Histories of the Schmitt Trigger in Handmade Electronic Instruments for Making Sound in the Arts: A Literature Review

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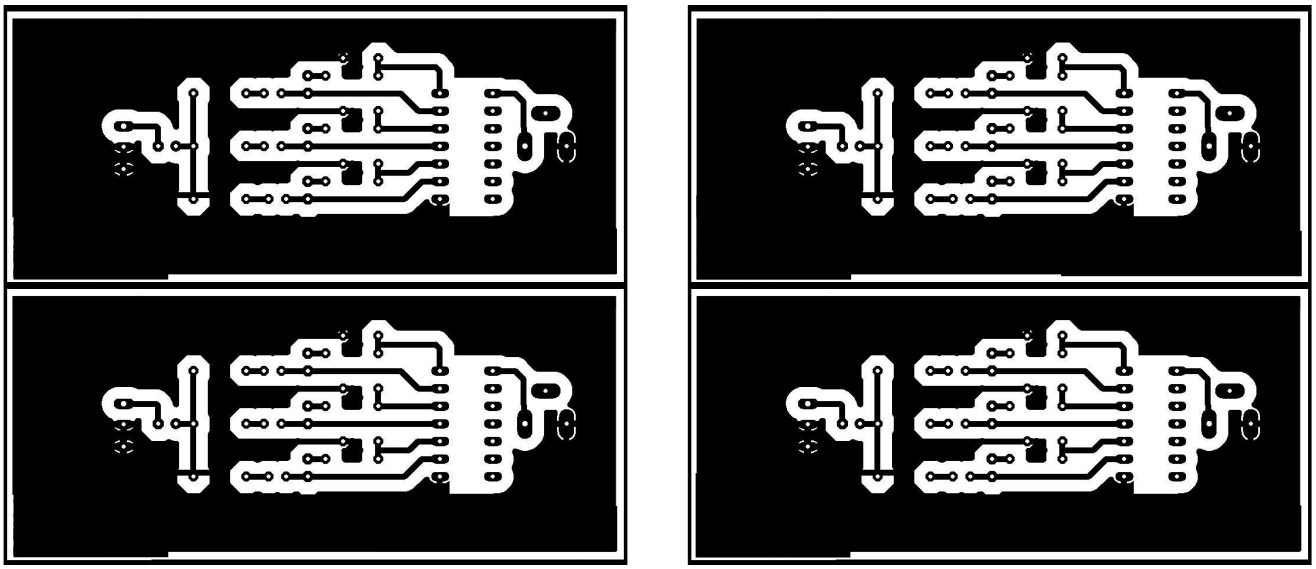


Figure 1: Perforated circuit board design for *[Mountain Operated Synthesiser,* 2013 by Andreas Siagian, Michael Candy and Pia van Gelder

Abstract

The Schmitt Trigger was invented by biophysicist Otto Herbert Schmitt in the 1930s as a "simple hard valve circuit" that "provides off-on control with any desired differential from 0.1 V to 20 V."[27] Schmitt was a graduate student at the time, stationed at a Marine Biological Laboratory working with large nerve axions of squid. Since its invention, applications of the Schmitt Trigger have proliferated, appearing in a variety of common technologies, popularly utilised for signal conditioning and to execute relaxation oscillators.

The Schmitt Trigger is also a popular integrated circuit used in introducing people to building their own electronic synthesisers. This is evidenced in Nicolas Collins' "Handmade Electronic Music: The Art of Hardware Hacking," first published in 2002, with projects from "My First Oscillator" to various noise makers, all utilising the Schmitt Trigger. This paper presents findings from a literature review investigating histories of applications of the Schmitt Trigger in the making of instruments for sound art and music practices. Preceding Collins, resources include handbooks for practitioners that reveal the circuit's cultural impacts and associated historical communities, while contemporary discourse in experimental practice have emerging thematics, some of which present curious parallels with Otto Schmitt's own research interests.

