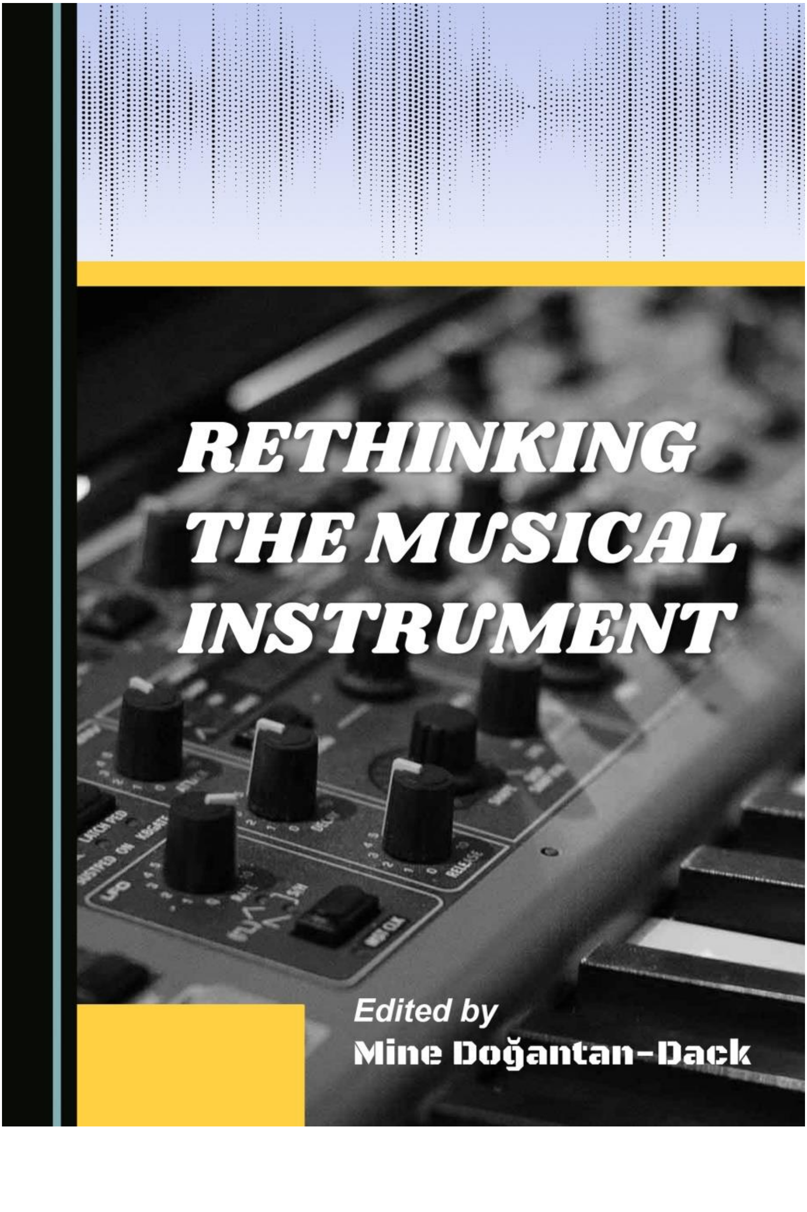
RETHINKING
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CHAPTER FIFTEEN

THE ANALOGUE SYNTHESIZER: CLASSIFICATION, DESIGN AND MUSICAL POTENTIAL

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Renaissance of the analogue synthesizer

> In an era of digital connectivity, musicians and music technologists are demonstrating wide-spread enthusiasm for a return to the synthesizer styles of the 1970s, complete with unpredictable sounds, networks of patch cables, and wood-paneled designs. Over the past few years, this analog revival has become a full-blown renaissance. Synthesizer keyboards, along with DJ gear, saw the largest gains in U.S. sales in 2013 compared to the previous year among all music product segments. (Rodgers 2015: 5)

In spite of its limitations, and at a time when digital technologies are increasing in sophistication, musicians are "actively choosing regression" by using analogue synthesizers (Rossmy and Wiethoff 2019: 343). Manufacturers have responded to demand for hardware synthesizers by producing innovative Eurorack modules, completely new instruments, and scaled-down reproductions of classic synthesizers from the 1970s and 1980s. Analogue synthesizers are problematic in many ways: they are "obsolete", noisy, inefficient, non-linear, contain "oddities and flaws", and are unsuitable for exploration of complex synthesis methods that require predictability (Scott 2016). These issues led to the ejection of analogue synthesizers from electronic music studios in the 1980s and 1990s as more reliable and accurate digital instruments became available; yet these analogue instruments have survived, and are now recognised for what they do well. The analogue synthesizer in particular, and synthesizers more generally are regarded by many musicians as affordable, expressive instruments that are "not the sole domain of nerdy geeks" in the twenty-first century (Dalton 2020: xiii). The analogue synthesizer was until relatively recently seen as the more "expensive and bulky" and less "egalitarian" cousin of small, portable digital synthesizers (Demers 2010: 8-9). However, mass-production of small, affordable instruments based on existing designs, and a lively Eurorack modular scene have transformed how the analogue synthesizer is viewed over the last decade.

There is an identifiable sound of the analogue synthesizer that is "stable" (as defined in Pinch 2016) or recognisable as belonging to that instrument. Pinch illustrates this idea with the "fat bass" sound that is closely associated with instruments such as the Moog Minimoog that uses a low-pass filter and detuned oscillators generating sawtooth or pulse waveforms (Pinch 2016: 42'29"). Although analogue synthesizers are still evolving into new innovative designs, several classic instruments have continued to be manufactured in hardware form as reproductions. The Minimoog is the most obvious example of a persistent design that was first introduced in the 1970s and is still available today. Several other synthesizers and drum machines from the same era that were originally designed by ARP, Korg, Sequential or Roland also persist in forms that are very close to the design and sound of the original instruments. As these once expensive and rare instruments become available again in hardware form, their sound and functionality is recontextualised by a new generation of musicians. These synthesizers have remained in use over the past decades and share many common sounds and a similar feature-set that will be discussed here in the context of defining the modern instrument of the analogue synthesizer.

