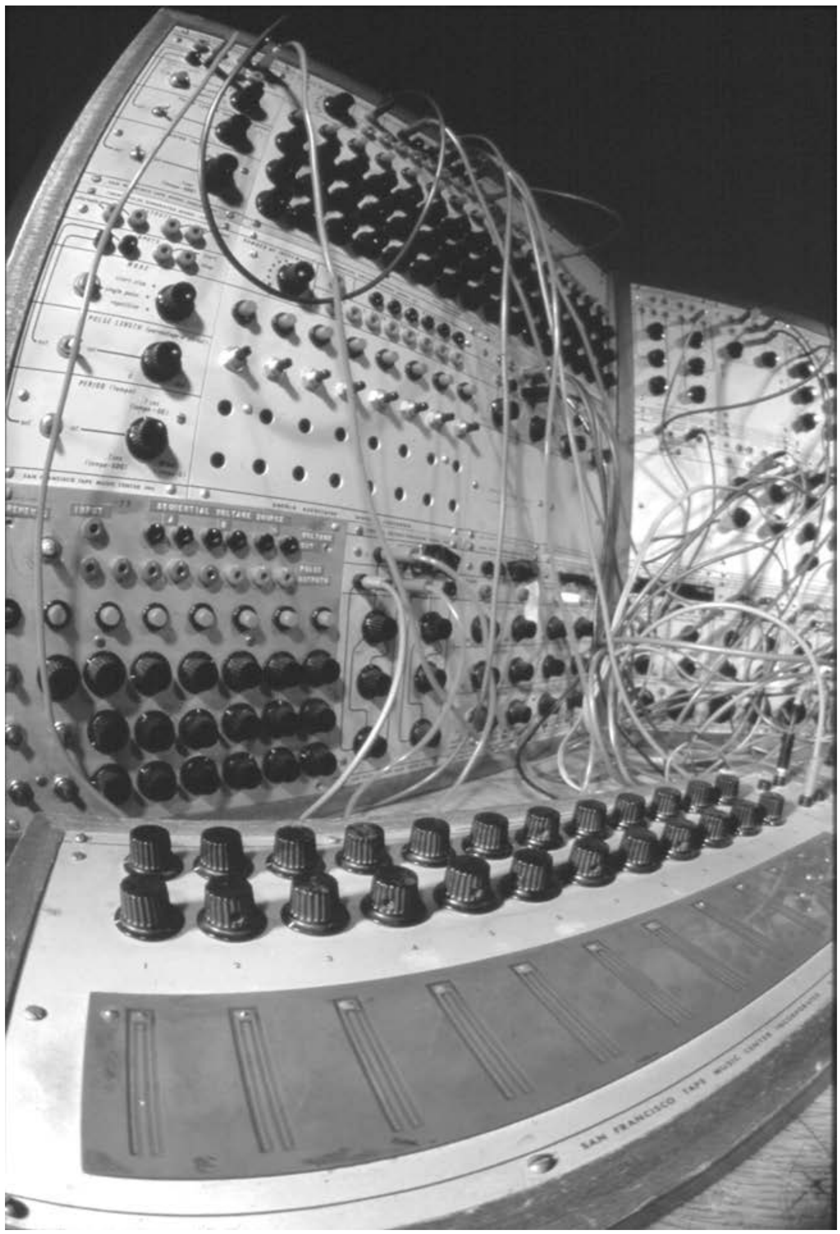
Some of the earliest efforts to replace *musique concrète* techniques with musical **voltage-controlled** instruments took place at the San Francisco Tape Music Center, co-founded by Morton Subotnick and Ramon Sender in the early 1960s. They engaged Don Buchla to begin designing electronic music devices in early 1963, drawing on his knowledge of physics and electronics, as well as his experience in building acoustic and electro-acoustic instruments of welded steel and other materials. Buchla's approach to designing instruments has always been scientific, organic, and user-oriented.

> *voltage-controlled:* analog circuitry whose status can be regulated or changed using electromotive force or a flow of electricity

Control over what those elements do over time was critical to Buchla. One characteristic that distinguishes most of his instruments from competitors' is the absence of an organ-style keyboard. Instead, he prefers capacitance- or resistance-sensitive touchplates organized in various arrangements. The touchplates are area-sensitive, with each plate transmitting three control voltages depending on finger position and the amount of force exerted, which increases or decreases the amount of skin coming into contact with the touchplate.