Keywords

Schmitt Trigger, Histories of Science and Technology, Histories of Music Technology, Histories of Media Art, DIY Communities

1 Introduction

Otto Herbert Schmitt is remembered for his invention of the Schmitt trigger, a circuit that he developed in order to accurately mimic how squid nerve cells fire, converting analogue electrical signals into binary signals. The circuit is capable of conditioning noise with its application of hysteresis, which is to say, the output signal remains the same until the input change meets a threshold which activates a change.[13] Schmitt went on in biophysics to establish the field of biomedical engineering where his term biomimetics describes processes of emulating complex biological systems for their study.

The Schmitt trigger has been broadly applied in varied technologies, iterating with the development of electronics from resistor-transistor

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logic (RTL), transistor-transistor logic (TTL) to complementary metal–oxide–semiconductor (CMOS) integrated circuits. The Hex Inverting Schmitt Trigger CD40106 is present in a number of my own circuits, having been introduced to it through the work of Nicolas Collins in the early days of overlording the Sydney faction of Dorkbot, a community of people 'doing strange things with electricity.'[5] My first official application of the Schmitt trigger was for a work I produced in collaboration with Indonesian biohacker and artist Andreas Siagian and Australian industrial designer and artist Michael Candy for the Instrument Builders Project in a work entitled *Mountain Operated Synthesiser*, where oscillator frequencies were varied by moisture in the soil, wind and humidity in the air on Mount Merapi, an active volcano in Java, Indonesia (Fig 1).

I recently had the opportunity to look at the original work Otto Schmitt developed, held in the Bakken Museum in Minneapolis, Minnesota. His 1930s rack mounted unit include contemporaneous components that render it 1.8 meters high.[8] Surveying documents from his career compelled me to investigate how the histories of the Schmitt trigger and Schmitt's own research interests are reflected in its application in contemporary sound and music practices. These practices might be considered "alternative cultures of the Schmitt trigger," and this literature review works to reveal some examples. The driving question for this project is: What is the history of listening to the Schmitt Trigger in the arts? For this literature review: What practices, ideas and communities emerge when we search for applications of the circuit as an active component to produce sound in handmade electronic music and sound? I will discuss some of the key findings from a literature review after summarizing its scope and methodologies.

2 *A* Literature Review

These findings are but one part of a larger literature review. Because the history of the circuit is discussed across a range of fields, published in a variety of forms such as journals, conference papers, books, patents, trade catalogues, magazines, as well as online forums, billboards, newsletters and blogs, this review is being approached in stages, the first of which is to look at published material in the form of books, and journal and conference papers. This paper discusses the results from this initial stage. I welcome suggestions on any missing sources.

Searches were limited to the following terms: Schmitt trigger, sound, art, music. Close to four hundred and fifty sources were reviewed. Exclusions were made on literature that discussed the circuit only for its ability to filter or process signals. Reviewed literature was limited to publications in English. A grounded theory approach was applied to analyse the literature and identify categories and concepts from patterns and comparisons in the literature.

I have organized this review over a timeline with literature from the 20th century and those from the 21st century, with the first section giving attention to chronology while the second section is grouped together based on themes. Where possible, I will highlight the associated communities that can be attributed to these sources. I will follow with some broader discussion of these themes and theoretical connections, concluding with some thoughts on the next stages.

3 20th Century

Handbooks for those interested in the emerging field of electronic synthesis became increasingly popular in the 1970s. Some were written for those wishing to engage with synthesizers without touching the internal circuits, others functioned as more practical guides such as Delton Horn's *Digital Electronic Music Synthesizers,* first printed in 1988 only includes reference to Schmitt triggers as a component in his envelope generator where "almost any signal may be used as a signal source."[12]