The decline of academic interest

Despite the rapid expansion of new, innovative analogue synthesizer designs in the 1970s and early 1980s, academic interest in these instruments declined so as to re-focus upon digital technologies and experimental software development. Even before the domination of computer music, there was a presumption that an improved technology was going to supersede the analogue synthesizer: "In the far future analogue devices may be swept away by more reliable and accurate digital synthesizers constructed from integrated circuits" (Mathews 1970: 129). Academic literature has produced only occasional engagement with synthesizer practice, with very few in-depth studies exploring the implications of synthesizer design for practice. The limited scope of academic studies was noted as early as 1975 by McCarty:

> Today's synthesizer experts are essentially self-taught. It is unfortunate that little has been written on the technology of electronic music systems

> and the compositional ramifications of it. Most literature is historical or aesthetic in nature, or single-product oriented in scope. (1975: 99)

Some early articles highlight the synthesizer's limitations, restrictions, over-commercialisation, or the view that synthesizers "do not readily encourage thinking about music in new ways" (Howe 1969: 180). Subtractive synthesizers were judged, perhaps unfairly, against the complexity of live sounds in the context of a growing awareness of instrumental acoustics. For example, Howe bemoans the lack of complex oscillators and filters in then-current synthesizers, and cites the early sound modelling experiments from Bell laboratories to illustrate the shortcomings of subtractive synthesis (1972: 125-126). In her sleeve notes for *Digital Moonscapes* (1984), Carlos cites the "narrow" sonic palette of the analogue synthesizer as a reason for her adoption of digital synthesis techniques. Wishart makes several interesting observations about the synthesizer in *On Sonic Art*, commenting, for example, that sounds from the "electrical circuits" of a synthesizer lack the liveness of sounds generated by human actions or by natural forces (1996: 180). He also compares the potential of the computer to create "impossible" sound-objects from a given model (such as the voice) with the lack of a real-world, or a sufficiently detailed model within the architecture of the analogue synthesizer, which will consequently always be perceived as synthetic (Wishart 1996: 327). Compared to the computer, the subtractive synthesizer has clear limitations when viewed as a system for creating complex new models for sounds.

A more positive view is also occasionally presented, for example by Subotnick (1970: 8-9), who describes the "real time" nature of composing directly with sound when making electronic music using the Buchla synthesizer, permitting a level of experimentation and performance with sounds that was more immediate than the purely tape-based methods at the time. Similarly, Howe mentions the advantage of being able to hear a complex musical process immediately with the Buchla modular system, particularly when compared to early computer music languages such as MUSIC IV. Many of the advocates of the synthesizer in the 1960s and 1970s were writing from the perspective of individuals with commercial interests in products made by Moog, Buchla, ARP/Tonus, EMS and other companies, or were closely involved in the design of particular instruments. This is evident in the small number of Audio Engineering Society papers that discuss synthesizers in those decades, for example (AES).

Before the widespread adoption of computers and digital instruments, analogue synthesizers were (briefly) viewed as a central component of the analogue electronic music studio for processing external audio signals in addition to generating sounds. Perera (1971: 68) suggests that a “miniature” synthesizer such as the EMS VCS3, ARP 2600, Minimoog, or EML ElectroComp could be used to create a cost-effective “practice studio” and a portable “electronic music demonstration” setup with the addition of a tape recorder. The Don Banks Music Box was a “synthesizer-like package” designed around the concept of a basic, affordable set of tools for contemporary composers with the more sophisticated EMS VCS3 instrument developing those principles further from 1969 (see, Gardner 2017, 2020). The VCS3 combined sound generation with features for processing external audio signals, such as a ring modulator, spring reverb unit and filter. In the 1970 manual, the VCS3 is described as a “compact electronic music studio” and also as the “Voltage Controlled Studio Mk 3”, but not a synthesizer (EMS, 1970). An initial reluctance to use the term “synthesizer” seems to have been shared by Don Buchla, as reported by Pinch and Trocco: “For him the word synthesizer had (and still has) connotations of imitation. ... He did not regard his new instrument as a vehicle to imitate or emulate the sounds of other instruments” (2004: 41). This report of Buchla’s view of the term is confirmed in online transcripts from Gardner’s interview with Ciani:

> Don Buchla didn’t like the word “synthesizer” because it had misleading connotations. Some people thought of the word “synthesizer” as relating to “synthetic”, or that it was imitating existing sounds, whereas he wanted to be clear that this was a completely new domain—this was a new instrument. (Gardner 2013)

Allen Strange, as an author and composer who had worked closely with the Buchla 200 series instruments, also acknowledges that he had previously “reacted against the use of the word ‘synthesizer’ as applied to contemporary electronic instruments” due to connotations with “synthetic music” and “synthetic sound” (Strange 1983: 3). However he adds that “If synthesis refers to building up from component parts, what is being synthesized are musical instruments” (ibid.). It should be noted that Strange was documenting techniques of electronic music largely from the perspective of modular synthesizers, which explains the reference to building instruments. More broadly, this also demonstrates a growing acceptance of “synthesizer” as a term to describe a process of creating sounds, rather than a particular sound-world, or musical aesthetic.

Many of the new instruments introduced in the 1970s (such as the ARP 2600, Korg MS-20 and Minimoog) were marketed as accessories for rock and jazz keyboard players (or less successfully, for guitarists) in parallel with marketing for educational applications. A difference in marketing approach between USA and UK, and the influence of distributers is detailed in Gardner (2020). A notion of the subtractive synthesizer as an *imitative* tool emerged at this time, which in many cases contradicted the aims of experimental avant-garde music. The operation of these “fixed-architecture” (Seago et al. 2004: 3) or semi-modular instruments was documented in relatively simple manuals with patch sheets that could be copied and used to create imitations of acoustic instruments. Synthesizer programming was more accessible due to the clear instructions that were easy to follow, and patch names from the ARP 2600 Patch Book such as “Heavy Metal Fuzz Lead”, “Jazz Guitar”, or “Zombie Organ” demonstrate a frivolous approach to patching, with the expectation that the synthesizer would be played conventionally as a keyboard instrument. The focus on imitative rather than more abstract sound design was part of a successful marketing strategy to broaden the appeal of the synthesizer, in spite of the fact that subtractive synthesis is not particularly effective for imitating acoustic instruments or real-world sounds. Howe’s 1967 *User’s Guide to the Buchla Modular Electronic Music System* provides detailed explanations of each module in the range available, with examples of how they could be patched together, but unlike the patch books for instruments such as the Minimoog or ARP 2600 Howe avoids the creation of imitative instrumental sounds, as do Carey’s tutorial patches in the EMS manuals for the VCS3.