Alternative Controllers

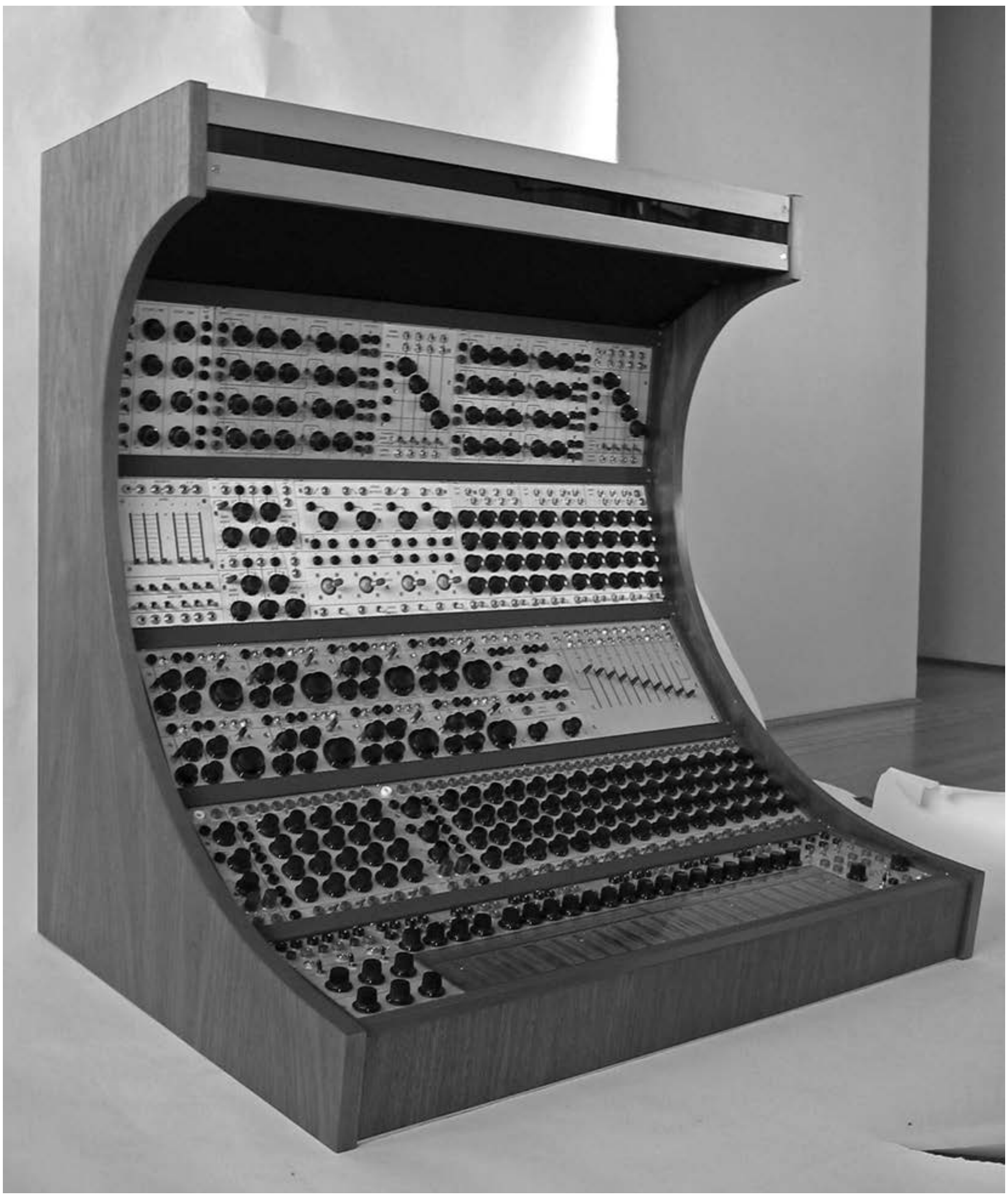
In case an organ-style keyboard, or any of its equivalents, isn't your first choice to play a synthesizer, you have many other options. While Don Buchla has contributed his fair share of *alternative controllers*, he isn't alone in their development. There are, for instance, wind controllers from sources including Nyle Steiner, Softwind Instruments, Eigenlabs, and Akai; percussion pads and instruments such as those from Alternate Mode Kat, Korg, and Alesis; complete electronic drum systems from Roland, Yamaha, and others; ribbons from Doepfer, Kurzweil, and Eowave; and a huge variety of unique controllers and electronic instruments. In addition, for those who'd rather do it themselves, manufacturers such as Electrotap, I-Cube, and Eowave offer sensors for tracking changes in acceleration, temperature, distance, light, pressure, and other physical actions, as well as interfaces for connecting these sensors to synths and computers to control specific aspects and parameters. See ch. 3 for more information about what's available and how you might use these instruments and devices to make music.