Collins refers to a collection of books in his resources section. Don Lancaster's *CMOS Cookbook*, first published in 1977 is one specific text that he has recently confirmed was where he was introduced to the Schmitt trigger oscillator.[6][15] He also discusses that the previous TTL Schmitt trigger was cumbersome due to its power requirements but with the advancement of CMOS integrated circuits, new possibilities were opened up to electronic music makers.[16][6] Lancaster's handbooks were comprehensive guides to integrated circuits, written as a general reference for anyone working with these circuits from any field, all with handy projects evidencing their various applications. In addition to his helpful cookbooks, Lancaster was a regular contributor to popular computing magazines during his career as an engineer at Goodyear Aerospace, also known for his invention of the TV Typewriter. M.C. Sharma's *41 Projects Using 741 I.C.* features the Schmitt Trigger, followed by Project 21 the Square Wave Generator, covering audible spectrums, amplification of its frequencies through loud speakers are not discussed explicitly, similar to Lancaster's work. Published in New Delhi, first in 1981, how widely this handbook was distributed is unknown at this stage. While information about Don Lancaster is easily accessible, background on Sharma and their context is difficult to establish other than a considerable catalogue of technical publications. Similar cookbook approaches persist to this day, Andrew Singmin's *Beginning Digital Electronics Through Projects* being but one example, a book that was originally published in 1997. It includes a chapter on "Schmitt Trigger Circuits" with four projects, including a Pulse Oscillator, Delay, Triangle Generator and a Switch Debouncer.[36]

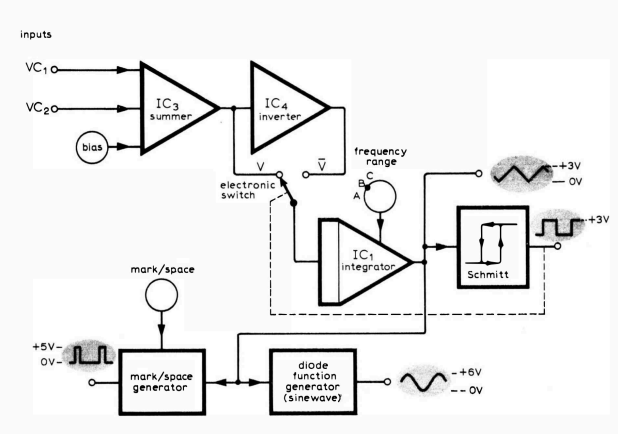


Figure 2: "Oscillator VCO 1 in a block diagram form." T. Orr, and D.W. Thomas. "Electronic Sound Synthesizer." Wireless World, August 1973. 368.

Two magazine articles that predate Lancaster's TTL and CMOS cookbooks are worth mentioning here. One article from *Electronics* magazine in 1961 discusses the Schmitt trigger's application as a part of a "percussive envelope circuit," developed by Harold Bode, who had been working with electronic instruments since the 1930s, namely with organs including the Melochord. By the late 1950s he began working on modular synthesis, work that was influential for people like Robert Moog and Donald Buchla. In a series of three articles entitled *The Electronic Sound Synthesizer,* published in 1973 in *Wireless World* is the earliest example I have found of a Schmitt trigger being used to generate an audio output directly as a square wave oscillator. The series introduces readers to how to build basic modules, beginning with a description of voltage controlled oscillators, the first of which produces "square, triangular and sinusoidal and a variable mark/space ratio rectangular waveform." (Fig 2) Here "The heart of the oscillator is a triangle-squarewave generator… where a Schmitt trigger provides positive feedback around an integrator; the integrator's output thus ramps up and down inside the hysteresis window of the Schmitt trigger… Two outputs are produced, a triangle at the integrator's output and a square wave from the Schmitt trigger…", specifically the SN7413N integrated circuit.[30] Written by Tim Orr and D.W. Thomas, both affiliated with the University of Southampton, Tim Orr having just begun his tenure with Electronic Music Studios where he worked on many of their units including their EMS Synthi E and the EMS Vocoder 2000.