A suggestion of academic disdain towards synthesizers that were marketed as imitative instruments is evident, for example in the 1977 AES convention paper “Compositional Limitations of Current Electronic Music Synthesizers”:

> Now any idiot can consult the patch book, get the trumpet patch, press a key, and there it is. No surprises. Synthesizer manufacturers are quick to point to their rising sales, and to the fact that one does not hear many rock groups using Buchla equipment to support the correctness of their idea that technology has freed the musician. (Ceely 1977: 4)

Ceely (1977) argues that developments in synthesizer design led manufacturers to abandon features of instruments that were not favourable to rock musicians. Specifically, he refers to design simplifications and a focus upon live performance with the synthesizer controlled by an organ-style keyboard, rather than tape compositions and more expressive (“touch-activated”) methods of control (Ceely 1977: 3). Howe is similarly critical of the monophonic keyboard controller used on the Moog synthesizer, which in his view is the key reason why “many less serious musicians, such as rock groups, are now becoming Mr. Moog's prime customers" (1969: 180). In his article for *Music Educators Journal*, Ehle (1971) identifies the differences between Moog and Buchla analogue synthesizers as being the difference between "note-oriented" versus "timbre-oriented" design philosophies respectively. This difference is further explained in terms of the Buchla Electronic Music System being able to use sequencers and touch-sensitive controllers to "'play' the harmonics of a sound or the bands of sound passing through a filter", whereas the Moog System IIIc was capable of playing Bach using a 5-octave piano-style keyboard controller that was "tuned to the twelve-tone equal-tempered scale" (Ehle 1971: 80). In reality, both Moog and Buchla systems were capable of sequencing simple patterns of notes, or creating complex sounds that could be pitched or unpitched, but criticism of the keyboard controller as a limiting factor in synthesizer design conflicts with marketing campaigns in the 1970s that featured the keyboard prominently. The keyboard was a perceived barrier to experimentation and musical freedom:

> For example, one can use the synthesizer as a keyboard instrument, as a souped-up electronic organ. The instrument is often used this way in popular music, and it seems to be with this in mind that synthesizer packages such as the MiniMoog are marketed. (Coren and Smoliar 1976: 122-123)

Howe (1972: 122) provides a more balanced view of the keyboard, which "gives excellent control over equal-tempered intervals and octave transpositions", and makes some synthesizers easier to "operate". Howe suggests (1972: 126) that the keyboard is worthy of consideration as a rhythmic controller, although most keyboards were monophonic at the time. However, he also acknowledges that keyboards have several deficiencies, including a lack of accurate control over the speed of "continuous frequency changes", and control over "the *overtones* of a fundamental frequency", which leads to "uniformity in the timbral structure of pieces created with keyboards" (Howe 1972:123). Criticism of the keyboard in this era was preceded by a proliferation of tonal musical arrangements created on ARP or Moog synthesizers in the late 1960s: Holmes (2014: 221) has catalogued 235 unique commercial recordings made on Moog modular systems alone from 1967 to 1970. Such an extensive catalogue of popular, tonal music played on keyboard-based synthesizers, usually with "uniform" timbres must have influenced the thinking of academics who were interested in synthesizers to explore new timbres and systems of intonation in the 1970s. Even in more recent literature, the presence of a keyboard can be seen as problematic as it "strongly pushes the user towards the 12-tone equal tempered scale common to a large body of Western music" (Dalgleish 2016).

A fundamental divergence in synthesizer performance practice emerged in the 1960s that still exists today: when the synthesizer is manually controlled by a keyboard, the performer's hands are not both free to explore changes in timbre via the control panel. An assumption could be made that when the synthesizer is controlled by a keyboard the musical focus moves towards pitch and away from deeper exploration of spectromorphology. Conversely when the synthesizer is used without a keyboard, the assumption is that the oscillators tend to be used to create drones (or are controlled by a sequencer), with the performer free to vary synthesis parameters over time. These assumptions are, of course, an over-simplification of synthesizer performance practice and the diverse range of music made with the synthesizer, which can often include sophisticated changes in timbre alongside keyboard-based techniques. Ciani retrospectively commented that while the keyboard "bridged a gap in understanding" between manufacturer and the broader public, it also

> short-circuited the potential of those instruments because the keyboard interface came from a mechanical universe. It produced, mechanically, one event for one action. Whereas in electronic music we were used to touching a key, say on a flat plate, and maybe 50 things would happen. (Ciani quoted in Gardner 2013)

Ciani's *Report to National Endowment* of 1976 provides a very useful description of the patches designed with Buchla 200 series modules, with (most notably) some detailed analyses of her performance practice. She discusses her sense of familiarity with a patch, discussing the patch itself (rather than just the system as a whole) on an instrumental level and the importance of "not having to 'think twice' (at least not more than once) about what effect —or series of consequences will be produced by a given action" (Ciani, 1976: 2). Ciani's patches use the Buchla 246 sequencer module with the 248-1602 Multiple Arbitrary Function Generator (MAFG) module to create complex interactions between simple patterns of pitches that are ordered and shaped by the MAFG. The multiple rows of 16-note sequences in some of the patches are reminiscent of serial techniques, and pitches are generally quantised to diatonic intervals. However, Ciani emphasises the inspiration of the technology itself behind the music and the creation of new musical forms from the interaction between modules:

> Although a single row of 16 ordered pitches is the basis for this idea, the constant shifting of emphasis as it moves along creates an "aural illusion" that conceals its simple origin. A constant pulse is the basis for the rhythm, and larger rhythmic units are created by timbral emphasis and registral displacement. In some ways this musical technique is related to serialism; however, it was actually born from the seemingly inevitable consequences of an Arbitrary Function Generator meeting a Sequencer. (Ciani, 1976: 8)

Reviews of early synthesizer-based music from the late 1960s provide an insight into how the instrument was viewed critically as both an instrument and an environment for composition. For example, Dockstader acknowledges the rhythmic power and potential of the sequencer "at the heart" of the Buchla synthesizer, but also questions "how much is the Machine, how much is the Man" in his review of Subotnick's "The Wild Bull" album (Dockstader 1969:136-139). Carlos is critical of the "dull peck-peck-peck-peck of sixteenth notes" from the Buchla sequencer in a review of Subotnick's "Silver Apples of the Moon": "the sequencer, the heart of the Buchla System, is to my ears simply over-used, and overly depended upon to make the composition move" (Carlos 1968: 39). Coren and Smoliar (1976: 109) bemoan the lack of "substance and impact" in synthesizer music when compared to the earlier works of Karlheinz Stockhausen or Luciano Berio, for example, from an academic perspective in the mid-1970s USA. In contrast, the analogue synthesizer was being successfully integrated into the sound world and working methods of tape-based acousmatic music during what Teruggi describes as the "electronic period" of the Groupe de Recherches Musicales (GRM) up to the end of the 1970s (2007: 219). The Coupigny and Moog synthesizer modules "brought fresh air to the sound of the music composed in the GRM" beginning with Bernard Parmegiani's "L'oeil écoute" in 1969, followed by many iconic works by François Bayle, Michel Chion and Guy Reibel (Teruggi 2007: 220). Other French composers seemed to be able to embrace the potential of the analogue synthesizer within the context of experimental sound composition, such as Éliane Radigue, who demonstrated an "unwavering simplicity and clarity of vision" in her use of the ARP 2500 (Thurley 2019: 75). Lesser known works for synthesizers are being rediscovered, such as Parmegiani's 50-minute "Stries" for Yamaha CS-40M, Synthi AKS, Roland System 100m and tape, which has been meticulously reconstructed with reference to the original instruments and patch sheets used to create the piece (Berweck 2016).

