Communal invention in Prehistoric NIMEs: a case study of Hugh Le Caine's Electronic Sackbut

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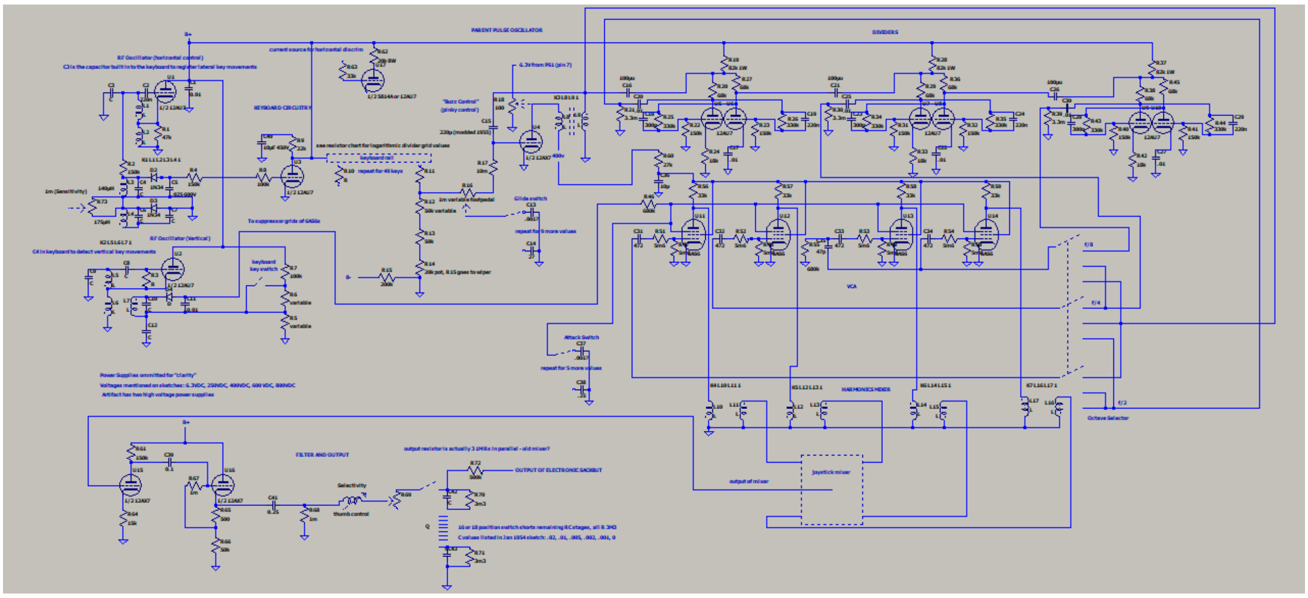

Figure 1: A simplified circuit schematic for the Electronic Sackbut. As this was a profoundly experimental project, the artifact is peppered with unconnected components (not shown here), values approximated by multiple components (simplified here) and a few additional circuits (not shown). This was assembled from existing schematics by Le Caine dated between 1946 and 1955, and examinations of the artifact. It is formatted to approximate common practice representations of canonical circuit topologies, such as the discriminator or divider sub-circuits.

Abstract

What was the Electronic Sackbut? Based on archival and material evidence, this paper highlights how historical and prehistorical NIME research can highlight community. Some scholars, like Hugh Davies and Gayle Young, have suggested that the first incarnations of Hugh Le Caine's Electronic Sackbut, usually presented as having been developed between 1945 and 1948, may be the first voltage-controlled synthesizer or even perhaps the first synthesizer. What becomes evident, in the investigations of these claims, is a) a lack of technical documentation has obscured more grounded claims about early NIMEs, and b) that such technical documentation can show how these objects resist monolithic description because they are composed of different parts with different allegiances. The communal negotiations and personal creativity which made them, then, may be a primary motor of creative labor across and beyond the NIME communities.

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Keywords

Reverse Engineering, Historical Study, Archival Research, Communal Development

1 Historical background and stakes

The Electronic Sackbut is an electronic musical instrument made by Hugh Le Caine in his early years at the National Research Council of Canada (NRC).[1] A Canadian born in Port Arthur, Le Caine had received a studentship from the NRC during his masters of science in physics studies at nearby Queen's University, where he had done appreciated work in the Nuclear Physics Laboratory with regards to the design of scientific instruments. In March 1940, he obtained a position at the NRC and began contributing scientific labour more formally to the wartime Canadian scientific effort as part of the Radio and Electrical Engineering Division (REED), focusing on microwave links for strategic communications [93].[2] Robert Moog and Donald Buchla's relationship to physics research is well documented [31, 66], but others like Gordon Mumma and Hugh Le Caine had also experienced a similar trajectory [59]. Only Le Caine would be lucky enough to have a career's worth of support given to

[1]This essay focuses on the vacuum-tube based Electronic Sackbut. The transistorized version from the late sixties and seventies deserves its own essay.
[2]For more on the role of radio in the development of Canada as a nation, see Edward Jones-Imhoteps's *The Unreliable Nation* [36].

him directly by a governmental body, without ever having to sell a single instrument.