Thanks to some more recent work to emulate the Roland TR-808 drum machine in Cycling 74 Gen~, where the original schematics and functions are discussed, we can see how the TR-808, released in 1980, included a cowbell, cymbal and open hi-hat, all produced by filtering oscillations from a single Schmitt trigger. The development of this machine is partly attributed to the work of organist Don Lewis and his personal modifications of Ace Tone Rhythm Ace FR-2L unit.[18] The authors reference the important work of Stanley Lunetta in the footnotes, editor of journal *Source: Music of the Avant-Gare*, and maker of what people now call the 'Lunettas', CMOS based synths. Lunetta's work will likely form a major component of the next part of this literature review, when it turns to online discussion. [19, 20]

In the process of reviewing early literature, the delineation between conventional and unconventional approaches to the circuit appears more defined. Conventional applications of the Schmitt trigger could be attributed to signal processing, and unconventional applications work with the Schmitt trigger as a sound producing oscillator. Ralf Schreiber's *Solar Sound Modules* of 1996 exemplifies the unconventional approach, not only in its schematic design but also in how he encourages its construction with soldered wires without the support of a perforated circuit board, assembling into tiny hand-held units (Fig 3). Worksheets and illustrations also evidence that the instrument was part of workshops, making it an example of the pedagogical approach to working with Schmitt triggers in sound and music.[24]

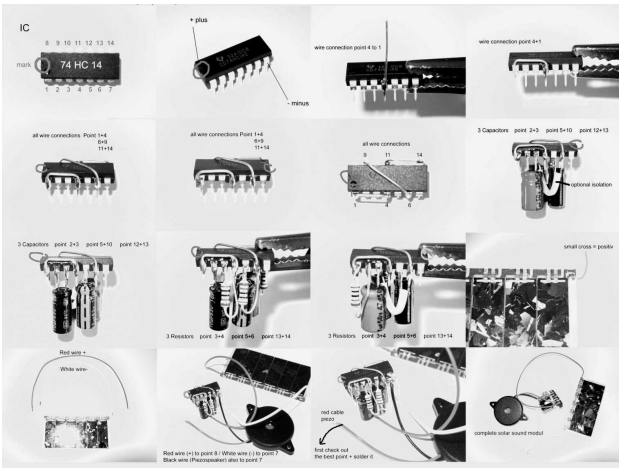


Figure 3: Assembly instructions for *Solar Sound Module* by Ralf Schreiber. Courtesy of the artist.

4 21st Century: Contexts for Handmade Electronic Music and the Schmitt Trigger

Collins began by making a handbook for a course on hardware hacking at the School of Art Institute of Chicago in 2002, a year after the first NIME conference. The official publication was released four years later when do-it-yourself (DIY) culture was making a new name, do-it-with-others and groups were finding space and resources in proliferating hackerspaces and makerspaces. Dorkbots were popping up around the world and Makezine was in its first years of publication. These activities established a popular method of making circuits in community with others, be that online or in person. Collins considered his "course as building the gap between the sound world of our thoroughly electronic culture and the timeless tactile habits of the human hand."[7] The resulting book progresses through a wealth of accessible projects, from contact microphones, circuit bending to building circuits from scratch, which formed the later sections, giving particular attention to hardy CMOS chips. Collins says "The designs I prepared for the class were easy to understand and build, virtually impossible to blow up, and could be assembled like lego bricks to create complex networks… (the chance of making a mistake in assembling a circuit is directly proportional to how many pieces you have to stick it together)."[7]

The book's *Chapter 18: The World's Simplest Oscillator: Six Oscillators on a Twenty-Cent Chip, Guaranteed to Work,* is where breadboarding is introduced along with CMOS Hex Schmitt Trigger (Fig 4). His explanation of the circuit's flip flop behavior is exemplary of Collins' knack for explaining what could otherwise be unapproachable scientific technical language to a creative readership:

> *The speed of the flip-flopping (the pitch we hear) depends on the values of the resistor and capacitor—just like in our earlier clock experiments, the smaller the values the higher the pitch. It's like the Monty Python argument sketch, or a dispute in a bar: I disagree with everything you say, so our output keeps flipping between yes and no according to how fast each of us can reply.*