Musical considerations of synthesizer design

Synthesizers are typically divided into conceptual units of sources, modifiers, and controllers, as described in many of the educational books available (e.g. Drake et al. 1975: 45). Performance controllers on the analogue synthesizer are defined typically as keyboard, ribbon controller, foot pedals, sequencer, arpeggiator, antenna (as used by the Theremin), pitch bend wheel/lever, modulation wheel/lever/switch, and audio input signals, on the Korg MS-20 for example, where the audio input can be used to control pitch and trigger notes. Pressing (1992: 13) makes a distinction between "fixed" synthesis controls and "real-time" controls, identifying the controls that are normally associated with (keyboard-based) performance as "real-time". However, on the analogue synthesizer the entire control panel can also be considered as a large suite of real-time performance controls, each with an individual function and character of response that is particular to each instrument. This is partially acknowledged by synthesizer manufacturers, who often make important parameters (such as filter frequency) larger and easier to find on the control panel. The design and layout of synthesizer controls has not been given the attention that they deserve, as noted by Howe:

> Just as not much thought has been given to compositional considerations in early electronic music, not enough thought has been given to human engineering considerations in early electronic music synthesizers. Many of the devices on some synthesizers have controls that are more appropriate for electrical test equipment than for a musical instrument. (1972: 121)

The standard layout of the analogue synthesizer tends to follow the logical signal flow of core components: signal generators, signal mixing, modulation sources, filters, and amplifier. The EMS Synthi-VCS3 (Putney) helped to establish this basic layout, as did the Moog Minimoog. As noted by Jenkins (2007: 16), this layout also follows the sequence of patching on a modular system, and control panels on fixed-architecture instruments were designed "as if the instrument comprised separate modules". The design and layout of the synthesizer control panel is important, particularly when the controls are viewed as an integral part of a performance ecosystem.

Comparing the Minimoog and VCS3, as two archetypal examples of synthesizer design, there are notable differences that affect how each synthesizer can be used. Both instruments feature a sloping front panel that brings controls closer to eye level and invites the performer to interact with sound parameters. The Minimoog is undoubtedly a keyboard-based instrument, whereas the VCS3 is more likely to be controlled in performance with the built-in joystick. The Minimoog is a fixed-architecture design, and this type of synthesizer can allow rapid changes to be made to the sound in real-time whereas the semi-modular VCS3 has a more flexible architecture overall, but may require some re-patching of functions to achieve a similar outcome. For example, re-routing a low frequency oscillator from modulating filter frequency to oscillator pitch is achieved via two switches on the Minimoog, or by moving a pin horizontally along a pin matrix on the VCS3. Both methods involve a simple physical action, but the pin matrix positions on the VCS3 are quite difficult to read in low light, and the pin holes are quite small to locate quickly compared to the switches on the Minimoog.

The modular synthesizer

Fixed-architecture (and semi-modular) instruments offer the opportunity to alter sounds quickly during performance while losing the ability to customise the modules that are used to build the synthesizer. Non-modular synthesizers also allow each instrument to be learned as a fixed musical instrument, potentially allowing a high level of performance practice to be developed over time. However, a flexible approach to the arrangement and interconnection of synthesizer modules has remained popular, particularly in the form of systems built from discrete modules that can be replaced and connected together. From early Moog systems to the smaller contemporary Eurorack modules, modularity has provided a high degree of flexibility and choice, but it also presents several restrictions in musical performance. Modular systems rely upon physical connections between modules to create a patch and while some basic automated switching is possible, it is not possible to switch between several completely different patches. Most modular systems use cables to make connections between modules, and even simple patches can result in several cables crossing over the parameter controls. This was a problem for Radigue, who chose the ARP 2500 synthesizer, which uses a slide matrix method of module interconnection, instead of the cable-based Buchla modular system:

> [The Buchla] had a big disadvantage: all the patching cables intersected between the modules and in the middle of that you had to manipulate the dials. It was like dipping your hands in a plate of spaghetti. If you weren't careful, you would accidentally disconnect one of the cables slightly, and finding it again became a real exploration. (Eckhardt and Radigue 2019: 114)

Conversely, Ehle (1971: 80) described patch-cords as "messy" but "instructive" because the cables show clearly how different modules are connected together. On the smaller modern Eurorack modular systems it is common for patch cables to obscure the view of parameter settings on each module, which renders patches made by someone else difficult to read visually. The significance of this becomes clear when attempting audio-visual analysis of modular synthesizer performances in a live setting or from online video recordings. There may also be a problem with audience engagement because of the incongruity between complex sound transformations and the minimal visual information presented about the performance practice, as identified by Auricchio and Borg: “From the viewpoint of the layman audience, no amount of visual or embodied visual input may help to better inform them of what is taking place in a manner that enables for a comprehensible and transparent performance” (2020: 109).

The selection of modules to include in a modular system becomes part of a creative process, as the modules dictate the functionality and sound of the instrument. Modular systems are, therefore, more customisable to meet the requirements of individual musicians or musical genres and may incorporate a variety of expressive hardware controllers to enhance the sense of live, responsive performance practice. Unlike in the late 1960s when Moog modular synthesizers were predominantly used as tonal keyboard instruments, the keyboard is “no longer privileged” in its status within the contemporary modular system; it is “only one of a number of input options”, but not entirely rejected either (Dalgleish 2016). Ultimately, the modular system is not necessarily an analogue or even a subtractive synthesizer, and modularity is not about “how the noise is made, but rather the concept of patching” (Paradiso 2017: 1).