Initial prototyping for the Electronic Sackbut began in 1945, on Le Caine's off hours from the NRC. As tubes and components became more affordable and available, he built the circuits into a desk at his home workshop. At the core of his vision of musical sound was an appreciation for the role of monophonic instruments. Flutes and trumpets leveraged single notes into lead lines with great effect, and Le Caine was curious to explore this paradigm electronically. Le Caine also believed in the potential of the square wave to achieve similar results: "I think of it as having a poignant, mysterious, and rather melancholy quality", he would later write [40]. Initial development of the instrument lasted at least until 1948, when the instrument was dismantled for storage as the NRC funded a temporary move to the University of Birmingham in the U.K. for his PhD [42]. In 1953, two years after his return, NRC secretary Helen Pattenson invited Le Caine to give a demonstration of the instrument to the Scientists' Wives' Association, and this led to it slowly becoming an official NRC project [93, pp.62-63]. In 1954, on the strength of these results with the Electronic Sackbut, his supervisors let him be his own one-man ELMUS (electronic music) department within the Radio and Electrical Engineering Division of the NRC (REED) [93, chapter 3]. As NRC machinist Horace Aubrey would later recall, World War II was a "period of unprecedented confidence and innovation", when "people believed that as Canadians we could do anything. It was an exciting to be around." [93, p.30] Somewhat protected from the conflicts ravaging the rest of the world, Le Caine was able to design a singular instrument, with relatively little pressure to publish on or commercialize any of his work. Unlike the composers working at the canonical early studios (the Columbia-Princeton Tape Music Center, the San Francisco Tape Music Center, the BBC Radiophonic Workshop, the Groupe de Recherches Musicales, or the studios of the West-Deutscher Rundfunk), his supervisors also had little expectation with regards to hisartistic output. Le Caine worked hard to acquire this independence; from 1940 to 1954, prior to ELMUS, his official employment was as a regular member of the REED and he performed his duties with just the right level of proficiency: the NRC leadership would not have let him start ELMUS had he been either not productive enough or too essential to research operations. Having skilfully navigated his importance within this research structure, he recorded quite a few sessions with him and others playing the Electronic Sackbut which eventually were released after the effort of his main biographer, the Canadian artist and composer Gayle Young [46]. It seems important to think of Le Caine's career, ELMUS, and the Electronic Sackbut as documentation of a rare instance of prehistoric NIME creativity under relatively little duress, especially considering what was happening beyond Canada.

The technical details of what, exactly, the Electronic Sackbut *did* were never exactly public knowledge. Shortly after his superior's approval to start ELMUS, he published two research articles [44, 45], of which only the latter provided information on the Sackbut. That information is, in retrospect, aspirational (even though Le Caine was probably capable of building everything he described); only fragments of what is presented in the paper are visible in the surviving artifact.

In a private letter dated 18 May 1955, he would confide to Don Kimble that "I have never made a complete drawing of the sackbut." [43] What he did do, however, was maintain prolific written correspondences with almost everyone in the English-speaking electronic music world. This, importantly, included Hugh Davies. The two would met at least once. After Le Caine's death in 1977, Davies would write that "[b]etween 1945 and 1948 he developed at his home in Ottawa what may be regarded as the first synthesizer—the electronic sackbut—which included elements of voltage control." [17] By 1989, Gayle Young would build on this to assert that Le Caine "used voltage control in the amplifiers and filters and used varied waveforms to generate different timbres. These techniques later became known as analogue sound synthesis. In essence the Sackbut was the first synthesizer." [93, p.40] [69, p.23] These are field-defining claims, as other scholars have placed the beginning of electronic musical synthesis at other points, e.g. the Coupleux-Givelet organ [16, 67, p.4] or the RCA Mark I and II [29, p. xiii].

The claim of first-ness will not be explicitly addressed here. Rather, I examine the profoundly collaborative construction of Le Caine's accomplishments, as materialized by the surviving Sackbut. Getting a sense of where Le Caine's idea came from, whether it was his imagination or other people's, dissolve somewhat the possibilities of firsts into a minutiae of subsystems, technical-epistemic lineages, and the occasional good idea. In that sense, I hope to contribute to sociological and relational musicologies and organologies, which have in various ways documented and highlighted the collaborative nature of making music and instruments [5, 51, 76, 85], as well as wider complementary projects in the humanities [56, 64].

In this essay, I argue the following: first, it is interesting to think of the Electronic Sackbut as a "prehistoric NIME" [89] because its core circuitry performs archetypic computational operations: pulse shaping and binary counting. This places it firmly within World War 2 and Cold War scientific cultures to which Le Caine belonged via his employment at a core governmental research facility. Second, it can also be meaningfully situated within electronic organ and radio engineering lineages, which also connects it to other early electronic musical systems like the Singing Arc, the Audion Piano, the Theremin, the Ondes Martenot and the Trautonium, who all adapted radio circuits to musical purposes (even if these borrowed different circuits than those Le Caine used for the Sackbut). Third, although Le Caine claimed to work mostly alone, I detail the rich chain of labour which made the Electronic Sackbut possible. I suggest that Le Caine's community building work may perhaps have been just as valuable a contribution to early electro-acoustic and electronic musics as his instrument building. All these arguments are built by retracing Le Caine's likely steps across technical, material, social, and epistemological fields.[3]

2 Methodology

Reverse Engineering (RE) is defined as "the process of analyzing a subject system to identify the system's components and their interrelationships and create representations of the system in another form or at a higher level of abstraction." [11, p.15] Although it is well accepted as a method in technical disciplines, it has received little critical attention beyond these, and is worth situating more precisely.

