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**Music in the Age of Communication and Control**

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in

COMPOSITION

by

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**Abstract**

**Music in the Age of Communication and Control**

**David Roberto Hernandez**

This dissertation is a study of DIY electronic music from the mid-20th century to the present, with a particular focus on analog system design. It weaves together prominent figures such as Louis and Bebe Barron, David Tudor, and Gordon Mumma as well as lesser-known figures in the recent analog system rebirth. This study is conducted from the perspective that musicians must grapple with the conditions of industrialization, and therefore gain mastery over the infrastructure of communication in the so-called "information age." Chapter 1 investigates the transmission of knowledge and creativity within the world of DIY electronic music. Chapter 2 is a meditation on the cultural climate within which this transmission has occurred. We have developed techniques of treating organisms, electronics, and acoustical spaces as analogs for each other, rather than as elements of a strict hierarchy.

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# INTRODUCTION

## THE COMPOSER/PERFORMER/BUILDER

If music is to remain a transformative art form in the 21st century, it will be up to musicians to engage with the problems of the time and free themselves from dominant cultures of the past, while they also maintain a critical distance from the dominant culture of the present. Over the past 50+ years, the ascendance of the composer/performer/builder, as exemplified by artists such as Harry Partch, David Tudor, and Gordon Mumma, has done much to challenge conventional hierarchies within musical culture. Traditional collaborative models of Western European Art Music tend to reinforce unilateral channels of control, in which a composer exerts control over a performer, who exerts control over a passive consumer of the final product. Improvisation and uncertainty (under their many names) have been useful tools for the subversion of this paradigm, but artists who compose the material resources required by the musical work are free to take or leave the existing artifacts of material culture, rather than being acted upon by them.

### Why Would a Composer Build an Analog Time-Domain Clarinet Model?

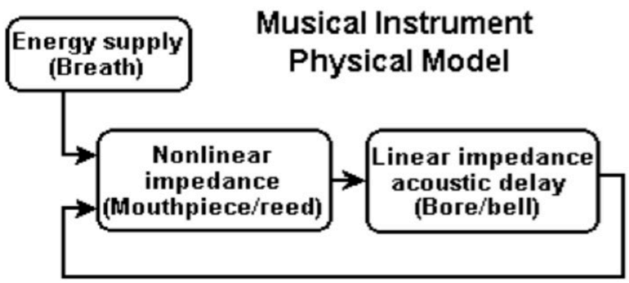
One of my primary motivations as a composer is to produce sonic art specific to the sound-producing technology in use, rather than employing orchestration techniques in service of an unrelated or tenuously related compositional process. Perhaps this stems from years as an instrumentalist, reading notation that could have been written for any instrument with a similar pitch range, harmonic structure, and attack/decay characteristics. As a performer, I often struggled with an external authority privileged with agency, while being expected to supply appropriate “expression” (omitted data) or to convert an unmanageably dense data stream into something performable and intelligible. Accordingly, I’ve long preferred listening to improvisation and (experimental and/or vernacular) works that exist as “authoritative” audio recordings of complex performances. I prefer to think of sound in time as the musical work. In this case, a score is just a document of a situation designed to stimulate the production of largely unforeseen events which reflect the internal organization and mutual influence of the sound-producing devices involved.

In the early 2000s, as part of my effort to escape the traditional composer/performer dynamic, I embraced analog modular synthesis as a primary compositional tool. Though revived economically by nostalgic musicians seeking familiar sounds and tactile interfaces, analog synthesis can lead to alternative techniques that require neither long-term memory storage nor direct numerical control of parameters. The desire for frequency-domain analysis/synthesis helped to turn electronic music studios digital, while the digital computer steered people toward computationally efficient frequency-domain techniques. Commercially available computers are now capable of the high-speed calculation required for time-domain physical modeling. In 2013, Randy Jones of Madrona Labs released a software instrument called Kaivo, which is based on recent research into finite-difference time-domain (FDTD) methods of solving differential equations. The argument for time-domain modeling is well-made in the introduction of “On the oscillations of musical instruments” by McIntyre, Schumacher, and Woodhouse (MSW).

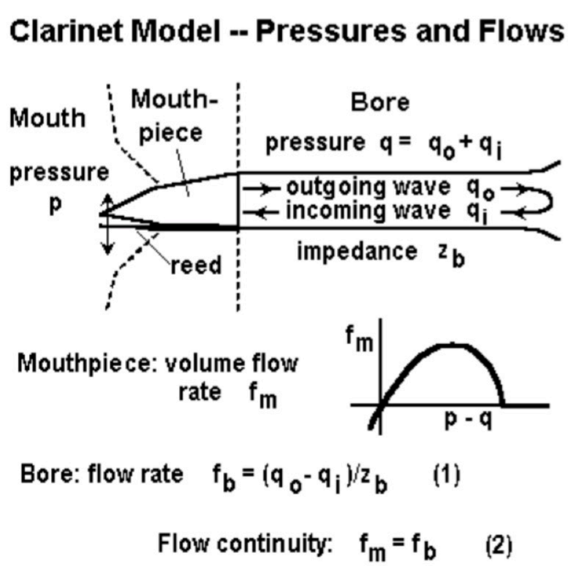
> It is an almost instinctive reaction among physicists to describe vibrating mechanical systems in terms of their normal modes. The method of normal modes is a powerful tool if the system is linear and time-invariant. But if the system contains nonlinearities, or has properties which vary in time, the case is less clear. There is no mathematical tool of comparable power and generality, and different nonlinear systems require different methods and often special ingenuity. This is especially so when nonlinearity is strong and not merely a small departure from linear behavior. Musically useful self-sustained oscillators, exemplified by the woodwind, brass, and bowed-string instruments, are often strongly nonlinear (McIntyre, Schumacher, and Woodhouse 1325).