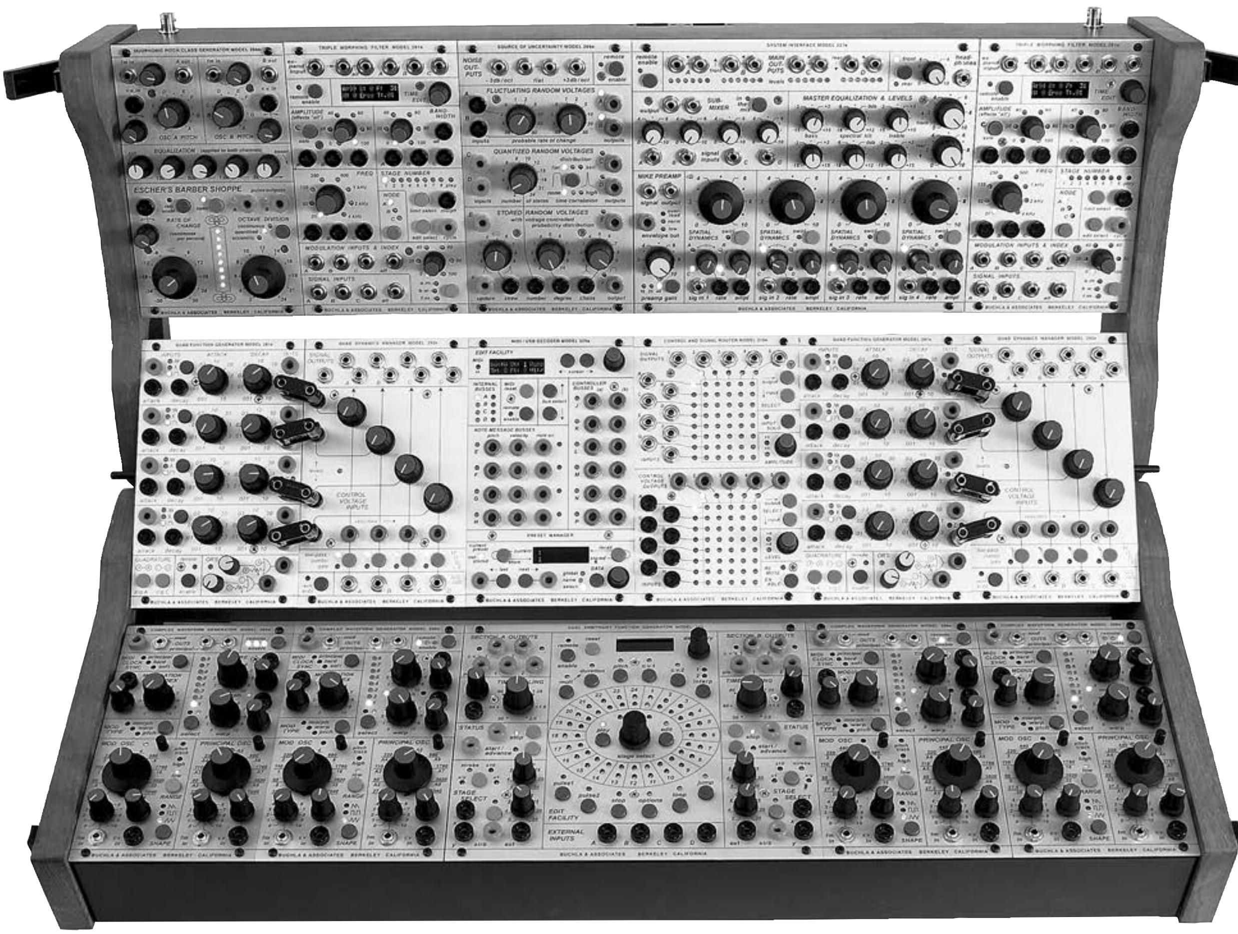
This is the first modular synthesizer Don Buchla built for and delivered to the San Francisco Tape Music Center in 1964. Included in this original member of the Buchla 100 Series were a Model 146 16-Stage Sequential Voltage Source, a Model 123 Eight-Stage Sequential Voltage Source, two Model 110 Dual Voltage-Controlled Gates, three Model 106 Six-Channel Mixers, a Model 111 Dual Ring Modulator, and two Model 112 Touch-Controlled Voltage Sources. This instrument has resided in the Center for Contemporary Music at Mills College since the late 1960s. (Bill Reitzel)

Buchla also developed some of the earliest **analog sequencers**. His first synth had three of them, two with eight stages or steps apiece, the third with sixteen. Each stage generated three voltage-control outputs. You could synchronize two sequencers to get six voltages per stage, and you could create complex rhythm patterns by setting the sequencers to different numbers of stages—for example, five stages against thirteen.

Over the years Don Buchla has created numerous series of **modular synthesizers** and custom instruments, including the original 200 Series Electric Music Box and (ca. 2005) its modernized and current 200e descendants, as well as the 300, 400, 500, and 700 Series. Control has always played an important role in Don's instruments.



Rick Smith completely refurbished this Buchla 200 Series Electric Music Box system, for which he began collecting modules in February 2000 and finished in 2004. He succeeded in his goal of making it classic, 200 Series era-correct with components from 1970 to 1972. (Rick Smith, Buchla Restorations, www.electricmusicbox.com)



Don Buchla revived his favorite synthesizer line, the 200 Series, in 2005 as the 200e Series. Among those touring and giving live concerts with a 200e modular is Morton Subotnick, who played a key part in getting Buchla to design synthesizer modules in the first place. (Paul Haggard)

analog sequencer: an analog module with multiple stages or steps, each of which outputs a set of one or more user-defined voltages; the sequencer may repeat all or some of the stages in the same order over and over, only once through, or one stage at a time according to input from the user or another module