The anthropologist Nick Seaver, studying recommendation algorithms, adroitly remarked that "[b]ecause it works from a

[3]According to Gayle Young, NRC technician Gordon Ellis saw Le Caine put the Electronic Sackbut on the loading dock of the NRC, headed to the dump. He took it away, and stored it in his garage for roughly 20 years because he didn't want to see it destroyed; as far as Le Caine knew, the instrument was in the garbage. The Electronic Sackbut was donated to Ingenium in 1975 as artifact 1975.0336.001.

narrowly technical view of what engineering entails, reverse engineering has a hard time telling us about the cultural work of engineers" [72]. In aggregate, it is certain that the majority of reverse engineering which happens outside humanities scholarship remains a pragmatic operation. But surprisingly, there is a precedent for a such a self-critical form of reverse engineering in the context of historical NIME research which uses another one of Le Caine's instrument, the Sonde (an additive synthesizer with 200 oscillators) as a case-study: "in the absence of historical evidence about the design, use, and impact of material devices, those practices can help us to reenact and re-imagine portions of the historical worlds they occupied and the meanings they held." [4, p.164] A number of other landmark studies of electronic sound implicitly or explicitly approach expanded and critical forms of RE [2, 3, 20, 21, 60, 77–81, 84]. Furthermore, I would argue that a minority of reverse engineers themselves understood the cultural work done by technical systems, even if it is not always recoverable from the artifacts themselves [73–75]. More generally engineers (whether they are going forward or in reverse) at least implicitly engage with this cultural work when they consider discursive evidence in their projects: it is rare they would discount a manual, a video of the system in use, or even online forums, if it is of relevance to their project [8, 87, 88]. People, even technicians, are not picky when they have no choice about where their information might come from, and a rumor or fragments is better than nothing. Although she was writing primarily in the field of mechanical engineering, Kathryn Ingle remarks that RE is a political act: "Reverse engineering helps those who have older playing fields compete with those who have bright and shiny equipment in a brave new world by sharing and developing detailed technical information." [34, p.144].

As a longtime reader of the freestompboxes forum (which is in part dedicated to the documentation of rare or interesting guitar pedal effects), from which I learned to read circuit schematics and computer code in all forms, I would also argue that there is a case for recognizing this critical form of reverse engineering as a longstanding, if discrete tradition within NIME and its associated fields of hardware and software practitioners. These practices are never solitary; even if you never post on these forums you are still reading *with* others and relying on them writing, digitizing and sharing information. Learning with others from the circuits of others, as instrument makers, is slowly being joined by historians and critical theorists in and outside of music, who are learning to read technical objects and documenting their increasingly creative and effective approaches [82, p.27-32][26, 35, 37, 62]. In what follows, I show how understanding the operations and meaning of the Electronic Sackbut implies, almost at every turn, considering what others were doing before and around Le Caine. Contextual clues are almost equally relevant to materials one. Although the rest of this article does not explicitly refer back to the vocabulary of RE, RE as a potentially critical recovery epistemology was influential throughout this project. The present essay joins numerous other instances of partial or complete re- and reverse engineerings of the technical history of electronic music.[4]

[4]RE belongs to a wider category of what I call "recovery epistemologies", which have approached the question of re-acquiring knowledge from non-discursive objects. Complementary tactics in and around music include: forensics [61], media archaeology [33], critical code studies [50], historically-informed performance [9, 65], chaînes opératoires in archaeology [22, 47, 48], developmental sequences in organology [55], cognitive biographies of things in cognitive science [19], indexes and distributed objects in anthropology of art [27] and anarchives and anarchaeologies in media studies [94].

Within the complex restrictions of international intellectual property laws, the best place to learn how to build synthesizers may remain around other people building synthesizers. Electronic musical instruments live in practice and discussion.

3 The Electronic Sackbut as a prehistoric NIME: analog implementations of digital signal processing

Based on examination of the surviving artifact performed in the last decade, and a variety of preexisting published and unpublished documents on the Electronic Sackbut, it is possible to draw up a functional description of this instrument which supports its consideration as a very old NIME. My main argument here is that the Electronic Sackbut operates in a computational way at the signal generation level. Furthermore, at the control level, it informs a history of how Digital Musical Instruments (DMI) and their separation of signal processing and interface via a mapping of human action onto musical parameters [52] came into being. Discussing these points requires a better comprehension of the Sackbut's circuitry than previously afforded in Le Caine's own 1956 essay.