In 2006, Ian Fritz designed an analog implementation of the MSW clarinet model and published it to his personal website. Though generally overlooked by synthesizer builders, this circuit served as a bridge between Fritz's previous work and the work to come. His early notable contributions to instrument design were related in one way or another to his background as a clarinetist. In 1977, he published a novel double-pulse circuit in Electronotes which made possible the generation of strong odd-only harmonics. Since 1997, he has been developing a sophisticated wind controller called The Stealth (and the Son of Stealth MIDI controller). Fritz discovered regions of chaos in the PM Clarinet by varying the shape of the reed nonlinearity. Aside from his substantial contributions to voltage-controlled oscillator (VCO) design, his work since 2006 has been dominated by nonlinear circuits and chaotic systems.

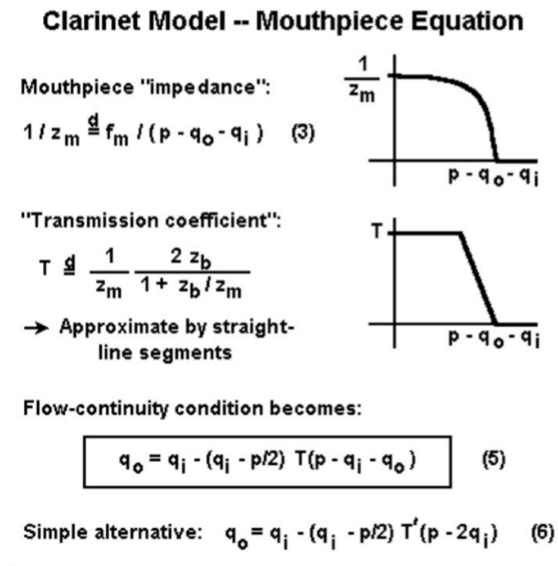
The most basic representation of the model is a nonlinear impedance (mouthpiece/reed) which is supplied with energy (breath) and feedback from a linear impedance acoustic delay (bore/bell) (fig. 1).



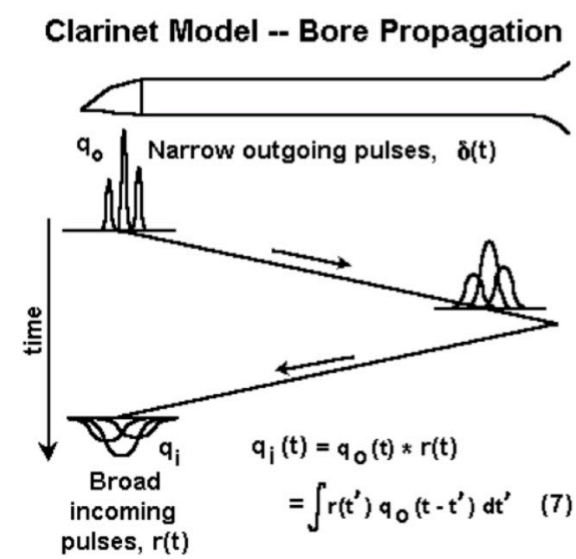

Pressure p is the player's mouth pressure and pressure q is the summation of outgoing and incoming wave pressure in the bore. The volume flow rate of air through the mouthpiece/reed is a nonlinear function of the pressure difference p-q across the reed. The volume flow rate through the bore is a linear function of pressure (difference in pressure between outgoing and incoming waves, divided by bore impedance) (fig. 2).




A transmission coefficient T, with the same general shape as the inverse of the mouthpiece impedance, is approximated in this implementation by straight-line segments (fig. 3).




The outgoing wave can be thought of as series of narrow pulses, which are broadened and inverted as they travel down the bore and back. This delayed and broadened response is expressed by the convolution integral of equation 7 (fig. 4).



## From Schematic to Instrument

The published schematic was as basic as possible, so quite a bit of independent development was going to have to occur in order to develop a fully voltage-controlled modular clarinet. “Wow, as far as I know you are the only person ever who worked on the PM Clarinet project!” (I. Fritz, personal communication, October 11, 2015) Luckily, adding voltage control required nothing more than multiplication and addition. I needed many high-performance 2-quadrant multipliers as well as a pair of high-performance low-pass filters. The original design featured a switchable 2/4-pole Butterworth low-pass filter (LPF) built with an increasingly scarce IC (CA3280 operational transconductance amplifier (OTA)). I decided to use the project as an opportunity to learn the SSM2164 quad exponential voltage-controlled amplifier (VCA) IC. The response can be linearized using an active feedback network, and each chip can be turned into a 3-pole LPF with the remaining cell used as a temperature compensating resistor (a technique devised by Roman Sowa around 1998/1999 and further developed by Osamu Hoshuyama around 2008/2009). The transversal filter of the bore circuit required crossfaders (to determine the weights of three successive samples), for which the response curve had to be “over-linearized” to maintain constant power through the fade, keeping the finely-tuned gain structure of the system intact. All of the 2164 designs were adapted from circuits posted online by semi-professional designers David Dixon and Mike Irwin. The choice of 3-pole filters was inspired by Fritz’s Threeler, a third-order chaotic VCF.

The MSW clarinet model ignores the instrument’s holes and keys. The fundamental frequency is instead determined by the sampling rate of the bore/bell circuit, along with a tracking LPF that smooths the sampling steps and lowers the frequency. Though this limits the realism of the model, it also circumvents many limitations of the acoustic instrument and allows for a wide range of pitch/timbre effects specific to the "pilot" VCO. The VCO generates a ramp that sequentially fires ten pulses (using a bar-graph LED driver as a window comparator). With each pulse, the incoming signal value is stored in a sample-and-hold circuit while three previous values are sent to the transversal filter. Since the feedback filter drops the fundamental by one octave, the bore/bell sampling rate is effectively 20 times the fundamental, regardless of frequency. For my build, I initially tested the system with Fritz's Teezer (through-zero FM VCO). Though the salient feature of this VCO is its ability to reverse direction (travel through 0 Hz), its continuously variable synchronization strength proved to be quite valuable in the clarinet model. In order to incorporate this feature, I started with Fritz's latest improvement (2008) of the Terry Michaels (formerly Terry Mikulic) sawtooth VCO originally published in Electronotes in 1976. The integrating core of the 2008 version is strikingly similar to the core of the Teezer, so it was quite easy to graft the Teezer's sync circuit onto the simpler VCO. The sync, exponential FM, and linear FM inputs not only allow for typical frequency and phase control, but also provide additional paths for feedback within the system.