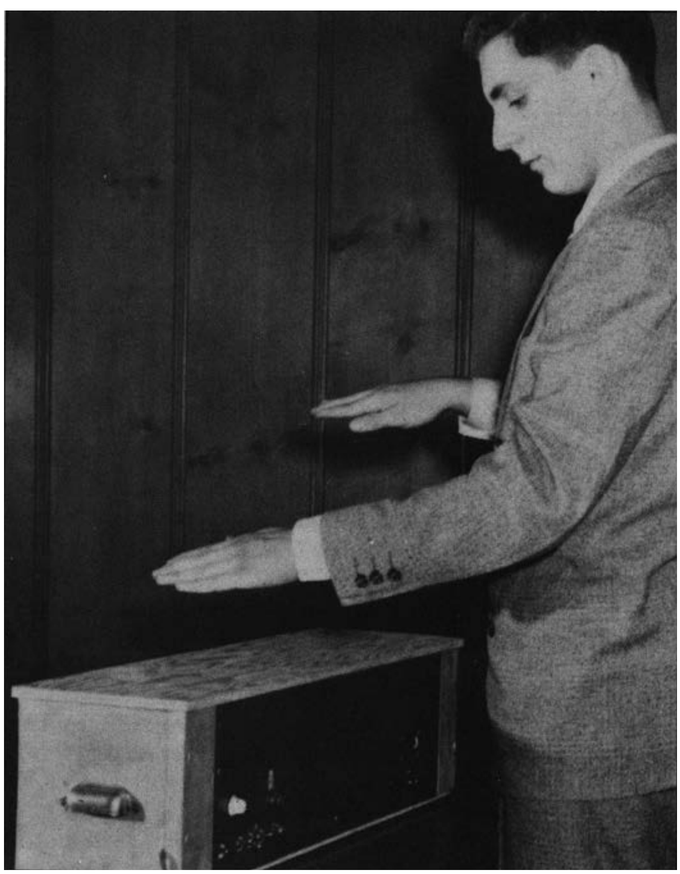
modular synthesizer: an instrument comprising independent modules that you can buy and/or assemble separately, freely arrange and mount in a case, cabinet, or rack during the assembly process according to your wishes, and subsequently rearrange and replace modules later on; in order for the instrument to generate audible sounds, you need to interconnect specific modules using patch cords, a pin matrix, or some other signal-routing arrangement, depending on the modular system

MIDI: acronym for Musical Instrument Digital Interface, the protocol introduced in 1983 that allows performance data created on one electronic instrument to be transmitted to other instruments—even those from different manufacturers—for voice layering, recording, sequencing, editing, and much more

In the early 1980s, Buchla co-developed WIMP (Wideband Interface for Music Performance) and included its connectors alongside those for **MIDI** on some of his instruments. Most synth manufacturers adopted MIDI and nobody else incorporated WIMP, so you don't hear much about it any more. During the late 1980s and early '90s, Buchla shifted his focus almost exclusively to alternative controllers, developing the Thunder pad and Lightning wireless controllers. They were followed in 2002 by the Buchla-designed Piano Bar, a retrofit that converts any acoustic piano into a complex MIDI controller and synthesizer. Ironically, the Piano Bar was for a time distributed by Moog Music—the company founded by Buchla's cross-country contemporary in New York, Bob Moog.

Voltage and Digital (Fingertip) Control

Before his death at age seventy-one on August 21, 2005, Dr. Robert A. Moog (rhymes with "rogue") made many groundbreaking contributions to the electronic-music industry, especially in terms of control and sound quality. He began building and selling Theremins in 1954. Inspired by the electronic music pioneer Harald Bode's 1961 article "Sound Synthesizer Creates New Musical Effects: New Frontiers in Electronic Music," Bob collaborated with the composer Herbert A. Deutsch in 1963 to design and construct a modular synthesizer, which he demonstrated at the Audio Engineering Society (AES) convention in October 1964. He introduced the first Moog Modular synthesizers in 1965.



At the age of seventeen, Bob Moog demonstrates his Theremin at Bronx High School of Science. (With the permission of Ileana Grams-Moog)

Wendy Carlos recorded her transcendental *Switched-On Bach* with a custom Moog Modular. Released by Columbia Records in November 1968, *Switched-On Bach* became the first album of classical music to go platinum—eventually selling millions of copies—and put Moog's name and instruments on the map.