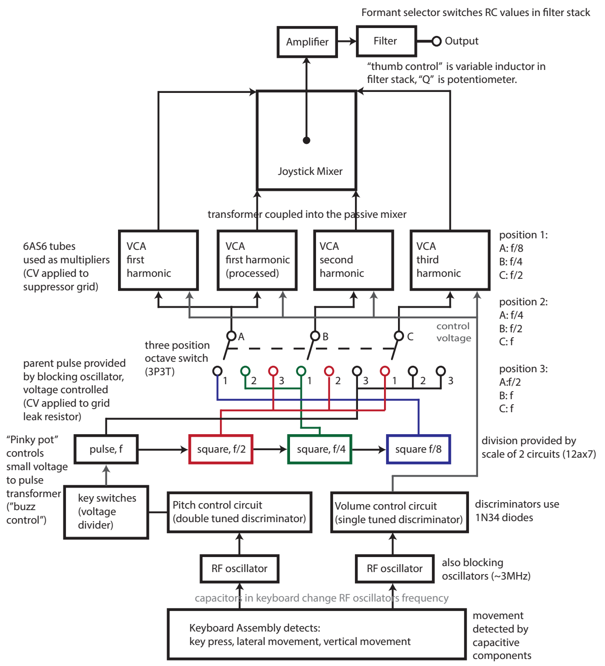

Figure 2: The current high-level block diagram of the Electronic Sackbut's signal and control building blocks. Subject to change.

In 1954 notes, Le Caine wrote that the core challenge of electronic music at that time was "that of putting the requirements of the musician or performer into objective terms, rather than inventing new circuits." [41, p.2] This tendency to adaptation is visible in the Electronic Sackbut's circuitry and its many adapted sections. Its core oscillator is a blocking oscillator [71] producing a relatively high frequency positive pulse train. As Davies and Young highlighted in the 1980s, the blocking oscillator is voltage-controlled, at least in the surviving artifact: capacitors in the keyboard frame vary in value with lateral and vertical movements of the keys, shifting the frequency of a high frequency oscillator. A double-tuned discriminator circuit converts this small frequency variation into a voltage variation (discriminators are in effect diode rectifiers: to detect positive as well as negative variations in frequency, one can stack two discriminators, one per direction). This results in a nonlinear voltage response, fine tuned by Le Caine for the force-to-pitch variation relationship he found most expressive. Once mapped to the double-tuned discriminator's characteristic S-curve response, the voltage variation is added to the output of a voltage-divider resistor grid, also actuated by the keyboard based on the key played. This combination control signal is fed, via a 10MΩ resistor impedance bridging these two circuits, to the grid of blocking oscillator triode (half a 12AX7). The current developed across that resistor changes the inter-pulse duration by varying the cutoff current required to switch the tube from blocking to non-blocking states. Therefore, the voltage of across that resistor controls the frequency of oscillation. This is, if we read generously a recent formal definition of voltage control [83, p.26], an instance of the concept as long as we consider the 12AX7 triode itself as providing most of the protection circuitry via its grid cutoff characteristics. This oscillator is "always on" and therefore requires an envelope generator, which in this case is effectively a voltage controlled amplifier (VCA), found in the next stages.

There the parent blocking oscillator from the oscillator stage drives a frequency division stage, with three cascaded dividers. These 12AX7 double triode scale-of-two circuits are almost directly adapted from the Hewlett-Packard (HP) decade frequency counter series which included the AC-4 [32]. Although that precise model is likely newer than the bulk of the Electronic Sackbut's, HP's influence on this particular subsystem within the Electronic Sackbut is explicitly acknowledged, and the circuit schematics' drawings are remarkably close [43, p.3]. The following stage is built around four 6AS6 pentodes (dual control miniature tubes, originally marketed in May 1948 [91]). Although counter circuits occasionally did employ these tubes [1, 58], Le Caine simply used these as "gain-controlled amplifier" tubes (one of their prescribed applications [24], in this context we would now say voltage-controlled). A second combination of high frequency oscillator and discriminator (this time, a single-tuned one, since it only has to produce positive variations in voltage) tracks the movement of a single key (as this is very intentionally a monophonic instrument). Pressing the key down changes the frequency of the control oscillator, causing a positive bias voltage from the discriminator. This is used as an envelope generator by the 6AS6's suppressor grid. This suppressor grid allows each quarter of this circuit stage to act as a voltage-controlled amplifier. After the divider and VCA stages, the four harmonics are transformer coupled to a passive resistive mixer, the output of which is the joystick controlling it, before a final amplifier and filter stage (see figure 2 for a simplified overall schematic).

At the signal-processing core of the Electronic Sackbut, then, is series of operations: first, a high-frequency comparison stage (the blocking oscillator), providing the core signal form of digital systems, the pulse. Second, counter circuits shape these pulses into square waves and afford Le Caine's circuit quite a bit of timbral variety by mixing harmonics and shaping them with a formant-type passive RL/RC combination. Finally, multiplication (with the dual control pentodes) gave Le Caine's instrument control over the dynamics of his monophonic instrument. As discussed in the introduction Le Caine's expertise with the scientific instrumentation of nuclear physics experiments made him intimately familiar with the numerous proto-computational tube circuits of the 1930s and 1940s; these are directly visible in the Electronic Sackbut itself (especially via the scale of 2 double triode division stage). This makes the Electronic Sackbut particularly relevant to prehistories of NIME.