## From Instrument to Composition

Musical instrument models provide a convenient and versatile set of resources for disciplined experimentation. The musical instrument becomes more than a tool used to advance external concepts. Some aspect of the instrument's structure can easily influence the structure of the work. Once broken down into functional blocks, those blocks suggest tangents which can lead to unexpected but coherent results. The model can also reveal how our perceptions are mediated by conceptual models, which may be at least as crude and hacky as a box full of circuits.

In my composition, *The Age of Communication and Control,* I use the Fritz/MSW clarinet as a means of investigating these issues. For example, the electronic implementation of bore propagation suggests other applications of bucket-brigade delay lines, such as digital shift registers, or a model of a (chaotic) giant squid axon. There are forms of resonance aside from acoustical resonance, and the topology of the model makes it easy to investigate these resonances. Time-domain models reveal how we operate highly nonlinear instruments in extremely narrow regimes of periodicity. When reconstituted electronically, those regimes are a mere subset of possibility. Appropriately, the clarinet can also be modeled by a chaotic circuit known as a time-delayed Chua oscillator (Rodet 55-57).

An alternative approach is to analyze an instrument's output and devise a method of achieving a similar result. Frans Fransson published a pair of articles in 1966-1967 about woodwind formants in which he demonstrated that they could be synthesized by imparting fixed rise and fall times upon a pulse waveform (or "triangular pulses") independent of frequency (Fransson 35-37). I use this method as a pivot point to move the piece into an exploration of unorthodox linear function generators, such as Peter Blasser's Fourses, which consists of four triangular generators, each with its upper and lower bounds contingent upon the surrounding generators, producing a quasi-chaotic output. When a digital implementation is controlled by integers, these “bounce/bounds” oscillators provide a unique method of generating rational intonation.. Finally, working with modular systems forces one to grapple at least intuitively with information theory . Data is sent and received, but information depends on the technological and perceptual apparati in between. Human beings, acoustic spaces, and electronic circuits can then all be understood as signal processors with characteristics determined by internal structure.

# CHAPTER 1

# ELECTRONIC FOLK MUSIC IN THE TWENTY-FIRST CENTURY

## 1.1 Musician-to-Musician Transmission of Electronics Knowledge

The classic narrative of electronic music history tells a story of collective industriousness, in which artist/technicians from around the world repurposed the cast-off junk of the military-industrial complex in an attempt to expand the possibilities of sonic art. Once the concept of the electronic music studio was firmly established, purpose-built tools for signal synthesis and processing were developed, expressing a wide variety of technical and aesthetic paradigms. This narrative tends to hold up well in regard to institutional tape-music studios with some non-zero budget for acquisition. In the mid-1950s, this model was widely applicable outside of the apartment of Louis and Bebe Barron and similar non-institutional artists. One technological advance that dramatically impacted institutional and non-institutional studios alike during this period (roughly 1950-1970) was the proliferation of the multiplier-type ring modulator. Earlier switching-type industrial-control modulators were generally considered of limited musical value due to the prominence of odd-numbered harmonics in the control signal. This distortion could be ameliorated somewhat with a series low-pass filter, but it made the device much less versatile than a true 4-quadrant multiplier. The germanium diode-transformer ring modulator, at appropriate signal levels, operates in the “square-law” region, resulting in much more accurate voltage multiplication (Bode 1967). The device overloads with a soft-clipping effect that dramatically increases the range of distinguishable timbres compared to a silicon semiconductor which clips more abruptly. The distortion in this circuit is a product of the nonlinear characteristics of the diodes, the finite time that it takes to switch between diode pairs at zero-crossings, and the transformers (in some circumstances) causing three diodes to conduct simultaneously (Parker).

Patented in 1935, the diode-transformer ring modulator began to appear at least as early as 1954 in well-known pieces of electronic music from WDR (Cologne), NHK (Tokyo), and RAI (Milan) (Davies 1976). The appeal of the device is obvious. Any two audio signals can be combined to produce a radically altered output signal, which can consist of harmonically related partials or inharmonic clangs, depending on the frequency relationships between the carrier and modulator signals. The device can be easily used intuitively or analytically with equal success. David Tudor's application of the ring modulator is a classic example of the intuitive approach. In the mid-1960s, Gordon Mumma built a simple ring modulator for Tudor. In typical fashion, Tudor exploited the weakly-gendered nodes of the passive circuit in order to subvert the intended purpose. Mumma recalled this development in 2000:

> I made an analog multiplier for David Tudor once. He didn't know what it was, but he had used one that I made for somebody else and he wanted me to make him one...some months later he showed up in town..and he had this thing, and he wasn't using it the way it was designed for use...but he had this whole thing going. He had a spectacular musical thing going on...and it's not that he misunderstood me; there was no misunderstanding at all. It was just that he asked me to make something and I had one point of reference and he had another (Mumma in Ashley 102).

The passive nature of the device not only allowed for Tudor-like experimentation (which would become more difficult with the proliferation of strictly gendered integrated circuits), but it also made the diode-transformer modulator the de facto circuit for peer-to-peer transmission of electronics knowledge around the world. The device was compact, it could be used with any two line-level signal sources, and it required no power supply, so the same unit could be used anywhere in the world without modification. Beginning in 1968, Hugh Davies built countless iterations of the device for fellow musicians before publishing a "A Simple Ring-modulator" in 1976. According to William Maginnis, Don Buchla's initial contribution to the San Francisco Tape Music center was a passive ring modulator (Maginnis in Bernstein 204).