The resistor and capacitor act like booze—the more you add the slower the argument goes, ergo the lower the pitch.[5]

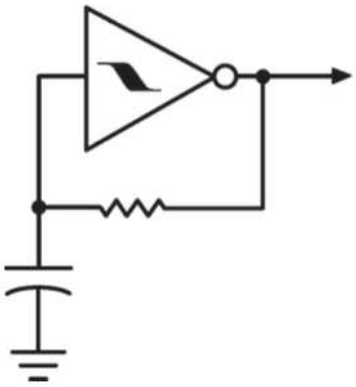


Figure 4: "Schematic representation of our oscillator." Nicolas Collin. *Handmade Electronic Music: The Art of Hardware Hacking*. Bloomsbury: New York, 2006. 114.

John Richards practice of "dirty electronics," discussed as being conceived in 2003, can be place adjacent to Collins work. Richards points to the decision by the 2006 NIME conference to bring together Do-It-Yourself instruments as a "new turn for the NIME community."[32] Richards *Sudofuzz*, developed for a collaboration with Merzbow in 2008, uses a Schmitt trigger, to make "a distorted oscillator with a feedback loop… controlled by touching the bolt and tin and additional coin-electrodes that are stuck to the side of the instrument."[25]

Ray Wilson's *Waveform Processing* from the late 1970s and his subsequent *Sound Lab Mini Synth* from the late 90s, which eventually started *Music from Outer Space*, did not culminate into a book until 2013, with his *Make: Analog Synthesisers* providing detailed projects for building synthesizer components with the Schmitt Trigger as well as a section dedicated to "Working with CMOS Logic Chips" in the appendix.[21, 35] Some of the impacts of this work is evidenced in the following section.

5 21st Century: Hardware Hackers, Pedagogies, Transductions and Transmutations

The following literature I will survey in this section is illustrative of issues, approaches and thematics that have emerged, to organize and group the projects, although many could fall into more than one category.

5.1 More Handmade Electronic Music Making

The following projects include parallel and continued electronic music making in the handmade variety and pay tribute to Collins as a primary source. Much of the following work has also been presented to the NIME community.

Most recently, Tate, Brown, Ferguson and Della-Bosca's *Hand Turned Synthesis*, a paper for NIME2024 aims to "provide a tool kit for common synthesis elements based around the use of the single 40106 IC." [33] The authors situate their work as furthering that of Collins, Lunetta and Wilson and approaches are discussed in context with their own work while providing a wealth of practical schematics for getting started with the 40106 along with useful references.

Don Derek Haddad, Xiao Xiao, Joe Paradiso and Tod Machover's *Fragile Instruments* take on an auto-destructive bent, designed to be played through the act of destruction, the simplest an oscillator circuit using the Schmitt trigger.[11] No doubt the affordability of the integrated circuit was integral to this project. Don Derek Haddad and Joe Paradiso's later *Kinesynth* uses capacitance and resistance in the human body in order to control a Schmitt trigger's oscillators, here emphasizing kinesthetic activity.[10]

A number of instruments have been developed in collaborations between Andrew Brown and John Ferguson over the last decade, their *Sonic Frisbee* incorporates the Schmitt trigger as oscillator and is based on an early instrument by Ferguson called *HST1d FERAL TECHNOLOGIES* of 2018 with a similar layout. The pair had made a sequencer in 2014 called *Analogue Revolutions*, that employed a Schmitt Trigger to drive the clocks, here configured in concentric circles. [3]

Nicole L Carroll's *Domino*, is a twenty two voice instrument assembled in a backgammon case "filled with noise circuits" that are controlled with a multitude of components including potentiometers, light dependent resistors (LDR), push buttons and toggle switches and bare wire resistors.[4] Carrol discusses how they integrate ideas from spiritualism, magic and ritual in their design process, providing insight into the meanings behind her complex systems.