Classification

Organologists have attempted to define synthesizers using coding systems to break-down the synthesizer into individual circuits or modules contained within an extended and revised fifth category of the Hornbostel-Sachs classification system. Gaining a deeper knowledge of instrument classification may benefit the designer, composer, or engineer, as suggested by Olarte:

> Studying these classification and taxonomy systems can be a way to explore the landscape of possible and impossible instruments, to investigate how musicians and engineers have set up and implemented different categories and combinations and even to imagine new ones. (Olarte 2019: 55)

Weisser and Quanten (2011: 139) provide a detailed description of the Korg MS-20 semi-modular synthesizer as an analogue synthesizer (code 523.1) comprising: two oscillators (511.1*2), white and coloured noise generators (511.2*1), one multi-mode filter (512.15*1), two amplifiers (512.2*2), one low frequency oscillator (514.11*1), one envelope generator (514.12*1), a sample and hold circuit (514.14*1), and an envelope follower (514.16*1). The coding system in this case has not recorded the semi-modular nature of this instrument, and several important technical details of the synthesizer are missing, such as the less-common Hz/V pitch control input voltage standard used by the MS-20. The characteristic filters of the instrument are also not entirely accurately represented by a single "multi-mode" definition as the synthesizer has two separate resonant filters (high-pass and low-pass) that can be used together to create a band-pass filter. There is an external audio input on the synthesizer (as suggested by the identification of the envelope follower), but also a pitch-tracking circuit, not included in the definition, that can enable pitch to be controlled by an external signal. The waveforms that are available from each oscillator (and LFO), and the specific filter circuits used in the synthesizer are also not recorded, and yet these are sonically important details when comparing the MS-20 with another monophonic synthesizer such as the Minimoog, which has a very different core sound and more limited functionality. Such a coding system is clearly inadequate as a means of describing a complex electrophone such as the MS-20, and this is readily acknowledged by Weisser and Quanten: "In the age of computers, there is no need to stick to a nineteenth-century linear system to codify complex modern technology" (2011: 140).

A more sophisticated, "rhizome-inspired" solution is proposed by Weisser and Quanten (2011: 141), and a similar "heterarchical" approach is discussed by Magnussen (2017) in the context of digital musical instrument (DMI) classification. Each proposal aims to overcome the limitations of the hierarchical, tree-like structure of the Hornbostel-Sachs classification system in favour of a more multi-dimensional approach, where complex instruments can be described "without the classifier having to choose only one route of description", within a "wider conceptual framework for classification" (Weisser and Quanten 2011: 141-142). Information about each instrument could encompass several different dimensions, such as technical specifications in addition to historical and sociological data, to create a searchable "map" with specific "tags" that can allow different instruments to be compared (Weisser and Quanten 2011: 141). Magnusson emphasises the "philosophical attempt to rethink classificatory strategies" (2017: 300) and "going beyond trees and metadata to actual machine analysis of content", as opposed to human organisation of the data (ibid.: 299).

One advantage of attempting to define a particular type of instrument is that common features can be more easily identified and compared. In the analogue subtractive synthesizer, the filter is one of the key components that can help to define each instrument. There are measurable and audible differences between different filter circuit designs, particularly when higher levels of resonance (or "emphasis") are introduced. Individual filters may sound quite different, such as the characteristically warm, smooth low-pass filter response of the Minimoog or the comparatively harsh and powerful resonant sound of the high-pass and low-pass filters within the MS-20. Within a multi-dimensional and multi-media approach to classification, differences in spectromorphology could be demonstrated by audio examples of the filter cut-off frequency from each instrument (or module) being swept gradually across the available range and with different levels of resonance applied. Additionally, musical examples of each instrument used to create sounds that are characteristic of the instrument could be included, in order to illustrate how other components contribute to the overall sound. Once instruments are defined with enough precision, music written on a particular synthesizer may be transferable to others with similar characteristics and functionality.

Synthesizers and DMIs

There are many interesting parallels between the complexities of classifying or defining digital musical instruments (DMIs) and analogue synthesizers. One obvious similarity is the complexity of describing mappings between control inputs and sound generating functions in DMIs and the interconnection of audio and control signals in analogue synthesizers. Whereas the number of possible mappings is notionally unlimited in the DMI, connections in the analogue synthesizer are limited by the number and type of modules available, or by pre-determined control voltage pathways within the analogue circuits. Distinctions between input (control) parameters and output (musical, sound-making) parameters can be fluid in the analogue synthesizer, as they can be in DMIs. For example, the function of oscillators may be switched between audio signals and control signals. This fluidity results in an ambiguous control system from the perspective of the audience such that an oscillator frequency control can transform from a pitch parameter (when the oscillator is heard as a sound source), to a parameter that changes timbre (when the oscillator is used as an audio-rate control source), or a parameter that can change the speed of a rhythmic effect (when the oscillator is used as low-frequency control signal). These functions are all related in terms of the technical role of the oscillator, and share the same physical control on the instrument panel, but the audible outcomes in each case are entirely different. This dual functionality of the oscillator is an example of a "polymorphic" circuit (or module) as defined by Hetrick: "a module that can serve multiple, distinct functions" (2017: 6).

Morreale and McPherson (2017: 195) identify three features of user experience in relation to the design of DMIs that can also be applied to the synthesizer: familiarity (such as "an intuitive instrument based on traditional modes of interaction"), simplicity of interaction, and set-up time. Similarly, Jordà's notion of "musical instrument efficiency" is used to measure "musical output complexity" against "control input complexity" in DMIs (2004: 333). Synthesizers, when measured on similar terms may provide a relatively "high-efficiency" entry point for amateur musicians to experience electronic music. While the sonic results or musical output of subtractive synthesis may be complex, the simplicity of the control panel interface allows for intuitive experimentation. The presence of a keyboard may also provide an accessible method of interaction with the synthesizer; however an integrated sequencer or arpeggiator (see, Young 1967; and Lozej 2016) allows musicians with little keyboard skills or technical knowledge to create patterns of pitched or unpitched sounds. The analogue synthesizer in fixed or semi-modular form, therefore, shares a high level of instrumental efficiency with well-designed DMIs. In the fully modular synthesizer (with no pre-determined or normalised signal pathways), the technological and visual complexity of the system will in most cases be a more daunting prospect for the novice. As in the DMI that offers many options for control and customisation, the analogue modular system requires a higher level of technical understanding to make sounds and set musical patterns intuitively.