The relative precision of this newly abundant style of multiplier also allowed for a more analytical approach to signal processing algorithms based on voltage multiplication. Bode offers a few rigorous applications in his 1967 article "The Multiplier-Type Ring Modulator." Aside from the most obvious application (multiplication of sine waves to produce sum and difference sidebands), Bode lists a number of more esoteric applications. His suggestions include inputting a square wave to the program input to produce two infinite series of odd-numbered harmonics (sum and difference), shifting a filtered band of noise to produce a tuned noise effect, inputting rationally tuned sine waves from voltage controlled oscillators to produce consonant timbres/harmonies, mixing the unprocessed program material with a low-frequency ring modulation to produce a "spatial amplitude-phase modulation," and turning a fixed bandpass filter into a tunable filter by heterodyning the program up to 10-20kHz, passing the signal through a narrow filter and demodulating with another multiplier (Bode 1967 14-15). The ring modulator can also be expanded into a single-sideband modulator (frequency shifter), which was used in Stockhausen's Telemusik (the "Gagaku circuit") and in many of the works by members of the Sonic Arts Union. Bode would later market two sophisticated frequency shifter designs under the R.A. Moog brand. By the time that Tom Oberheim began selling his famous ring modulator in 1969, the original topology had largely been supplanted by the MC1495 integrated circuit, which was much closer to an ideal multiplier, but lacked the interchangeable I/O of the passive circuit (Oberheim 1970). In 2004, Ken Stone of rural Australia published the old diode-transformer circuit to his website and offered printed circuit boards for sale. He also published a webpage about the use of two ring modulators as a ring modem (modulator/demodulator), much like in Bode's tuneable bandpass filter. The bidirectional capability of the passive circuit makes the process as simple as patching the demodulator backwards in order to reverse the signal polarity. Assuming an ideal multiplier, this patch would be pointless outside of a broadcasting context. However, as an audio synthesis tool, it functions as a kind of nonideality detector for one of the most common blocks in a block diagram. The ring modem suggests an entire class of patches which draw attention to the topology of a circuit or of a model, rather than necessarily treating similarly labelled black boxes as equivalent.

The development of memory-based pseudo-random control voltage sources illustrates a more elaborate and sustained community participation in instrument design. Don Buchla made stepped random signals a standard control method with his model 165 Dual Random Voltage Source. By the time that he designed the Music Easel in 1973, his implementation of an "uncorrelated random" source closely resembled the topology of a typical linear feedback shift register (LFSR). The LFSR is a widely-used series of 1-bit memory cells (digital shift register) with feedback via an exclusive-or (XOR) gate. It is a deterministic system in which the output is a linear function of some previous state. It has been used, for example, as a noise approximator, a counter, a stream cipher, a test-pattern generator, and a scrambler for cell phone signals. When Buchla added a similar circuit to his model 266 Source of Uncertainty module in 1976 (Quantized Random Voltages or QRV), he included the provision for weighing the bits equally (n+1) or unequally (2^n) via two digital-to-analog converter (DAC) circuits, providing either "linear" or "geometric" access to the number of random states (Strange 85).

In 2001, Ken Stone published a digital shift register design that he referred to as a "gated comparator." Stone's design resembles Buchla's Quantized Random circuit in several ways. The maximum number of bits is increased from six to eight and it includes a 2^n DAC for generating stepped control voltages of up to 256 states. The new design is considerably more flexible, with the ability to advance the register with any input signal (when it crosses a user-defined threshold). The binary outputs of the register are made available for external use and for patching custom feedback loops within the system. It's one of many Stone designs that was mysterious to most DIY instrument builders until the concepts of Buchla (and Serge Tcherepnin) became more widely understood.

Between 2003 and 2007, Rob Hordijk developed a chaotic sound-generating device called the Blippoo Box, with a digital shift register and two cross-coupled VCOs feeding its data and clock inputs as its "chaotic core," which feeds impulses to a complex bandpass resonator. Hordijk's aesthetic goal was to produce a sound that was "not the sound of a synthesizer" but instead a "generalized electronic sound" reminiscent of the

Barrons' "Forbidden Planet" soundtrack. He found that, after many years away, the quality of readily-available analog components had increased to the point that he had to design distortion back into the circuit in order to reflect this reference point (Hordijk 35-38). This chaotic core, or "rungler," reappeared in 2009 in his Benjolin device, which was designed to be built at DIY workshops throughout Europe.

In 2004, Scott Stites published a riff on the 266 QRV section simply referred to as the Shift Register Sequencer (SRS). Stites (along with his collaborator Jeff Pontius) had been experimenting with the original QRV design and it occurred to him to provide continuously variable weighting for the bits rather than one or two fixed options. Stites' reasoning was that a typical pseudo-random LFSR-like circuit would repeat after some finite number of steps and providing real-time user access to the DAC was one way out of that repetition. Another feature (borrowed from Stone) was to allow the user to load bits into the register serially, rather than merely seeding the register with a non-zero value to avoid a latching condition. Finally, Stites included a random/loop switch for selecting either the randomly generated incoming bits or a feedback tap.

In 2006, while attempting to clean his work bench, Stites discovered a forgotten stash of CD4034 shift register chips. While looking up the datasheet, Stites realized that these chips could help him overcome the limitations of the SRS (now referred to as the Klee sequencer). The early version, along with the Stone and Buchla circuits could only load bits serially, so programming a specific startup state across all bits was either impossible (Buchla) or tedious (Stone). Random loading was a convenient and useful solution, so the design was constrained to random patterns that could be looped at will.