John Ferguson and Peter Bussigel's 2015 work *TRaNsMOGRiFiER* is an instrument presented as installation and durational performance, driven partly by public participation, using donations of objects "that involves collective improvisation, found materials, cardboard, electronics and hot glue" to undergo the apocryphal transmogrification.[9] Part makerspace, the work "introduces participants to simple sound-making and light-flashing circuits using CMOS 40106 (Hex Schmitt-Trigger) ICs…" Transmogrified objects are then exhibited and their owners are invited to collect them. Ferguson and Bussigel's "reanimation" of volunteered objects harks back to David Tudor's *Rainforest* workshops, where participants used transducers to sonically reanimate found objects. The objective of this work invites "fictional narratives" as a catalyst for generating instruments, all centralized around "capacitor trees" that are suspended rotating wires and component structures they discuss as the "brain" for the piece, the part that turns one thing into another.[9] Creative imaginaries and speculative approaches to building instruments with the Schmitt trigger reemerge in subsequent thematics for contemporary practices as well as participatory approaches.

5.2 Doing-It-With-Others and Their Pedagogies

This section discusses how Schmitt trigger circuits have generated pedagogical approaches. For example, John Richards *Dirty Electronics Workshops* have incorporated the *Sudofuzz* and its derivatives as "pedagogic devices and workshop primers."[25] Collins says that he had thought that when his book was widely available, invitations to conduct workshops would diminish "but the reverse happened. People could now study and build the projects on their own, but they

preferred doing it in groups." [7] He calls this ethos Do-It-Together, and reflects that the workshops are valued as "a way to build or strengthen a community."[7] This is exemplified in the more recent two year sound art initiative *Push the ENVELOPE* developed by *Contemporary Musiking Hong Kong* (CMHK) including "Pre-courses," a Teacher Retreat and Camps, with an oscillator building workshop led by instrument builder and artist Kin Lam, using the Schmitt trigger. Two years later CMHK report that "more than half of the participants of the camps in 2023 have established themselves as artists who work with sound as a medium."[36]

5.3 Transductions [of Light to Sound]

A number of artists have developed approaches to the Schmitt trigger that highlight its capacity to transduce one energy into another. The following specific projects discussed in published literature involve the process of turning light into sound.

Two projects explore photovoltaic cells (photocells). *SolarDuo Project* (2003) was produced at Media Lab Helsinki as a collaboration between Koray Tahiroglu and Joni Lyytikainen to create sound structures with light waves. Crediting Ralf Schreiber's earlier *Solar Sound Module*, this work harvests the solar cells from calculators as inputs. A Voice Controlled VCO instrument also uses an amplified microphone signal to generate an input signal for the Schmitt Trigger.[31] Scott Smallwood's *Solar Noise Discs* make use of compact photocells to control Schmitt trigger sounds. Smallwood places this instrument in a body of work he calls "solar sound arts" that contribute to an "aesthetic direction" for soundscape and acoustic ecology studies.[28]

The following two examples work to transduce light into sound using LDRs, although Eleonora Oreggia's (aka *xname*) *Phantasmata* of 2017, includes both components, LDRs and photocells. These are sculptural instruments called *Noise Bots* that are powered by photocells and employ LDRs to control Schmitt trigger oscillators. They are assembled without PCBs or breadboards, somewhat like the arrangements by Schreiber or Ferguson and Bussigel, soldering together components with wire to extend the circuit, shaping it into a wiry interface for gestural interaction.[22] Mári Mákó's *Schmitt* utilizes a Schmitt trigger oscillator with light dependent resister and a lamp, Mákó using the shadows of her hand gestures to modulate frequency. An additional layer of control for timbre is added with an accelerometer, the same hand, connected to an Arduino.