Kvifte and Jensenius (2006: 223) outline different categories of parameters which are used to describe the various gestural, technical, and musical elements of an instrument. Distinctions between discrete and continuous parameters are of particular relevance to the synthesizer, and the potential complexities of such distinctions are illustrated. For example, when considering the connection between input (gestural) and output (musical) parameters, the mapping of gesture to sound may be analogous, such that "a continuous output parameter needs a continuous input control", or dissimilar: "it is also possible to use a discrete input to *trigger* a preprogrammed continuous variation of output like a vibrato on a synthesizer" (Kvifte and Jensenius 2006: 224). Extending these definitions further, a keyboard (discrete) may be used to create continuous changes in pitch or other parameters via portamento, glide, lag or slew functions. Conversely, the slow continuous physical movement of a filter frequency control may result in what are heard as a series of jumps between discrete tones moving up or down the harmonic series when the filter resonance is set at a high level. The setting of the filter resonance parameter in this case transforms the mode of the filter frequency control between continuous and discrete. Not all filters will produce the same result, however, and this lack of consistency illustrates the problem of attempting to accurately define even a sub-category of analogue synthesizers in detail.

Comparison of modern instruments

To fully understand the musical potential of analogue synthesizers from sonic and aesthetic perspectives, it becomes necessary to explore individual instruments, or small clusters of similar instruments. One important early study appears in Tellef Kvifte's *Instruments and The Electronic Age*, which includes a detailed analysis of the Roland JX-8P (2007: 171-179). Kvifte defines 75 "control organs" within the JX-8P, including the 46 "instrument definition" parameters on the PG-800 programmer for this instrument (2007: 172). Although Kvifte's book was first written in 1988, the parameters of the analogue synthesizer have retained many common features and similar terminology to this day. The importance of Kvifte's study lies in the level of accuracy and detail when describing each of the parameters, although a much larger study is needed to define the musical significance of these parameters within a wider context of synthesizer design.

To explore how the modern synthesizer has evolved as an instrument, I have undertaken a comparison of ten monophonic (or paraphonic) analogue synthesizers. The ten synthesizers were chosen according to the range of panel controls offering the widest range of specifications available within the price range. These synthesizers were widely available in 2020 and priced between 200 and 400 Euros. Six out of the ten synthesizers included here are currently made by Behringer, but five of these instruments are in fact reproductions of synthesizers from the late 1970s and early 1980s. Specifically, these are: the Roland SH-101 (Behringer MS-1), Korg MS-20 (Behringer K-2), Sequential Circuits Pro One (Behringer Pro-1), ARP Odyssey (Behringer Odyssey), and Moog Minimoog (Behringer Model D). The other Behringer synthesizer that has been included is the Neutron, which is not based on an existing instrument. Also included in the survey were the Arturia Minibrute 2, Korg Monologue, Novation Bass Station II, and Roland SE-02. Half of the synthesizers in the survey include a keyboard while the remaining five synthesizers are in a desktop module format that can in most cases be integrated into a Eurorack system with some control voltage (CV) patch points available for interconnection with other modules.

These ten instruments share a similar range of basic synthesis options: oscillators, filters, and amplifier, with LFOs and envelopes for modulating pitch, filter frequency and amplitude. Most of them have a fixed architecture, but the Minibrute 2, K-2, and Neutron are categorised as semi-modular, with more extensive patching capabilities. These three instruments offer a similar level of flexible patching as the pin matrix system of the VCS3, although the range of patchable circuits available on each synthesizer varies considerably. When compared to an instrument such as the Minimoog, all of the instruments are more sophisticated in terms of functionality and connectivity. However, there is evidence of certain sound design functions being omitted from this sample of modern synthesizers. Ring modulation is absent from six out of ten instruments, and where this circuit is implemented it can only be used between internal oscillator signals rather than for processing external sounds. This omission distances modern synthesizers from the EMS notion of the synthesizer as an experimental studio tool kit, where ring modulation was once one of the key effects for processing sounds from a microphone or tape in the 1970s. Similarly, although external inputs are included on all of the synthesizers surveyed, in most cases this input is limited to a single fixed signal path through the filter section of each instrument, with no option to modulate the amplitude or frequency of the audio signal directly with oscillators, which was possible on the VCS3 (EMS 1970: 20).

Subtractive synthesizers require a sound generator of some kind, and since the 1960s, the voltage controlled oscillator (VCO) has been the primary sound source on an analogue instrument. The VCO remains a consistent element in nine out of ten of the modern instruments surveyed, together with the digitally controlled oscillator (DCO), an analogue oscillator circuit that is controlled by a high frequency digital clock signal, as used in the Novation Bass Station II. VCOs ostensibly have more inherent drift in pitch than the DCO, although modern VCOs can be designed to be very stable in pitch. Synthesizers that are designed as reproductions of classic instruments retain some of the instability or drift of the oscillators on the original instruments and tuning is affected by ambient temperature changes. Oscillator drift is often regarded as a desirable feature—a characteristic sound of the analogue synthesizer to the extent that it may be emulated in software. All of the synthesizers surveyed include at least two oscillators (or one oscillator with a sub-oscillator), allowing for sawtooth and pulse/square waveforms to be used simultaneously at different pitches. A noise generator is included in every case to allow unpitched sounds to be mixed with the periodic oscillator waveforms. Sawtooth and variable pulse waveforms are two of the harmonically richest sounds that can be generated on a subtractive synthesizer, and the effects of filtering are particularly clear when using these waveforms. Most instruments also include either a triangle or sine waveform, which can be useful either as a sound source or when used for audio-rate frequency modulation between VCOs or between an oscillator and filter. In such circumstances, these waves can often produce less noisy sonic results than sawtooth or pulse waves.

The dominance of the resonant low-pass filter is clear in the modern instruments, as all of the synthesizers feature at least one low-pass circuit: this filter is at the heart of the most archetypal sounds of the analogue synthesizer. Five synthesizers that were surveyed also include a high-pass filter, which allows for thinner, brighter sounds that emphasise high frequencies. Four instruments also offer additional filter types such as band-pass or band-reject (notch). In comparison, the original Minimoog and VCS3 only featured a low-pass filter, albeit with characteristic response curves that reduced the level of low frequencies in the sound at higher resonance settings, giving a near band-pass filter response (EMS 1970: 13).

The sequencer has been demoted from being the “heart” of instruments such as the Buchla to an added feature that is limited in scope or omitted entirely in the modern synthesizers. Integrated sequencing is provided as a simple pattern generator with a limited number of steps available, often with the addition of an arpeggiator function that repeats a pattern of notes held down on the keyboard. None of the modern instruments surveyed allows the sequencer parameters (such as speed, gate time, or number of steps) to be modulated. As sequencers are digitally controlled, an integrated sequencer or arpeggiator will not drift in tempo significantly and can be locked to the tempo of an external MIDI device or another sequencer. Sequencers that are started at the same time (or synchronised via a common clock signal) allow the composer to create complex polyphonic patterns when more than one synthesizer is sequenced at the same time.