The CD4034 can load binary values either serially or in parallel, so the initial state of the register can be reliably pre-programmed using panel-mounted switches. With this new capability, random sequences become a mere subset of the device's features. The 4034 is an 8-bit device, so two are used to replace the 16-bit register used in the original SRS. Each chip can be made to circulate its own bits, or the two can be chained. Stites describes Klee programing in the following terms,

> The concept is much the same thing as looking at the sky, and instead of seeing a cloud, suddenly seeing a winged horse or perhaps the Statue of Liberty. Within the practically limitless possibility of note sequences, tempo, and timing, a pattern may be recognized and formed into a musical image in your brain (Stites 12).

This description explains how such a seemingly esoteric device has become so widespread. There are problems associated with parametric control in an electronic music system. Users experienced with conventional instruments find themselves confronted with the decoupling of formerly interdependent parameters, such as loudness/timbre and pitch/envelope, and the availability of a continuum from one extreme to another. One tempting solution to this problem is to reintroduce some or all of the limitations of a conventional instrument in order to access years of conditioning/learning. Another extreme response is to develop parametric control schemes entirely specific to the technology, which may or may not be in dialogue with human perception and/or artistic goals. In this context, the Klee falls somewhere between these extremes, generating patterns via random sampling and/or data resonance which may then be incorporated into the improvisational technique of an experienced musician.

In 2007, while sharing the project development with other builders on the electro-music.com DIY forum, Stites was approached by a moderator to produce a set of printed circuit boards incorporating the design features generated by Stites and the forum participants, with the proceeds going toward website expenses. What emerged was an extremely complex but easy to use control source that has since become an extremely popular module, particularly after the design of a no-wiring kit. It has an interface designed for the intuitive real-time mixture of periodic or nonperiodic pulse streams, but it also provides provisions for experimenting with more rigorous procedures related to the industrial application of shift registers.

Another widely circulated DIY random looping sequencer was introduced by Tom Whitwell in 2012. Inspired by the Buchla 266, along with the Triadex Muse (a deterministic event-generating synthesizer produced in 1972) and Grant Richter's Wiard Noise Ring (a QRV-inspired "data resonator modulated entropy voltage source," "synthetic tonewheel," or "digital transversal filter" introduced in 2003), Whitwell's Turing Machine sequencer has found its way into many modular systems in a number of configurations, either as a bare-bones looping random source, or with internal nodes made available on the panel like the Stone and Stites designs. Though these various interpretations of the shift register sequencer differ from each other significantly, each serves as a nexus of contradictory impulses in electronic production. Electronic musical instruments offer extraordinary facilities for kinesthetic control and/or automated response. It's a scenario ripe for a showdown between allopoietic systems (which are "defined functionally or teleologically rather than reflexively") and autopoietic systems, "which have as their goal the maintenance of their own self-organization" (Hayles 14).

**1.2 Emerging Folk Traditions and Analog Systems**

Since the mid-1990s, analog modular systems have again become common among a diverse population of musician/technicians. Not coincidentally, this rebirth has coincided with the growth of the World Wide Web. With its status as an historical instrument, there is a particularly strong tension between different forms of nostalgia. Many musicians are content with the orthodoxy of the subtractive synthesis patch controlled by an equal-tempered keyboard and/or a simple step-sequencer. This conservatism supports the musical genres that rely upon such orthodoxy, such as "progressive" rock, Krautrock, "Switched-On" classical music, and the myriad sub-genres of electronic dance music (EDM) that exist today. The new cottage-industry reflected this cultural condition by producing many familiar modules, such as oscillators (typically linear function generators with waveshaping circuitry to provide sine, triangle, sawtooth and pulse waveforms), resonant filters, and VCAs (2-quadrant multipliers) controlled by ADSR (attack/decay/sustain/release) envelope generators. For many users, a modular system is an open-architecture system used to simulate a fixed-architecture performance synthesizer from the 1970s with perhaps a variety of filters to choose from.

Though there were a few manufacturers of modular systems that never went away, such as Sound Transform Systems (Serge Modular), the analog rebirth can largely be traced back to Dieter Doepfer in Germany and Bob Williams in England. Around 1995, both marketed compact systems packaged in 3U industrial racks, commonly referred to as Eurorack. While Williams' Analogue Systems collaborated closely with famous musicians such as Johnny Greenwood of Radiohead, Doepfer has conducted much of its product research on an online mailing list where prominent and obscure users alike are free to propose and vote upon module ideas. So, in addition to the standard components of a subtractive synthesizer voice, the Doepfer system has included more esoteric designs related to the special interests of its user base. These modules include a dedicated phase-locked loop module, a selection of nonlinear waveform modifiers, and a Mixtur-Trautonium subsystem, among others. In Toronto, a former luthier named Bruce Duncan began offering versions of his DIY modules around 1997. The Modcan system featured several modularized sections of Serge panels, combining some of the more esoteric features of west-coast instruments (Buchla/Serge) with the standardized subtractive synthesis architecture. Though expert programmers can produce complex results with a large Moog-like system, this type of system lacks parameter automation when compared to a Buchla or Serge-style system, making the system more reliant upon the kind of data that can be provided by turning a potentiometer or flipping a switch. Though an inventive user can do much with the automation of pitch, brightness, and amplitude, without the means of generating complex timbres and control structures, the results are often quite similar to what can be produced by conventional instruments with signal processing.