Consider now the user controls of the Electronic Sackbut. Monophony restricts it to one-handed lead, but Le Caine took advantage of this in two ways. First, lateral movement of each individual key is nonlinearly converted into a control voltage via another discriminator circuit for pitch variation; this is more sensitive at the beginning of this action then towards the end of the lateral key travel. This affords the keyboard (right) hand quite a bit of pitch control. Second, the left hand provided control over the some "scientific" parameters of sound (rather than the registers and stops of organ terminology) as afforded by the underlying circuitry. A lever, controlled by the player's little finger, applied a small DC bias to one of the secondaries of the blocking transformer in the oscillator.[5] The central joystick lets the player change the ratio of four harmonics provided by the dividers in real time. The thumb lever controls one of the tunable elements in the filter stack. A series of potentiometers provide control over another filter center frequency, the filter resonance, the attack for each note, glide between notes, and finally the large right-most switch set the octave range of the keyboard between three possible ranges. A variety of electronic organs had preceded the Sackbut with related, if not identical, sets of control, but no organ before or even since has leveraged the single-handed nature of monophonic keyboard performance into anything comparable to the left hand controls of the Sackbut. The Ondes Martenot preceded the Sackbut for lateral key pitch control, but its signal generation routine is much simpler and less versatile. The Electronic Sackbut's pitch and timbre controls prefigure contemporary DMIs considering their symbolic separation of sound generation and control [25], while at the same time the profoundly interrelated design of the underlying circuitry, where subcircuits are connected in multiple complex ways and fulfill plural duties contrasts with modern modularizing logics. Figure two provides a block diagram summarizing the discussion above.

4 A material genealogy of the Electronic Sackbut

The above establishes a variety of precedents for the Electronic Sackbut: pulse and counting circuits from computing, double- and single-tuned FM discriminators for automated frequency control, and scientific laboratory counter equipment. Also important are the more traditional filters and amplifiers from the earlier, less diversified beginnings of circuit design, such as the RL/RC filter stage, and the few gain stages which couple some of the main sub-circuits. What of more implicit references or reactions to precedents?

The left hand control of the Electronic Sackbut was not unrelated to that of the earlier Ondes Martenot, whose relevance Le Caine himself discussed in his 1956 essay. He also acknowledged the Hammond Solovox and Novachord instruments, Thaddeus Cahill's Tellharmonium, and the RCA Mark II. Le Caine explicitly situates his instrument against the Novachord's polyphony, and the Mark II's "synthetic" implications; he would almost to his death reject the "synthesizer" label for the Sackbut [93, p.244,

[5] Further analysis is warranted for understanding exactly the effect of this bias. During the reconstruction project at Ingenium, Ed Eagan suggested it gave Le Caine a controllable noise burst with which to imitate the noisy onset transient of, for example, some brass instruments.

fn.3]. In this section I discuss two larger and more semantic classes of precedents: the connection between the Sackbut and frequency division organs like the Solovox, and a more infrastructural connection via the Sackbut's high-frequency components to radio-engineering. Of course exhaustively documenting the minor influences on the Electronic Sackbut over 80 years after its beginning is somewhat of an act of simplification; but it is done in hopes of making this mysterious system more legible.

4.1 Frequency division organs

Le Caine was not the first to chose blocking oscillators for his instrument. The Audion Piano, from 1915 and the Coupleux-Givelet Orgues des Ondes, from 1930, both used a keyboard's keys to simply select different taps on a blocking oscillator's pulse transformer, changing the resonant frequency of the oscillator and therefore the pitch it produces [10, 14, 18]. Similarly Le Caine was not the first to make extensive use of frequency division for musical purposes. Most relevant here are the Hammond Solovox and Novachord: both commercially introduced in 1940 but with development phases dating back to at least 1938, they both use multiple stages of frequency division as well. The Solovox, specifically, uses a blocking parent oscillator. Both also feature, in their earliest incarnations, electromechanical vibrato control of the parent frequency. By the Model L of the Solovox (1948), this was replaced by a fully voltage controlled oscillator and active, triode based LFO [13, 39, 54]. The Novachord features voltage controlled amplifiers from its earliest model [12, p.9].

In his 1956 essay, Le Caine mentions the Solovox (and a "superficially similar" system, the Hohner [45, p.470]). In a preparatory unpublished manuscript from 1955, he also discussed the Novachord system, displaying thorough technical understanding of their oscillator, divider, and control/keyboard mechanisms [43, p.3]. Throughout his research notes, as well, he mentions corresponding patents and Hammond publications. Most tellingly, perhaps, is the fact that his 1956 essay titled "Electronic Music" focuses in no small part on electric and electronic organs, their operations, and their uses.[6] This supports a partial but strong connection for the Electronic Sackbut within the electronic organ rhizome generally and the Hammond subset specifically. It does not diminish Le Caine's accomplishments, whose circuit remains impressive for the multiple purposes filled by some subsystems, like the 6AS6 VCA stage or the keyboard assembly, and the unique left-hand interface dedicated to timbral control of his monophonic instrument.