Digital control and programmability

Analysis of the electronic control methods found on these instruments reveal two important differences: instruments with only analogue potentiometers and switches, and instruments with digital encoders and switches. The analogue potentiometer (used on all of the non-programmable instruments: the Model D, K-2, Neutron, Odyssey, MS-1 and Minibrute 2) sends a control voltage directly from the panel control to the corresponding parameter on the analogue circuit board. Encoders (used in the Monologue, Bass Station II, and SE-02) send information about their current position as a digital value that is converted to an equivalent voltage by a digital-to-analogue converter. This intermediate stage is useful: the digital value can be stored and recalled before being converted to the analogue control signal, allowing patches to be memorised. This makes these instruments programmable and also allows MIDI information to be generated from the encoders. However, a disadvantage of digital control is that the visual state of the panel controls does not always necessarily reflect the current settings of the analogue parameters because the encoders do not physically move when a new patch is recalled and the analogue parameters are updated. Knowledge of the type of control system in use is important as a visual analysis of the synthesizer control panel may not be a reliable guide to the settings that have been used to create the sound. Significant differences in performance practice also emerge from using the two types of parameter control when an instrument is programmable, as it becomes possible to rapidly make drastic changes to the sound when a new program memory is recalled.

Patches are more difficult to share and reproduce when they are not able to be recalled digitally, as was evident from the patch books from the 1970s, where patches had to be manually recreated from diagrams. Similarly, on a modern synthesizer without patch storage and recall, patches must be recorded visually using a blank patch sheet, or a photograph. Sounds must then be reproduced laboriously by following the settings as they were recorded, which is cited in the popular literature (e.g. Graham 1980: 104) as an activity that encourages learning about synthesis and listening to sounds on a deeper level. This is the synthesizer equivalent of music notation: a visual representation of sound that may vary in levels of accuracy, and may require some degree of artistic interpretation. Modern programmable synthesizers can save patches in digital form, enabling patches to be shared online, and recalled by another musician using the same instrument.

There is evidence of innovations in modern synthesizers that would not have been possible in the 1980s. For example, the Bass Station II synthesizer has taken the principle of programmability further, by allowing the composer to create sets of 25 separate sub-patches that are assigned to each key of the keyboard. This innovation radically extends the functionality of the keyboard on the analogue synthesizer from being a control device that is primarily used to regulate pitch, to a method of triggering 25 discrete patches. Each "note" on the synthesizer, therefore, potentially triggers a complex change in spectrum. Sequencers are also being redefined, for example in the Korg Monologue, which permits the sequencing of synthesis parameters within each event in addition to pitch and velocity information. Sequences of notes can become more than rhythmic, pitched phrases that are repeated with the same sound; they can become patterns of timbres as well. Fixed-architecture analogue synthesizers were seen as relatively conservative instruments by experimental composers in the 1970s, but are now capable of exploring microtonality and complex, expressive spectromorphologies. A type of synthesizer practice is now possible (on inexpensive instruments) that is reminiscent of Ciani's work with the Buchla: complex transitions between patches, and multi-layered sequences of different parameters which can also be manipulated manually in live performance.

The full potential of the analogue synthesizer in experimental music remains unexhausted, particularly within the context of a synthesizer ensemble, where many complex, polyphonic interactions between patches and sequenced patterns may be explored. When synthesizers were viewed as an integral component of the multi-track recording studio in the 1970s and 1980s, as a partner to the tape recorder, the notion of a synthesizer ensemble was not considered in any depth within contemporary literature. Synthesizers were combined with other recorded sounds in studios such as the GRM, played alongside other instruments in live rock, jazz and pop music, or layered with other synthesized parts in often complex, multi-timbral arrangements by virtuoso programmers such as Isao Tomita. Modern instruments offer an affordable pathway to experimental electronic music and an alternative to computer-based approaches to composition that has been largely overlooked in academic research.

References

Audio Engineering Society. *AES E-Library*. URL: <https://www.aes.org/e-lib> [Accessed 22 May 2020]

Auricchio, N. and Borg, P. (2020). New modular instruments and performance practice. In N. Wilson (ed.), *Interpreting the Synthesizer: Meaning Through Sonics*, pp. 102-111. Newcastle upon Tyne: Cambridge Scholars Publishing.

Berweck, S. (2016). Reviving Parmegiani's "Stries" (1980): translation of historic analogue works into the digital domain. *eContact!* 17.4. URL: <https://econtact.ca/17_4/berweck_parmegiani.html> [Accessed 2 May 2020]

Carlos, W. (1984). CD liner notes. *Digital Moonscapes*. URL: <http://www.wendycarlos.com/+dmci.html#1notes> [Accessed 2 May 2020]

—. (1968). Review: Silver Apples of the Moon by Morton Subotnick. *Electronic Music Review* 7: 38-39.

Ceely, R. (1977). Compositional limitations of current electronic music synthesizers. *58th Convention of the Audio Engineering Society*, November 4-7, NY: New York. URL: <https://www.aes.org/e-lib/browse.cfm?elib=3063> [Accessed 2 May 2020]

Ciani, S. (1976). *Report to National Endowment. Re: Composer Grant.* URL: <https://people.finearts.uvic.ca/~aschloss/course_mat/MU307/MU307%20Labs/Lab3_BUCHLA/Susanne%20Ciani%20Buchla.sm.pdf> [Accessed 15 September 2020]

Coren, D. and Smoliar, S.W. (1976). Some experiments concerning the musical theory of voltage-controlled synthesizers. *Interface* 5/3: 109-123.

Dalgleish, M. (2016). The modular synthesizer divided: the keyboard and its discontents. *eContact!* 17.4. URL: <https://econtact.ca/17_4/dalgleish_keyboard.html> [Accessed 22 May 2020]

Dalton, T. (2020). Foreword: meaning through sonics. In N. Wilson (ed.), *Interpreting the Synthesizer: Meaning Through Sonics*. Newcastle upon Tyne: Cambridge Scholars Publishing.

Demers, J. (2010). *Listening Through The Noise: The Aesthetics of Experimental Electronic Music*. Oxford: Oxford University Press.

Dockstader, T. (1969). Reviews of records, Morton Subotnick: The Wild Bull. *The Musical Quarterly* 55/1: 136-139.

Drake, R., Herder, R. and Modugno, A. D. (1975). *How to Make Electronic Music*. New York: Educational Audio Visual Inc.

Eckhardt, J. and Radigue, É. (2019). *Éliane Radigue: Intermediary Spaces / Espaces intermédiaires*. Brussels: Q-02 Umland.