Therefore, in an effort to locate a musical folk culture specific to this type of instrument, I will focus primarily on users of west-coast-inspired modular systems who are able to translate patch ideas from one system to another and share an expanded notion of what constitutes an adequate synthesis architecture. In addition to Buchla and Serge, this architecture has been expanded by designers such as Grant Richter, Rob Hordijk, and Peter Blasser, who have each made significant contributions to DIY culture in addition to their commercial offerings. In 2004, the same year that Buchla reintroduced his modular system, Scott Stites included a pair of audio demos to the 'Klee sequencer" thread on electro-music.com. In "Shift Register Magnus Opus," Stites fades from one recorded loop to another, with overdubbed sustained tones providing continuity between the loops. This type of track is immediately accessible to fans of Krautrock, EDM, and other loop-based musics. For those less interested in repetition for its own sake, it offers an interesting conflict between the equal-tempered synthesizer pads and the arbitrarily weighted output of the Klee sequencer. In "Shift Register Random," Stites disables feedback, periodically modulating the probability of loading a new bit by modulating the threshold of the input comparator. The sonic result is not as far from the recirculating behavior as one might expect. The tuning of the DAC exerts great influence on the character of the output. One salient aspect of these recordings is the separation of the monophonic output into distinct syncopated streams in multiple registers. Even in its simplest state, the design functions a bridge between repetitive groove-based structures and more differentiated structures. A survey of Klee-based tracks posted on sites such as Youtube and Soundcloud confirms this hypothesis, with many strongly periodic grooves being stretched out by random acquisition and a smaller number of loose, exploratory pieces inching toward coherence through the short-term recirculation of data. Stites himself continues to record Klee pieces of remarkable breadth, reflecting both his technical expertise and his improvisational skill. One of the simplest techniques that he employs to achieve such breadth is to utilize a variety of clock speeds, from glacial through audio-rate, rather than giving in constantly to the syncopated groove like so many who have built or purchased the sequencer.

Another notable cultural transmission among modular system users is the self-playing patch. For many users, Allen Strange's "Electronic Music - Systems, Techniques, and Controls" is a foundational text, due in part to its lucidity and technical relevance but also due to its documentation of creative work by the author and other composers. Among the many subjects covered in this exhaustive resource is the self-playing patch, or 'dream machine." Strange includes his version in order to demonstrate the capabilities of the Buchla 266 Source of Uncertainty. The high degree of parametric automation in the 266 facilitates the incorporation of self-monitoring into the system, which can be used to maintain a "tail-chasing" behavior that never devolves into small-scale sameness.

Strange's dream machine and Douglas Leedy's *Entropical Paradise* (originally for the Buchla 100 and included in Strange's text) have resonated in today's electronic folk culture, spawning a tiny cultural movement known as the "Krell Muzak Patch." Popularized by Todd Barton in 2012 with a patch for the Buchla 200e, the Krell patch has continued to travel from one system to another reflecting a diverse range of aesthetic assumptions and patching habits. Unlike Strange's and Leedy's dream machines, which rely on a network of pulsers, sequencers, and random voltage sources placed in feedback, the Krell patch has a randomly modulated, looping function generator (such as those designed by Buchla and Serge) at its core, simultaneously triggering the acquisition of random stepped pitches and gating the audio output. It is a much simpler algorithm, depending heavily on the internal organization of the random source and careful tuning of the function generator in order to produce the desired range of behaviors. The name of the patch gives away the aesthetic goal of the exercise. Louis and Bebe Barron's "Ancient Krell Music" from the Forbidden Planet soundtrack weighs heavily on the sonic results of a typical Krell patch. The self-reflexivity of feedback systems can, when balanced carefully, provide a sense of coherence without overt repetition as the system gradually reveals its internal structure. The exchange of Krells continues as of this writing, with modular system users from around the world posting self-playing pieces based on Barton's basic patch. This common framework elucidates the differences between ostensibly similar functional blocks within the system, as well as the differences between the various system operators. Some recordings are live monophonic takes, some feature multiple uncorrelated voices, some generate quasi-polyphony, some are quantized to 12TET, and some expanding in the direction of a dream machine by closing additional feedback loops.

One particularly prolific Krell generator (Canadian artist Queer) has produced two large-scale Krells (the four-movement Polycube and the one-movement Requiem Partes Autem Animae) based on the correlation of multiple Krell patches, each producing 12TET chords (or in the case of Requiem, Messian's modes of limited transposition). Even through the thick texture of glossy harmonies and the complication of the underlying algorithm, the dependence of the system's behavior on the attack/decay settings of the function generator locates it squarely in the heart of this particular musical discourse. One effect of this cultural transmission has been the modest expansion in the number of musicians interested in exploring problems of communication and control in improvisatory musical works. By simplifying the dream machine algorithm and teaching it to a diverse worldwide population, Barton helped provide a channel for the multi-directional transmission of musical influence in an era of media saturation in which it can be difficult to discover colleagues despite unprecedented access to each other's work.

# CHAPTER 2

# CYBERNETIC SYNTHESIS

## 2.1 The Birth of Cybernetics and The Barrons

The field of cybernetics was founded during the Macy Foundation conferences of 1946-1953. The conferences were an attempt to establish an "interdisciplinary framework that would allow humans, animals, and machines to be constituted through the common denominators of feedback loops, signal transmission, and goal-seeking behavior" (Hayles 441). During the conferences, two competing constellations appeared. There was a conservative camp, interested primarily in homeostasis, and an opposing camp, interested in change and complexity (446). Claude Shannon, an electrical engineer at Bell Labs, argued that information should be defined solely as a mathematical function without regard to meaning or context. Guest lecturer Donald MacKay argued for a close connection between information and meaning. He said that Shannon's information was "selective information," calculated by considering the selection of message elements from a set. MacKay proposed a kind of information that he called "structural information," as a opposed to "subjectivity." Structural information is a metacommunication that affects the interpretation of a message (448-449).

Shannon's distinction between signal and noise presumes that exact replication of a message is always the desired result and that a goal is a preexisting state achieved through a series of distinctions between correct and incorrect choices. Shannon's theory implies that change must be corrected. MacKay's theory is concerned with the difference in the state of the receiver's mind before and after the arrival of the message. In this model, rather than being opposed to change, information is change (452).