4.2 Radio-engineering electronic musics

Another uncontroversial influence for the Electronic Sackbut is radio circuitry. Many organ and electronic instrument makers borrowed and experimented with designs indiscriminately from the rapidly growing field of electronic communication and signal processing.[7] In these same 1955 notes, Le Caine discusses discriminators of the "two independent tuned circuits" and single tuned circuit varieties, "not of the Foster-Seeley type" [43, p.4]. In 1937 John F. Rider published *Automatic Frequency Control Systems*, a book dedicated to self-tuning drift correction systems which could extract FM carrier frequency drift automatically and provide a corrective voltage to a voltage controlled demodulator circuit, ensuring that carriers within a certain range could be tracked effectively [68]. These circuits are the core of the Electronic Sackbut's voltage-controlled elements, and the book contains a circuit close enough to Le Caine's own variation to be a clear case of adaptation. Barring new evidence or different interpretative approaches, it does appear as if the "cybernetic" aspects of the Electronic Sackbut come from self-tuning radio systems. In that sense the Electronic Sackbut is both related to and markedly different from the Theremin, the Ondes Martenot, and other early heterodyne oscillator-based electronic musical instruments. These used radio circuitry to generate signals. By the time of the Electronic Sackbut, relatively stable general-purpose oscillators like the blocking oscillators had been developed, and Le Caine worked with radio circuitry in the control sections of the instruments instead of the signal sections.[8]

5 The communal process of building and modifying the Electronic Sackbut

The first two sections above paint a picture of the Electronic Sackbut as a complex, richly interconnected device for musical expression. The following discussion, however, identified how this complexity was the result of on the one hand, restless experimentation and research from Le Caine, but on the other, also a wide variety of artistic and technical precedents. In this section, I also want to point briefly to the institutional and material support Le Caine likely received from the NRC, as well as the means of production of his daily work: electronics.

5.1 A glimpse at the support staff of the NRC

5.1.1 Fabrication staff. In *Sackbut Blues*, Gayle Young provides us with invaluable summaries of her meticulous reading through the Le Caine archives and her interviews with Le Caine's coworkers and collaborators who were still alive at the time of her research . Some remarks give us profound insight on what it was like to see Le Caine at work at REED and then ELMUS; for example, in his first years at the NRC, Le Caine's tube circuitry was prototyped by attaching tube sockets to strings nailed to the ceiling, after which he would solder components and connect test probes until the assemblage provided the desired behaviour. At that point, he would take it to Gordon Ellis' desk, and leave notes along the lines of "Gordy, would you make one of these." [93, pp.40-41] This is visible in the Sackbut's internal circuitry, which looks like it wasn't much more organized than simply taken off the string and soldered to existing parts of the system, occasionally with a screw or external control component adding some structure (e.g. figure 3). Further archival research will determine other technicians and machining staff which Le Caine would have relied on to build his increasingly refined instruments after the Electronic Sackbut. Some of his later collaborators, like David Rocheleau or John Chong (whom participated in the transistorized redesign of the Electronic Sackbut) are already parts of Young's story in *Sackbut Blues* [93, chapter 11].

[6]Le Caine explicitly cites Robert Eby's *Electronic Organs* [23] as a resource [45, footnote 36]. A dozen or so articles and patents cited in the 1956 article are also for organ circuits or from organ constructors. In the mid-fifties electronic music was often understood, "perhaps too quickly" as Gérard Létraublon would write, to imply electronic organs, as instruments like the Theremin or machines like the RCA Mark II were not commodities widely accessible to the wider public [49, p.7, translation mine].

[7]For example, see the wide variety of oscillators used across tube radio engineering, [86]. Signal processing has been primarily historicized by electrical engineers themselves, see [90].

[8]Because Rider's book was published before Le Caine began tracking his readings in a card catalogue, and because discriminator circuits were discussed in a variety of other papers, it is unsure if Le Caine read Rider's book specifically or another equivalent resource.

Figure 3: A close up of some of the circuitry inside the Electronic Sackbut, displaying some of the design and assembly style. The two leftmost tubes are the parent oscillator and a current source. The middle hanging tube assembly is the frequency divider board. The four tubes on the right in the center are the VCA. The transformers on the bottom right couple the VCA to the left hand joystick mixer, not shown. The discriminator circuitry, filter, and output stages are also not visible here. Photo by the author.

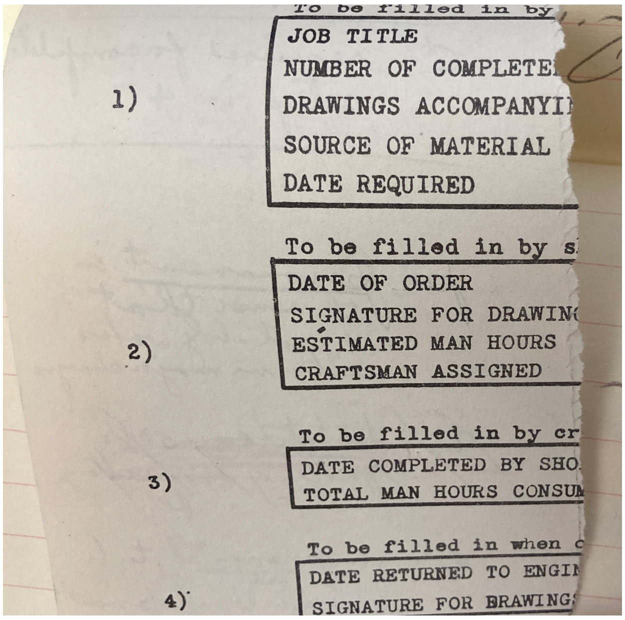

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Figure 4: A fragment of the form Le Caine would have used at the NRC to request staff assistance, probably for a prototype or drawing. From the Queen's University Archives, Hugh and Trudi Le Caine fonds, 5157, box 12, file 2.