Carlos and Deutsch were among numerous composers who influenced Bob in designing new synth modules. Besides assisting Bob on technical issues, modifications, and improvements, Wendy helped Moog add touch-sensitivity to the synthesizer's keyboard, which had previously responded like an organ or harpsichord: all notes played the same no matter how hard keys were struck. Bob also modified two **fixed-filter banks** as encoder and decoder filters for her custom **vocoder**.

fixed-filter bank, aka *a formant filter:* a series of bandpass filters with specific audible-range frequency centers and level controls for boosting or cutting the frequency content and harmonics of an incoming audio signal

vocoder: a circuit or device that imparts the spectral characteristics of one incoming audio signal—the program—onto another input signal—the carrier—resulting in an output that has the pitch of the carrier signal with some or most of the timbral character and articulation of the program signal; for example, if the program is a spoken voice and the carrier is a synthesized violin, the vocoder will make the violin voice seem to talk—provided both signals are present simultaneously

Synth pioneer Bob Moog poses during the mid-1970s with, from *left to right*, a Sonic Six, a Moog Modular, and a Minimoog. Out in *front* is a Moog Percussion Controller. (With the permission of Ileana Grams-Moog)

Bob Moog and Keith Emerson stand before Keith's big Modular Moog and Hammond C-3 organ in the mid-'70s. (Mark Hockman, with the permission of Ileana Grams-Moog)

In this 1974 photo taken at Radio City Music Hall, Roger Powell (synthesist for Todd Rundgren's Utopia) plays his custom dual-manual keyboard controller while Bob Moog surveys Roger's Moog Modular system, the equivalent of two Synthesizer 55s. (Alan Blumenthal, courtesy of Roger Powell)

A complete Moog Modular Series 900 system from the late 1960s. (With the permission of Ileana Grams-Moog)

Another contributor was Vladmir Ussachevsky, who provided specifications for an **envelope follower** and **envelope generator**, and it was Gustav Ciamaga of the University of Toronto whose module description led to Bob's first voltage-controlled **low-pass filter**. Moog's lineup of voltage-controlled oscillators, **noise generators**, lowpass and **highpass filters**, **sample-and-hold**, and analog sequencers—as well as **ribbon**, **joystick**, and drum controllers—set standards that defined the synth industry and continues to do so in a modular/**patchable synthesizer** market, which rebounded to a remarkable extent during the late 1990s.

envelope: a two-dimensional shape or contour of acoustic elements of a sound, such as its amplitude; envelopes are typically illustrated with level or intensity mapped on the vertical (y) axis and time on the horizontal (x) axis

envelope follower: a device that monitors incoming audio signals and generates a control-voltage envelope proportional to the changes in amplitude of those signals

envelope generator (EG): a device or circuit that generates a control signal that simulates the sequence of an acoustic sound, which has a beginning, middle, and end; the parameters for one of the most common EGs in analog synthesizers are attack, decay, sustain, and release (ADSR), where the attack, decay, and release parameters signify time or rate values and sustain is a signal level *filter:* a circuit that can be used to attenuate or emphasize specific frequencies in an electronic audio signal

lowpass filter: a circuit that attenuates higher frequencies while allowing lower frequencies to pass unattenuated

noise generator: a circuit that produces a random collection of multiple frequencies that can be perceived as hiss, wind, static, and other non-pitched sounds, depending on the noise "color," filtering, and envelope control; also described as a source of random frequencies that may sound like radio static or a sizzle; the most common types for synthesis are: white noise, a hissing-like sound weighted such that there is equal energy per unit bandwidth throughout the frequency spectrum; and pink noise, sounding lower pitched than white noise and weighted such that there is equal energy in every octave of the pitch range

highpass filter: a circuit that attenuates lower frequencies while allowing higher frequencies to pass unattenuated

sample-and-hold: a circuit that continually scans a voltage or numerical-generating source, measures its level when triggered, then locks on and outputs this voltage or value until the next measurement; the resulting output seems to be a random voltage or value