Ehle, R. C. (1971). Synthesizers, anyone? *Music Educator's Journal* 57/5: 78-82.

Electronic Music Studios (EMS). (1970). VCS3 *The Putney: Compact Electronic Music Studio*. User manual. London: Electronic Music Studios (London) Ltd.

Gardner, J. (2020). Peddling the Putney: the early marketing of the VCS3 synthesizer. In N. Wilson (ed.), *Interpreting the Synthesizer: Meaning Through Sonics*, pp. 1-20. Newcastle upon Tyne: Cambridge Scholars Publishing.

—. (2017). The Don Banks Music Box to The Putney: the genesis and development of the VCS3 synthesiser. *Organised Sound* 22/2: 217-227.

—. (2013). Interview: Suzanne Ciani. *These Hopeful Machines*, 13 July 2013. URL: <https://www.rnz.co.nz/concert/programmes/hopefulmachines/audio/201812321/interview-suzanne-ciani> [Accessed 22 May 2020]

Graham, B. (1980). *Music and the Synthesiser*. Watford: Argus Books Ltd.

Hetrick, M. L. S. (2017). *Modular Understanding: A Taxonomy and Toolkit for Designing Modularity in Audio Software and Hardware*. Unpublished PhD thesis. University of California Santa Barbara.

Holmes, T. (2014). The sound of Moog: using vinyl recordings to reconstruct a history of the Moog synthesizer. *Notes* 71/2: 219-236.

Howe, H. (1972). Compositional limitations of electronic music synthesizers. *Perspectives of New Music* 10/2:120-129.

—. (1969). Recent recordings of electronic music. *Perspectives of New Music* 7/2: 178-181

—. (1967). *User's Guide to the Buchla Modular Electronic Music System*. Valencia, CA: Columbia Broadcasting System Inc.

Jenkins, M. (2007). *Analog Synthesizers*. Oxford: Focal Press.

Jordà, S. (2004). Instruments and players: some thoughts on digital lutherie. *Journal of New Music Research* 33/3: 321-341.

Kvifte, T. (2007). *Instruments and the Electronic Age*. 2nd ed. Oslo: Taragot Sounds.

Kvifte, T. and Jensenius, A. R. (2006). Towards a coherent terminology and model of instrument description and design. *Proceedings of the 2006 International Conference on New Interfaces for Musical Expression*, pp. 220-225. Paris: France. URL:

<https://www.nime.org/proceedings/2006/nime2006_220.pdf> [Accessed 2 May 2020]

Lozej, M. (2016). *The Arpeggiator: A Compositional Tool for Performance and Production*. Masters thesis. York University, Toronto.

Magnusson, T. (2017) Musical organics: a heterarchical approach to digital organology. *Journal of New Music Research* 46/3: 286-303.

Mathews, M. (1970). The electronic sound studio of the 1970's. In W. Skyvington (ed.), *Music and Technology*, pp. 129-141. Paris: UNESCO/La revue Musicale.

McCarty, F.L. (1975). Electronic music systems: structure, control, product. *Perspectives of New Music* 13/2: 98-125.

Morreale, F. and McPherson, A. P. (2017). Design for longevity: ongoing use of instruments from NIME 2010-14. *Proceedings of the 2017 International Conference on New Interfaces for Musical Expression*, Aalborg University, Copenhagen, Denmark, pp. 192-197.

Olarte, L. A. (2019). *Elements of Electroacoustic Music Improvisation and Performance: A Pedagogical Toolkit*. Helsinki: Sibelius Academy, University of the Arts.

Paradiso, J. A. (2017). The modular explosion: deja vu or something new? Paper delivered at the *Voltage Connect Conference*, March 10-11. Berklee College of Music, Boston MA.

Perera, R. C. (1971). The three part academic electronic music studio. *College Music Symposium* 11: 66-70.

Pinch, T. (2016). Electronic music filtered through science and technology studies. Keynote presentation delivered at the *International Conference: Alternative Histories of Electronic Music*, 14-16 April, Science Museum, London. URL: <https://doi.org/10.5518/160/22> [Accessed 2 May 2020]

Pinch, T. and Trocco, F. (2004). *Analog Days: The Invention and Impact of the Moog Synthesizer*. London: Harvard University Press.

Pressing, J. (1992). *Synthesizer Performance and Real-Time Techniques*. Oxford: Oxford University Press.

Rodgers, T. (2015). Tinkering with cultural memory: gender politics of synthesizer historiography. *Feminist Media Histories* 1/4: 5–30.

Rossmy, B. and Wiethoff, A. (2019). The modular backward evolution: why to use outdated technologies. *Proceedings of the International Conference on New Interfaces for Musical Expression*, UFRGS, 3-6 June, Federal University of Rio Grande do Sul, Brazil, pp. 343–348. URL: <http://www.medien.ifi.lmu.de/pubdb/publications/pub/rossmy2019nime/rossmy2019nime.pdf> [Accessed 2 May 2020]

Scott, R. (2016). Back to the future: on misunderstanding modular synthesizers. *eContact!* 17.4. URL: <https://www.econtact.ca/17_4/scott_misunderstanding.html> [Accessed 22 May 2020]

Seago, A., Holland, S. and Mulholland, P. (2004). A critical analysis of synthesizer user interfaces for timbre. *Proceedings of the XVIII British HCI Group Annual Conference HCI 2004*, Volume 2, pp. 105-108. Bristol, UK: Research Press International.

Strange, A. (1983). *Electronic Music: Systems, Techniques, and Controls.* 2nd ed. Dubuque, IA: Wm. C. Brown Company Publishers.

Subotnick, M. (1970). The use of the Buchla synthesizer in musical composition. Paper delivered at the *Audio Engineering Society Convention 38*, paper 709, May 1970.

Teruggi, D. (2007). Technology and musique concrète: the technical developments of the Groupe de Recherches Musicales and their implication in musical composition. *Organised Sound* 12/3: 213–231.

Thurley, O. (2019). Éliane Radigue, oeuvres électroniques. Review. *Tempo* 73/289: 74-77.

Weisser, S. and Quanten, M. (2011). Rethinking musical instrument classification: towards a modular approach to the Hornbostel–Sachs system. *Yearbook for Traditional Music* 43: 122–146.

Wishart, T. (1996). *On Sonic Art*. Amsterdam: Harwood Academic Publishers.

Young, A. C. (1967). *Electronic Organ Arpeggio Effect Device*. United States Patent Office. Patent 3358070. 12 December, 1967.