Latinx queer performance artist Erica Gressmans's *Wall of Skin,* 2016, uses the Schmit trigger to produce three oscillators, the frequencies of which are controlled with LDRs. The instrument is embedded into a performance with a costume composed of layers of white Lycra zentai suits that are tethered by cables to the back wall of the stage, constructed with drywall, mounted in front of a set of eight fluorescent lights. Over the duration of the performance, beginning in darkness, Gressman destroys the wall, ripping out sections as they struggle to take away layers of the zentai suits. As the lights are revealed, her white costume is consumed by light, causing the oscillators to progressively shift in frequency. Sandra Ruiz discusses how the artist takes the act of transducing light into sound, one generated by the reflection of their white layers of skin, as a metaphorical device, placing "pressure on white, heteronormative practices of sound performance and the ontic infelicities of Brownness and sexuality."[26]

5.4 Material Explorations or Transmutations

The material implications of practices involving computation and electronics has been a topic of rising concern and inquiry as artists consider how their work contributes to e-waste and the ecological impacts of mining rare earth minerals. Alongside these concerns, new materialism offers possibilities for understanding agential behaviors of matter. Further, interests in historical occult and alchemical practices have been generative for the design of electronic instruments. The following examples bring attention to these issues through their material approaches to the Schmitt trigger.

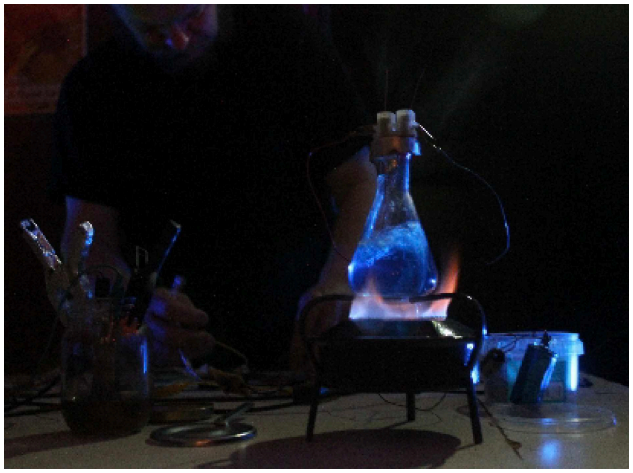


Figure 5: Jonathan Kemp's Chemical-Material live performance system, Rio de Jainero, Brazil, May 2012. Courtesy of the artist.

Jonathan Kemp discusses manipulating computer derived minerals to "generate amplified noise through mixing, heating, electrolysis, and the application of direct current," these reactions used as variables for the Schmitt trigger oscillator (Fig 5).[14] Similarly focused towards interrogating computer materials, Ralf Baecker's *Irrational Computing* 2011, includes a Schmitt trigger to sonify the piezo electric effects of his *Crystal Field Oscillator*, composed of Rochelle salt crystals and copper wire. [34]

Marloes van Son's *Rick*, which they classify as a "rock-device," uses a rock as an "unfriendly user-interface" (Fig 6).[29] By carving the surface of a rock, van Son mounts toggle switches, a potentiometer and fader onto its surface and yet the device is notoriously unpredictable, the artist explaining its behaviour as "moody."[29] By personifying materials, Van Son takes a more playful approach to develop her enigmatic electronic instruments while staying grounded in a critical approach to materials.

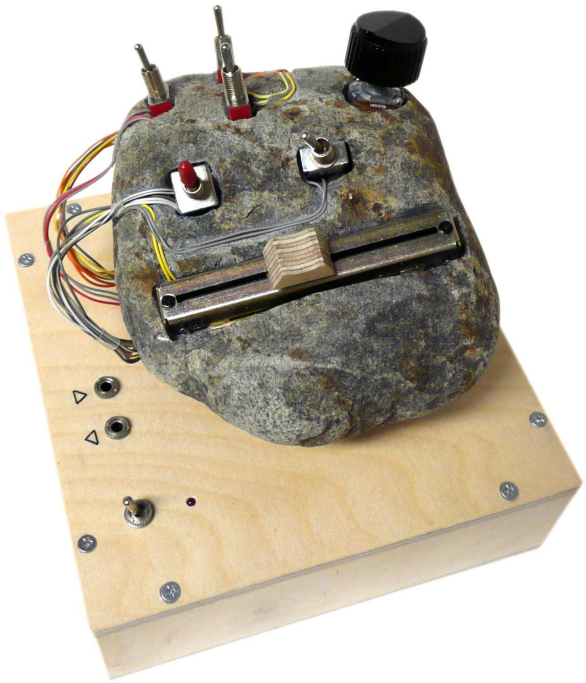


Figure 6: Marloes van Son's *Rick* rock device. Courtesy of the artist.