In the late-1940s, Louis Barron studied Norbert Wiener's *Cybernetics or Control and Communication in the Animal and the Machine*. He followed examples in the text to design and construct many variations of oscillator and multiplier circuits. Wiener describes a vacuum tube neuron model, which likely influenced many of Barron's circuits that appeared to undergo "permanent or semi-permanent change" due to the application of stimuli. (Taylor) Eventually, he would construct a menagerie of semi-living circuits so relevant to the study of life-cycle that they warranted a visit from a Salk Institute scientists. Barron's synthesis method was quite unusual, despite superficial similarities between his circuit topologies and those of existing instruments. His circuits were fundamentally unpredictable, often operating in regimes that caused critical component failure. Stimulus was applied by manually applying a voltage, varying an internal current, or adjusting feedback. Rather than thinking in terms of component sound-shaping processes such as filtering, amplification, and oscillation, Barron imbedded those functions deep inside devices without such parametric designations. Regarding the matter of control, Barron remarked,

> The question is, should I be concerned primarily with what's going to come out or with what's going on inside of me.This need to have control all down the line- the composer has to control the performer, the performer has to control the audience- this is an influence that we're going to have to shed (Barron in Greenwald).

The 1959 article "What the Frog's Eye Tells the Frog's Brain," by Lettvin, Maturana, McCullock, and Pitts, is an analysis of the species-specific ways in which a frog's visual cortex responds to stimuli. If perception is species-specific, then each perception is already encoded by the perceptual apparatus of the observer, thus there is no transcendent position from which to observe reality. Data from experiments on the primate visual cortex led Maturana to conclude that stimulus acts as a trigger for a response determined by the internal organization of the sensory receptors and central nervous system. According to Maturana, one event does not cause another. Rather, events act as triggers for responses dictated by a system's internal organization (Hayles 459-462). This challenge to conventional causality has great potential for synthesis applications. Structural coupling, Maturana's term describing the relationship of one formally-closed self-organizing system to another, also describes the way perception is mediated by the perceptual apparatus (465). Signal-based electronic music systems provide the resources to exhaustively explore structural information, internal feedback responses, causality, and goal-seeking behavior in an improvisatory manner.

**2.2 Process and Product In Analog Electronic Music**

Though there is much common ground between the live and studio works produced with analog electronics during the 1960s and 1970s, there are several critical distinctions to be made in order to conscientiously build upon the legacies of these works. I his 1968 article, "Systems Esthetics," art theorist Jack Burnham argues for a reevaluation of the art work.

> ...increasingly, 'products' -- either in art or life -- become irrelevant and a different set of needs arise: these revolve around such concerns as maintaining the biological livability of the Earth, producing more accurate models of social interaction, understanding the growing symbiosis in man-machine relationships...We are now in transition from an object-oriented to a system-oriented culture. Here change emanates, not

from things, but from the way things are done (Burnham 31).

In the field of live electronics, The technological and artistic output of Gordon Mumma during this period is particularly illustrative of the distinction between process and product. In 1958, when they established their Cooperative Studio for Electronic Music, Mumma and Robert Ashley intentionally avoided building a do-it-all synthesizer, instead opting to build new equipment in the course of composing. According to Ashley,

> We would decide that we needed a certain kind of equipment, and so Gordon would make it, or I would make it, or somebody would make it...it just seemed very natural for that kind of music to evolve through the availability of equipment (Ashley in Dewar 113).

This avoidance of general-purpose synthesis tools in favor of idiosyncratic autopoietic systems (often exploiting defective or damaged components) mirrors the attitudes of Louis and Bebe Barron. In an era when many important instrument designers (such as Max Matthews and Donald Buchla) sought to create general-purpose systems with highly versatile functional blocks, artists such as Mumma and David Tudor adopted the Barrons' willingness to collaborate with unique self-organizing systems designed to subvert conventional notions of control. Morton Subotnick's work with the Buchla 100 and 200 systems offers a convenient counter-narrative. By 1969, Subotnick had begun to formulate a geometric structural foundation known as the "energy-shape" concept. In *Touch*, he extracted amplitude information from improvisatory vocalizations in order to humanize the dynamics of the largely sequencer-generated music. By the time of *Sidewinder* (1971), Subotnick had devised his ghost-score techniques of encoding DC control signals in the amplitude of AC signals and recording the performance data to tape. It was a technique that contributed to the elasticity of the final product, but still led to a fixed musical object composed partially in real time and partially outside of real time (Gagne 334-335). The energy-shape concept reached a climax with *Until Spring* (1975) and *A Sky of Cloudless Sulphur* (1980). Subotnick explained,

> It had to do with the idea that things like melodic contour could be understood in terms of energy shapes. So, I reduced everything to energy shapes. There were energy melodies, which could be in the form of crescendo/diminuendo, loudness and softness, timbral changes, the location of a sound in space, and pitch changes. It was a way to organize [my] thinking...You could actually have parametric counterpoint (Subotnick in Gagne 357).

The Buchla 200 is somewhere between a performance instrument and general-purpose hybrid analog/digital music computer. It can easily be programmed as a self-organizing musical collaborator. However, several characteristics of self-contained general-purpose systems such as the Buchla limited their attractiveness to artists such as the Barrons, Tudor and Mumma. Louis Barron explained in 1986, "A synthesizer is, designed to do something precisely and repetitively, even if the repetition is just the cycles of a sine wave. It's locked in, it's lobotomized - it doesn't have a chance to express itself." Bebe Barron was less dismissive. "The Buchla may be the only computer which would work for our kind of music." When asked about his heavily modified Oberheim synthesizer Louis replied, "It's convenient. I suppose, ultimately, the optimal setup would include the synthesizer, my circuits, and a computer, but I haven't put that together yet" (Louis and Bebe Barron in Greenwald).