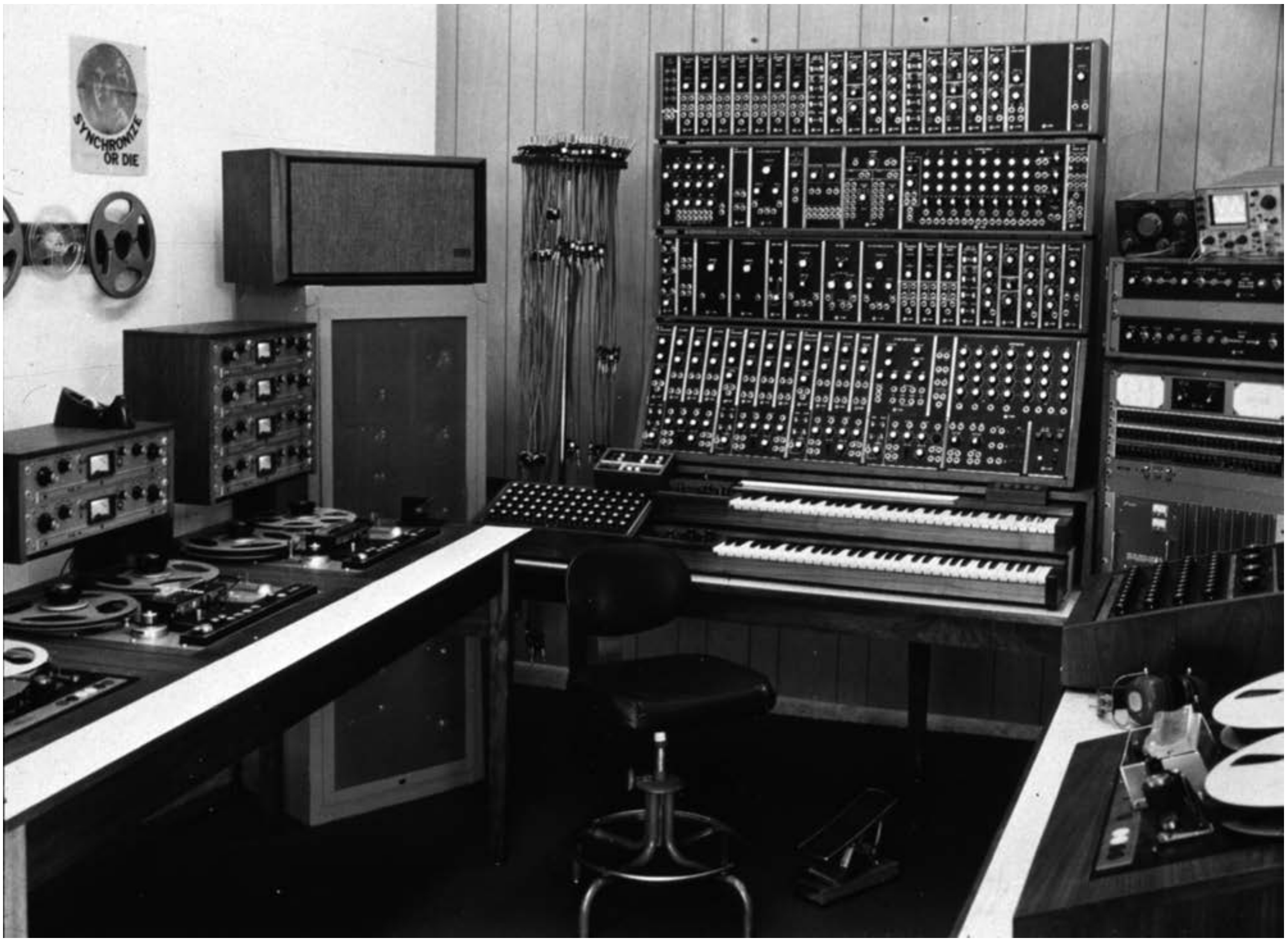
ribbon controller: an elongated touch-sensing strip of material that tracks the movement of a performer's finger across its surface and outputs a corresponding voltage or value to control oscillator pitch or some other parameter

joystick: a two-dimensional controller in the form of a vertical shaft that can be smoothly moved forward, backward, and from side to side to output control signals according to current x and y axis positions

patchable synthesizer: an instrument consisting of modules that are configured and arranged according to a manufacturer's control-panel design; unless they're **normalled**, modules must be interconnected for the instrument to generate audible sounds

normalled: all of the synthesizer circuitry has been wired together behind the control panel, negating the need for patch cords with which to connect modules—although some normalled synths have front-panel patch points for custom signal routing

During the late 1960s Bob decided there was a need for a performance-oriented synthesizer, so he teamed with Bill Hemsath, Jim Scott, and Chad Hunt to design the Minimoog. Its signal-routing structure—oscillator, noise, and external input signals go into a mixer, which passes the aggregate signal through the envelope-controlled lowpass filter and amplifier before reaching the main outputs—became a standard in the synth industry. The Minimoog proved so popular, thanks in good part to Keith Emerson, Jan Hammer, Chick Corea, Rick Wakeman, and many others who played it onstage and in studios, that Moog Music made more than 12,000 of them from 1970 to 1981, making it the most popular American-made monophonic analog synthesizer of the twentieth century.



A shot of the Moog studio in Trumansburg, New York, where Moog instruments were manufactured between 1963 and 1971. Note the conveniently placed patch cord tree directly to the *left* of the big Moog Modular. (With the permission of Ileana Grams-Moog)

After reluctantly leaving Moog Music in 1977 and subsequently losing the legal right to put his own name on musical instruments, Bob Moog founded Big Briar in 1977 and continued to develop new Theremins and other products. He finally reclaimed the legal right to his name in 2002. Bob spent several years developing a Minimoog for the twenty-first century, what became the Minimoog Voyager—complete with modern circuitry to not only duplicate as closely as possible the original's tone and functionality, but also to deliver extras such as a three-dimensional touch surface, secondary **VCF**, MIDI I/O, programmability and patch memory, and dedicated LFO. It began shipping in 2002. A variety of models are available, including the Old School—which like the original Minimoog lacks MIDI and patch memory for synthesists who want to work the old-fashioned way—and Minimoog Voyager XL, featuring a sixty-one-note keyboard that responds to velocity and **aftertouch** and a front-panel **patchbay** for extended signal-routing flexibility. Moog Music has also released the Little Phatty analog performance synth series, the unique Moog Guitar, a contemporary re-creation of the Taurus synth-bass pedals, and even iOS applications for Apple's iPhone, iPod Touch, and iPad. Throughout the years, Bob Moog's companies have produced Theremins.