Alejandra Pérez Núñez's 2024 performance lecture entitled *Proxies*, speculates about how "sound serves as a proxy for understanding control as the dynamics of human and more-than-human coordination."[23] Working with coils as transducers, and light with photocells that are connected to Schmitt trigger oscillators, fermented fruit connected to electrodes, radio, active elements and their behaviors function as probes to explore philosophical and theoretical proposals about new materialism, from Karen Barad's agentialisms, intra-action and transmaterialities, to Bruno Latour's semiotic analysis of Pasteur on lactic acid yeast.[1, 2, 17] Núñez says "elements involved are mutually entangled, co-constitutively shaping the material properties and cultural meanings of the resulting sonic phenomena."[23] Nunez's work makes proposals about how Schmitt trigger instruments might explore critical issues in our broader contemporary discourse, and using the context of the *Speculative Sound Synthesis Symposium* of 2024, they emphasize the political and cultural implications of hardware hacking.

6 Conclusion

Conclusions for this review are historiographical, pertaining to the challenges and triumphs of recalling and recording these histories. A thematic also emerges that will be worth following as this project continues that relates to Schmitt's biomimetics.

The NIME community clearly plays a major role in this part of the literature review, most papers functioning to document these unique instruments while meta discussion emerges in 2024 with Tate et al.[33] This can in no way be a comprehensive review of all published literature on this topic due to the inadequacies of archiving of such literature and the nature of the discourse that at times lacks specificity necessary for locating historical case studies. It is likely that the next phases of the review will locate case studies that have been so far hidden and some fun can be found in reconnecting their work with these official timelines and communities.

A striking pattern to emerge in this survey is how, either by the circuit's own design, turning complex analogue signals into digital signals, or through desires to find meaning in its outputs, a recurring connection can made to Schmitt's own biomimetics. The circuit's accessibility, simplicity and contemporary context as an introductory oscillator circuit finds its way to creative practitioners who are thinking through, and making for the more than human world and challenges of the Anthropocene. Here, the Schmitt trigger provides a means to observe and interact with signals from biological to mineral. Materials, through their conductivities, are explored as a control voltage for frequency modulation. These configurations are created from artist's chosen samples, like rocks, crystals, fruit, the performer's gesture or skin-conductivity. The circuit becomes a means to play directly with energies, functioning like a bridge to transduce them, one into another, many into sound. The creative modulation of these oscillators revisits biomimicry in its signal conversion, although often crude or limited, these circuits can be seen to do a doubling in another format, a mimicry of the signal from one input, generating another kind of output.

Books and scholarly publications present timelines from the perspective of academia, however a considerable amount of work lies outside the confines of universities. The next steps for this literature review are to tend to these gaps by looking at printed materials like historical periodicals and patents and much of the subsequent work that is likely to have been captured in online spaces such as forums and blogs. My hope is that this work is likely to uncover a library of projects coming from more diverse networks and communities.

Ethical Standards

This project does not include any financial or non-financial conflicts of interest. The research did not involve animal or human subjects. Artists who have participated by corresponding or whose work is featured pictorially, were informed and consenting.

Acknowledgments

Thanks to the reviewers for your helpful suggestions and special thanks to Nicolas Collins for corresponding with me via email right up to the deadline of this paper! Deep gratitude to the artists who have given me permission to publish images of their works to bring more life to some of these references. Without the work of artists, none of this discussion would exist.

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