Tudor and the members of the Sonic Arts Union had their own explanations for avoiding electronic musical instruments (though Tudor used a modular spatial distribution rig designed by Buchla). Part of this impulse was to enforce the confrontation with the unknown. Even when configured as an autonomous system, a modular interface will always be circumscribed by parametric thinking. David Behrman explained in 2006, “[Tudor] often didn’t understand what was going on - it was the beauty of it - that it was complex feedback paths and so on that he liked but that wasn’t really understandable” (Behrman in Dewar 127). At times Mumma, Tudor, and Behrman would sabotage electronic devices (later known as circuit-bending) in order to break down the repetitive functions intended by the designer. “In the case of synthesizers that were coming at circa ‘68, ‘69, ‘70 (because you didn’t want to dig into the Moog) they were all marvelous, but it was too early to rebuild them - they cost a lot of money” (Mumma in Dewar 128).

To effectively draw inspiration from this line of development is to embrace a complicated understanding of the work-concept, in which system design and construction is part of the compositional process. Live electronic music based on such systems tends to exist in a “liminal situation between composition and performance...This creates a musical situation in which advance planning is only partially useful, perfect compliance is impossible, and the concepts of contingency and action are essential” (Kuivila 22). As Mumma explained, “I consider that my designing and building of circuits is really ‘composing.’ I am simply employing electronic technology in the achievement of my art” (Mumma 76). When a composer requires contingency and intentionality, there exists the possibility of impossible compositions. Mumma describes the performance conditions of *Diastasis, as in Beer* (1967) in the following manner,

> the two guitars are interdependent in performance, with the pitch (or frequency) of each guitar determined by the amplitude of the other guitar...The effect proposes a musical challenge for the guitarist: they must strive to execute their parts with accuracy, but their individual efforts seldom

> produce a one-to-one correspondence with the results. Their attempted pitches do not remain constant, though the conditions of the music require the achievement of specific relationships of pitch and rhythm (Ibid. 77).

In Europe, a long-term cybernetic music project was undertaken during this period by Roland Kayn. Kayn came into contact with the philosopher Max Bense at the Technical University in Stuttgart in 1953. Bense was instrumental in the dissemination of cybernetic theory outside of the Anglophone world, influencing the so-called "Stuttgart School," an informal, interdisciplinary association of artists interested in "systems thinking." After three years with Bense, Kayn traversed the iconic avant-garde movements of post-war Europe. He visited WDR, where he was awed by the sound-producing techniques but discouraged by the serialist dogma. In the late-50's, he studied "statistical composition" with Boris Blacher in Berlin and presented the resultant chamber music at Darmstadt. In 1964, Kayn was an original member of the Gruppo di Improvvisazione Nuova Consonanza in Rome. The group was founded by Franco Evangelisti, who had used the term "cybernetic" to describe the dynamics of listening and reacting during live performance. Kayn left in 1968, dissatisfied with the group's reliance upon clichés and his inability to properly introduce cybernetic concepts into the improvisatory framework (Patterson 49-52).

In the liner notes of the 1970 LP *Simultan,* Kayn defined cybernetic music as a phase of electroacoustic music distinct from electro-instrumental, concrete, electronic, and computer musics. He defined cybernetic music in opposition to computer music, in spite of work by composers such as Iannis Xenakis and Herbert Brün. Regardless of the content of a computer program, it must be formulated by the composer in a programming language and then executed in a manner analogous to the performance of a score. Cybernetic music is instead based on “a generative process in which existing sound materials are fed back upon themselves in order to create deviations from what came before.” The nonlinearity of cybernetic systems allows the system to break out of cyclical patterns and jump from one state to another. While simple negative feedback loops tend to produce homeostasis,  complex feedback networks can cause unforeseeable transformations and “the immense expansion of the acoustic domain … which can neither be imagined nor attained through other than cybernetic means” (Ibid. 52-61).

Between 1971 and 1982 at the Institute of Sonology at Utrecht, Kayn produced a series of works elaborating upon the cybernetic concept using a voltage-controlled system of oscillators, multipliers, filters, function generators and logic gates. The subversion of conventional control mechanisms suggests a possible reconciliation between the idiosyncratic techniques of Tudor and Mumma and a full-featured general-purpose system such as a Buchla or Serge. Musicologist Frans von Rossum described Kayn’s method as such,

> (Kayn’s) electronic pieces start by defining a network of electronic equipment. The nature of the network, and its inherent potential, play a large role in determining the audible result. Next, the composer collates the basic information about this network and develops a system of signals or commands that it can obey and execute. These have to be incorporated in a system of controllers, adjustments, and operations, which can realise the composition. … The composer presents his music as an artifice which he constructs and sets in motion, but once he has done this, it is left to move through space, a ‘free’ music, which, like the fabric of the cosmos, follows its own internal laws and conditions (Ibid. 62-63).

The Utrecht pieces share an expansive, evolutionary time-scale and a sonic continuum from pure tone to noise, with particular attention paid to the the intermediate zones of chaos and turbulence. During moments of relative order, the mechanisms of control are detectable in the proportional response of the audio-generating circuits. The neutral sound of the system then gives way to unpredictable and unrepeatable waves of complexity. This complexity is not dependant upon defective, stressed or damaged components, though it does rely upon the nonlinearity of analog circuitry as a generative principle.

The electronic works of Kayn, Tudor and the Sonic Arts Union challenge us to reassess traditional notions of the musical work and where it is located. Undoubtedly, many musicians are still interested in the faithful execution of documented commands. There is no need to supplant one orthodoxy with another. However, for those interested in a definition of composition that accounts for the unforeseeable and unknowable aspects of phenomena, this particular tradition has much to offer. The drawing of analogy between machine structure and models of general system-behavior provides the electronic performer/composer with an avenue of exploration that is at once directed and unconstrained. These works are notable for their acknowledgement of uniqueness, whether it is that of the circuit, performer, room, or moment. They require the performer to attend to the environment within which the performance occurs, whether it is a physical space or the cyberspace that increasingly mediates our perceptions.

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