Bob Moog poses with five Moogerfooger processors and an Etherwave Theremin at the Smithsonian Institution in April 2000. The occasion was a two-day conference called "The Keyboard Meets Modern Technology," a series of programs specifically honoring synthesizers during the Smithsonian's "Piano 300: Celebrating Three Centuries of People and Pianos." (Mark Vail)

Posing in the Moog Music office in July 2004 behind the guts of an Etherwave Pro Theremin are Steve Dunnington holding a Moogerfooger MF-105 MuRF stompbox, Bob Moog behind a Minimoog Voyager, and Mike Adams holding the control box from a Buchla Piano Bar. (Mark Vail) *aftertouch: the varying amount of downward force or pressure applied to a key after it has been struck and reaches the bottom of its travel*

patchbay: a panel or **rackmount** unit containing multiple jacks that are interconnected to allow flexible patching and rerouting of signals

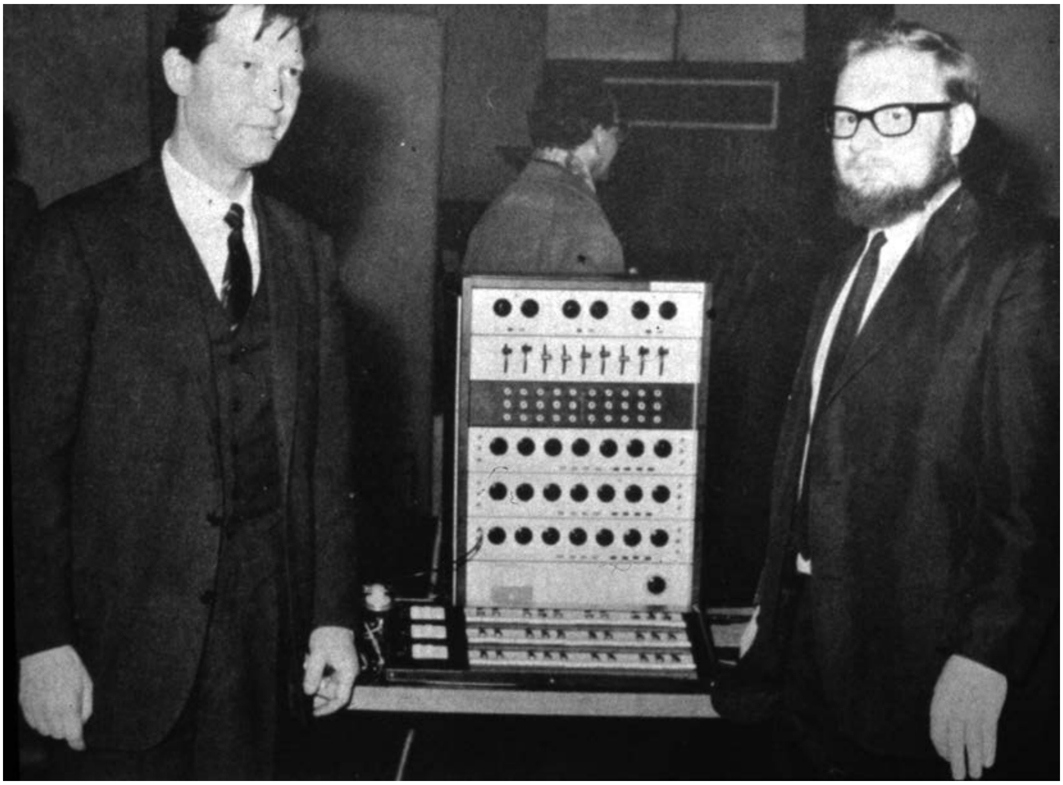
rackmount: a device with permanent or removable "ears"—vertical, perpendicular extensions on either side of its front panel—perforated with two or more holes and measuring 19 inches across, allowing the device to be mounted in industrial-standard 19" racks; the letter "U" identifies the device's height, 1U indicating a single-space rackmount unit, with 1U being equal to 1.75"

Perhaps a little-known keyboard controller best epitomizes Bob's dedication to the craft of control: the Multiple-Touch-Sensitive Keyboard, on which Bob began working with the composer John Eaton in 1968. They finally completed it as a MIDI controller in 1991. Each of its forty-nine keys can sense finger position, how much skin is touching the key surface, how far down the key is pressed, and how hard the key is depressed at the bottom of its travel, so the instrument can transmit **polyphonic aftertouch**. When he began working with the finished Eaton-Moog keyboard, Eaton discovered it generated more MIDI controller data than he could find interesting parameters to control on synthesizers of the early 1990s. However, he returned to working with it in late 2006 and discovered the situation had much improved with contemporary software instruments.

polyphonic aftertouch: each key of a keyboard senses pressure exerted on that key independently of other keys; allows the performer, for example, to impart LFO-driven vibrato on individual notes within a chord or play melodies inside a sustained chord by increasing the amplitude of single notes; also referred to as "poly pressure" and "poly aftertouch"

Synth Italia

What mostly inspired John Eaton to work with Bob Moog on the Multiple-Touch-Sensitive Keyboard? An electronic instrument called the Syn-Ket from the early 1960s, when electronic music and various arts thrived at the American Academy in Rome, Italy. Eaton was one of several American composers who worked there, alongside Otto Luening, William O. Smith, and George Balch Wilson. A talented sound engineer named Paul Ketoff had constructed a large, studio-confined instrument called the Phonosynth with the composer Gino Marinuzzi. After Ketoff demonstrated it for the Americans, they persuaded him to make a smaller, less elaborate version. Thus was born in 1963 the Syn-Ket, the Synthesizer Ketoff.