5.1.2 Draughting staff. Less explicit but nevertheless remarkable in the Le Caine archives at Library and Archives Canada and the National Research Council Archives are the technical drawings for Le Caine's devices, including dozens describing (primarily mechanical) aspects of the Electronic Sackbut which were being reconsidered as late as the second half of the fifties (drawings from that period designate a "Sackbut Mk III", suggesting that the desk unit was the mark I, and the pre-PhD version was the mark II). Although Le Caine regularly did sketch some of his circuit schematics himself, more formal "production" was documented through commissioned technical drawings which would have been undertaken by dedicated support personnel. It is unclear whether or not this was subcontracted outside the NRC [53], but just as Le Caine would have gotten Gordy to "make one of these", he would have also followed some kind of standard process to requisition the 199 drawings which survive in the various Le Caine documents. Unfortunately, these drawings were only signed by initials; between 1949 and 1971 (the year of the oldest and newest drawings), no less than 15 different draughter's signatures are identifiable. Only a few used more than initials: Ken S., E. Moore, C.M. Rose, U. Hlaigh. A glimpse at the process underlying these separation of labours can be found in the back of a torn piece of paper on which Le Caine wrote some notes (figure 4). This fragment documents the bureaucracy underpinning how scientists like Le Caine would have interacted with technicians and documentalists in daily research.

Here we get a sense of the bureaucratic processes and metadata which made the operations of the NRC as an institution operate. As example of the results of one of these processes, the scale of two circuit for the Sackbut, drawn in two different versions by "E. Moore" (triple counter, 1954), and "REP" (single counter, 1955) are detailed in figures 5 and 6. Compare this scale of two circuit to the HP AC-4 circuit to appreciate how Le Caine was quite pragmatic about inventing when he wanted and adapting when he could [32].

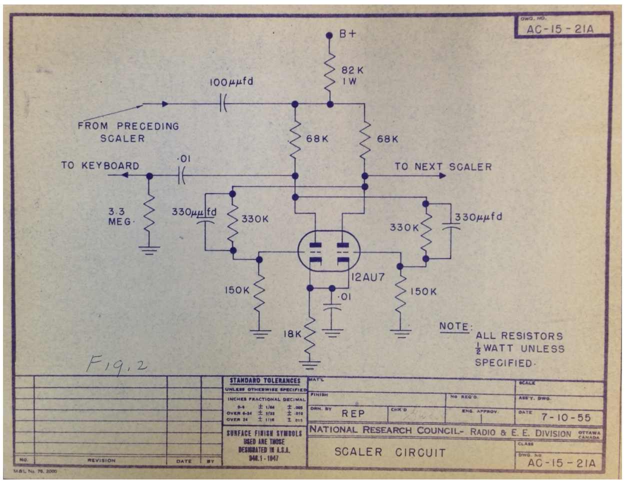

Figure 5: The 1955 circuit schematic made at the NRC for a single divider within one of the frequency division subsystem included in the Electronic Sackbut. National Research Council Archives, box 1, volume 1.

5.1.3 Secretarial and Archival staff. Le Caine had extensive correspondence with hundreds of people over the course of his career. Some of the most interesting surviving exchanges concern or began in the period where he was experimenting with the Electronic Sackbut, highlighting the instrument's aura as a materialization of composers' and technicians' widespread (geographically, if not culturally) curiosity for electronic sound. But this correspondence, although Le Caine did hand-write many letters, was not just his work. A political economy of the paper

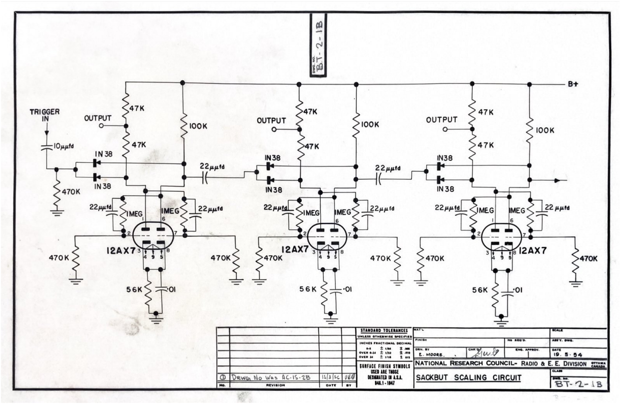

Figure 6: The 1954 circuit schematic made at the NRC for one of two frequency division subsystems included in the Electronic Sackbut, with three dividers. REED technical and architectural drawings, © Government of Canada. Reproduced with the permission of Library and Archives Canada (2026). Source: Library and Archives Canada/RG77M, 1997-01180-1, BT-2-1B.

industry and mailing infrastructure of the mid-20th century are beyond the scope of this essay, but Le Caine undeniably relied on secretarial staff at the NRC. This is visible in the annotations at the bottom of his letters, which tend to bear some kind of secretarial mark. For example, within the fifties and sixties, there are at least five secretaries which helped Le Caine in his day to day documents: "HLeC:HP" (1955), "HLC:kmf" (1965) "HLC:pjm" and "LHLC/ecp" (1967), and "HLC/mnh" (1969).[9] All contributed to Le Caine's instruments, despite the upper/lower case hierarchy, and some, like Helen Pattenson, served quite important roles in the eventual formation of ELMUS.