Paul Ketoff and John Eaton pose with a Syn-Ket in 1965. From the *top down* are modulation generators; a nine-band fixed filter bank; a patchbay matrix; three voice channels; a module containing a white-noise generator, spring reverb, and VU meter; and three twenty-four-note keyboards. (Courtesy of John Eaton)

Following completion of the original, Eaton recommended numerous musical features that Ketoff added to subsequent models. In essence, the Syn-Ket contained three synthesizers. It had three cascading twenty-four-note keyboards like the manuals of an organ console. The keys were small, like those on a toy piano, but you could wiggle them back and forth to bend notes and produce vibrato. On the second Syn-Ket, made specifically for Eaton, the keys also responded to velocity for control of amplitude and the filters. Each keyboard controlled its own voice, or "sound-combiner" as Ketoff referred to them, consisting of a square-wave oscillator; a series of button-controlled frequency dividers capable of dividing the incoming frequency by factors of 2, 3, 4, 5, and 8 to produce different harmonics; three complex filters; an amplifier; and three independent modulators. Vacuum-tube and solid-state circuitry made up the sound-combiners, which you could interconnect for a wider range of timbral possibilities. Eaton felt the Syn-Ket offered a human nuance missing from other early electronic instruments, and he enjoyed the ability to perform counterpoint parts with it alone.

Ketoff hand-made about a dozen Syn-Kets between 1963 and 1977, and there were considerable differences among them. Designed for live performance, the Syn-Ket proved challenging and difficult to learn—much like an acoustic instrument—but very rewarding given enough effort. Eaton, a renowned opera composer who frequently combined synths with orchestra and voice, wrote many pieces for Syn-Ket and toured extensively with one or two of these instruments between 1964 and 1977. Over time the aging instruments began to malfunction and eventually failed entirely.

Armand Pascetta's Pratt-Reed Polyphony

As synthesizers became more prevalent during the early 1970s, many players lamented their monophonic nature. The musician/technician Armand Pascetta was among the first to tackle synthesizer polyphony. Doing business as Electro Group, Pascetta wired Pratt-Reed keyboards to a unique processor (before microprocessors were commonly available) he had hand-assembled from transistors, resistors, diodes, and military-grade surplus integrated circuits to develop keyboards that responded to note velocity, **release velocity**, and aftertouch, and also allowed advance functionality including **keyboard splits** and **polyphonic portamento**. By the mid-1970s he'd created pre-MIDI keyboard controllers capable of transmitting more than twelve separate channels of gate and voltage-control data and handling multiple synth modules, even across multiple networked keyboards.

> *release velocity:* how quickly a finger is pulled from a key
>
> *keyboard splits:* dividing a keyboard into two or more sections, each capable of triggering different sounds either from different synthesizers or samplers, or from a synthesizer or sampler capable of **multitimbral** operation
>
> *multitimbral:* capable of generating more than one timbre simultaneously, with independent control of the individual timbres
>
> *polyphonic portamento:* when multiple notes are played, pitches glide at an adjustable rate from those previously sounding to the newly played notes rather than the pitches of the individual notes sounding immediately; other names for portamento include glissando and glide
>
> *CPU:* central processing unit, the circuitry in a computer that executes instructions from programs

Pascetta's polyphonic keyboard operated particularly effectively because it electronically sensed activity without continuously scanning the entire keyboard. If no keys were played, no processing time was spent. If you hit a single key, the system took one **CPU** clock tick to acquire the information from the keyboard. Playing two keys took only two clock ticks. Microprocessors in typical polyphonic keyboards scan all of the keys all of the time, which eats up processing power.

Among those whom Pascetta credits for making his keyboards happen is the organ builder and repairman Vince Treanor III. Malcolm Cecil, one of the first synthesists to discover Pascetta's work, incorporated a polyphonic keyboard into his massive TONTO (The Original New Timbral Orchestra) system, which Stevie Wonder played on *Music of My Mind*, *Talking Book*, *Innervisions*, and *Fulfillingness' First Finale*. The multitalented jazz/pop/gospel organist/synthesist/singer Don Lewis was another client, working with Pascetta to improve the keyboard's capabilities and user interface. In 1974, Lewis added a four-channel Pascetta keyboard that drove four Oberheim SEMs and two ARP 2600s in LEO (Live Electronic Orchestra), Don's fabulous electronic performance system. Other notable musicians who used Pascetta keyboards were Sergio Mendes, Quincy Jones, and Henry Mancini.