There is no reason to stop at secretaries. The very existence of the letters today points to the labour of the archival staff. All of them have been confronted with the profoundly interdisciplinary aspects of Le Caine's writing and circuit designing. At Library and Archives Canada, for example, the bulk of Le Caine's papers are kept in the Music collections, but his technical drawings are with the REED materials. This chain of labour links the work of scientists like Le Caine to that of researchers like those operating on the more historical aspects of NIME research. Their work should be acknowledged as well.

5.2 Re: Le Caine's extensive correspondence

Within the period of the Electronic Sackbut's initial development (1945-1958), Le Caine learned and shared concepts, designs, and news with a surprisingly extensive part of the anglophone electronic sound and music community of that time. He had correspondence with Morse Robb (maker of the Robb Wave Organ); Winston E. Kock, J.R. Pierce and Max Matthews (Bell Labs); Vladimir Ussachevsky and James Beauchamp (Columbia-Princeton Electronic Music Center), Pierre Schaefer, Norman McLaren, Harry Olson (RCA), O. Kendall (Canadian Marconi), Hugh Davies, and the technical staff of the West-German radio stations which were assisting composers in experimental music composition with scientific test equipment. Le Caine's ill-fated donation of a Multi-Purpose Tape Recorder in 1959 is well documented [30, 57]. His 1968 providing, to David Tudor, via John Cage, of a touch-controlled organ keyboard constructed by René Farley (used, for example, on Tudor's "Forest Speech"), is perhaps less well acknowledged [70, p.351-352]. As Le Caine's correspondence becomes better understood, some highlights have emerged: for example, an extensive and long term conversation between Le Caine and Vladimir Ussachevsky (who only relented in purchasing an instrument from Le Caine after years of asking about the Electronic Sackbut and the Tape Recorder), and Le Caine and Gustav Ciamaga, show that he acted as an unofficial hub of information, technical documentation, feedback, and suggestions. In a fashion typical of Le Caine, all serious questions got serious answers, regardless of the level of notoriety of their authors. Especially within Canada, but across North America, he seemed accepted as a reference for a burgeoning field, even though he only taught a few courses at the University of Toronto in the mid-sixties.[10]

5.3 On the emergence of electronic music instruments from standardized and commercially available electronic components

To conclude this section, I want to highlight the period within which the Electronic Sackbut emerged as an object known beyond Le Caine's immediate sphere of collaborators and friends. Between the end of world war two and the commercial emergence of transistors as commodities in the 1950s, scientific and hobby applications of war-time affordances like much more reliable fixed-value components and tube circuitry reshaped the range of possibility in a variety of fields including electronic music instruments [7]. In this field largely dominated by radio engineers and amateurs with a propensity for experimenting at home, the rapid drop in prices which accompanied that increased reliability and variety of components was made almost entirely possible by the public-private partnerships which fuelled the growth of the North American electronics industry at breakneck speed in the mid-twentieth century [92]. This, in turn, was made possible by a variety of extractive politics: first, the profoundly anti-labour collusion of a variety of state, provincial and federal agencies which sought to both minimize socialist organizing and rising labour costs [38]. Second, the establishment of what would later be known as the global South as the source of materials, before labour itself was outsourced (first to Mexico, then south-east Asia) [6, 15]. There is no evidence Le Caine thought of these connections, which is unsurprising considering most scholarship on these phenomena has only become more available in the last few decades. Nevertheless, in Siegfried Gidieon's terms, the anonymous components with which the Electronic Sackbut was built should also be taken into account [28].

6 Conclusion

The Electronic Sackbut materialized Le Caine's transition from nuclear physics to electronic music instrument design. It also

[9]A secretarial note from 8 June 1955 signed "Helen" suggest a first name for "HP", this is likely the Helen Pattenson who first encouraged Le Caine to demo the Electronic Sackbut as discussed in Young's book.

[10]Famously, Pauline Oliveros attended and composed some of her best known early works in response to Le Caine's suggestions and lessons in those courses, such as *I of IV*, published in 1967 [63].

acted as one of many flash points for a burgeoning English-language electronic music community which bridged electrical engineering, tinkering, instrument design, scientific experimentation, and composition. Analyzing the lineages of the Electronic Sackbut's circuitry based on material and archival evidence shows that, although circuitry and recordings may mediate prehistoric NIMEs, it is also always humans all the way down: materials and their physical properties are always mediated by cultural objects and attendant workers like forms, technicians, draughting rooms, parts rooms, and so on. Exploring this document inevitably leads to re-contextualizations, sometimes within the same project: Le Caine was not shy about modifying his Sackbut because he operated in an environment where learning and trying were valued more than units sold. This remains, perhaps, the most exciting aspect of the Sackbut.

7 Ethical Standards

This postdoctoral research project was funded by a private, anonymous donation to Ingenium. The museum houses the artifact and its curatorial division has, since 2012, undertaken the Electronic Sackbut Reconstruction project, resulting in a functional and visual rebuild of the device. Travel funding, which incidentally also allowed me to consult the only copy of Le Caine's doctoral dissertation, was provided in part by the University of Birmingham's Department of Music. No statistical inference tools other than optical character recognition were used in the research or writing for this essay. Using it for training, data mining, or automated semantic analysis of any kind goes against the direct wishes of the author. All references are real and were read in preparation for this essay. Annotated copies can be provided upon request.

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