Oramics: Precedents, Technology and Influence

Daphne Oram (1925-2003)

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Tom Richards

Arts and Computational Technology

Goldsmiths, University of London

Supervisors:

Dr Tim Boon Head of research, Science Museum, London

Dr Mick Grierson Professor of Computing, Goldsmiths, University of London

I, Tom Richards, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the text.

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ABSTRACT

Since the recent re-emergence of the work of British composer and inventor Daphne Oram, and the purchase of her Oramics Machine by the Science Museum, and their subsequent *Oramics to Electronica* exhibition, there has been much enthusiastic comment and re-appraisal of her work since she faded into obscurity from the late seventies onwards. Some of her recordings have been (re)released and she is now regularly written and blogged about, yet still, relatively little is known about her in terms of real detail with regard to her research and innovational achievements.

Drawing heavily on the Daphne Oram archive at Goldsmiths, and the Oramics Machine in the collection of the Science Museum, this research is an attempt to define and contextualise Oram's achievements with the Oramics Machine and her subsequent attempts to miniaturise and commercialise the concept with *Mini Oramics*. It is an investigation as to why her ambitious and holistic approach to electronic music production did not make a bigger impact, at a time when the palette of the electronic musician was rapidly expanding, and anyone with good ideas, technical prowess and financial backing might have succeeded, before the eventual domination and homogenisation of the synthesiser/sequencer market by the major electronics corporations of Japan; before the era of the home studio.

Central to this research is the construction of a version of *Mini Oramics*, an existing design (of Oram's with a considerable input from John Emmett, Norman Gaythorpe and others), which, had it been developed further and brought to market, would have become Oram's commercial and educational product. The newly constructed *Mini Oramics* has been experimented with and evaluated by musicians and composers. This practice-based research will inform the other strands of the research and will feed into arguments about the artistic, technical, and commercial feasibility of the Oramics Machine at what became a pivotal moment for Electronic Music and Music Technology.

CHAPTER 1.1: INTRODUCTION

The Oramics Machine: the Existing Understanding of a Musical Innovation

Before examining the wider issues surrounding Daphne Oram's career and her research with drawn-sound, or the detailed technological specifics of her innovations, it is necessary to summarise the existing understanding of the device that forms the initial focus of this body of research. This is so that the reader may approach with an understanding of the starting point for the thesis, as well a basic understanding of the intricacies of the Oramics Machine, which will be examined in depth in due course.

The Oramics Machine is best described as a graphical score reading machine, born of the modernist Varèsian notion of a universal musical tool, a notion itself born of new developments in electronics technology in the early 20th century. In effect it worked as a combined sequencer and synthesiser, but one that worked in a very different manner to the early voltage-controlled analogue synthesisers and digital/analogue sequencers of the period 1964 - 1980.

When referring to the Oramics Machine in this thesis, it is with specific reference to the machine Oram developed with several technical assistants in the period 1961 to 1972. After this period there were two more physical manifestations of the project: Mini Oramics and Computer Oramics, and these will be referred to as such and will not be discussed in this section.

In this introductory description, the workings of the machine are described within the bounds of the current general understanding of its functionality and this understanding will be expanded upon throughout the rest of the thesis. It is important to note that the machine was never a static finished entity, and as Oram and her technicians developed it over time, a number of its features were changed and adapted.

The Oramics Machine created single lines of musical melody by electronically combining three forms of coded graphical information, all of which were to be hand drawn by the composer. One set of information was to provide options for musical timbre (waveforms), one set was to determine musical pitch/melody, and the other was to set out the eventual timbral and dynamic structure of the piece, before finalising by recording the composition to tape. Oram also intended this process to be repeated, building up multiple simultaneous melodies, enabling chord progressions, counterpoint etc, by meticulously recording each new line of melody onto a multi-track tape recorder, which was to be physically synchronised with the Oramics Machine using a common drive mechanism.

In order to make a composition in *Oramics,* first the composer had to draw a selection of waveforms on glass slides to enable a selection of timbres or voices to be available in the compositional process. These waveform drawings would be then inserted into the oscillator section of the machine and were then repetitively optically scanned using a combination of a cathode ray tube (CRT) and a photo-multiplier (a light sensitive vacuum tube component). A sawtooth waveform at the desired frequency was fed to the X input of the CRT, generating a repetitive horizontal sweep, and a feedback circuit in combination with the photo-multiplier caused the scanning spot of the CRT to follow the contour of the waveform. This was achieved by setting up the circuit so that using negative feedback; the output of the photo-multiplier was always seeking a light level approximately half the output generated by full exposure to the CRT screen. This in effect pushed the Y-axis of the scanning spot up when too dark (obscured by the waveform drawing) and down when too bright (above the waveform drawing), effectively causing it to follow the contour of the wave outline. Taking a signal tap from the Y-axis of the CRT monitor then gave an output that was an electronic copy of the drawn waveform, with the frequency of the incoming X-axis sawtooth wave controlling the fundamental frequency or musical pitch. The machine had four identical scanners, allowing four timbres of the same fundamental frequency to be used in the composition. The four waveform-scanners were housed in what has been known as the 'commode'[1]

[1] Vallance, C. 2011

due to its re-purposing of what appears to be a sideboard or dresser, but which in fact is more likely to be the cabinet from an old radiogram.[2]

Fig. 1: Oramics wave scanners and associated circuits

Fig. 2: Oramics drawn waveforms on glass slides

[2] 'The commode' section of the Oramics machine has often been described as such. However, the Science Museum received an image via email in the early stages of this project, which appears to confirm that this piece of furniture was more likely to be an old RCA radiogram cabinet.

The next step in the process was to assign a series of frequencies within a timeframe, to generate a melody for the wave-scanning oscillators to follow. This was achieved using four synchronised tracks of clear 35mm motion picture film moved using a mechanical transport mechanism conceptually similar to a multi-track tape recorder. Each of the four tracks had a further four light sensitive components underneath and therefore could optically read a four bit binary coded decimal (BCD) number. The four films were illuminated from above using a linear incandescent light bulb in a light-proof housing. Each of the tracks was assigned a decade (ones, tens, hundreds and thousands) and these numbers were added together electronically and converted into the same number of hertz (cycles per second) using a sophisticated network of resistors, relays (electrically operated switches), and capacitors to control the time base circuit, which in turn drove the wave-scanning oscillators described above. This optical-digital system allowed the fundamental frequency to vary between 1-9999 hertz, roughly half the audible spectrum, but the actual frequency range was greater than this due to the possibilities of drawn overtones or harmonics, for instance if one drew two waveforms in the space normally assigned to one, a doubling of frequency could be achieved. The pitch control relay system was latched, meaning a very short set of drawn dots would change the system to the next desired frequency, and it would output that frequency until the next set of pitch instructions were received.

This digital pitch-control system also had an analogue adjustment feature intended for use as a vibrato control. This utilised a further synchronised track of clear 35mm film and in this case a constant line (drawn graph) adjusted the digitally determined frequency up or down proportionally to the distance of the line from the centre of the track – again using a light sensitive component beneath the film with a lamp suspended above.

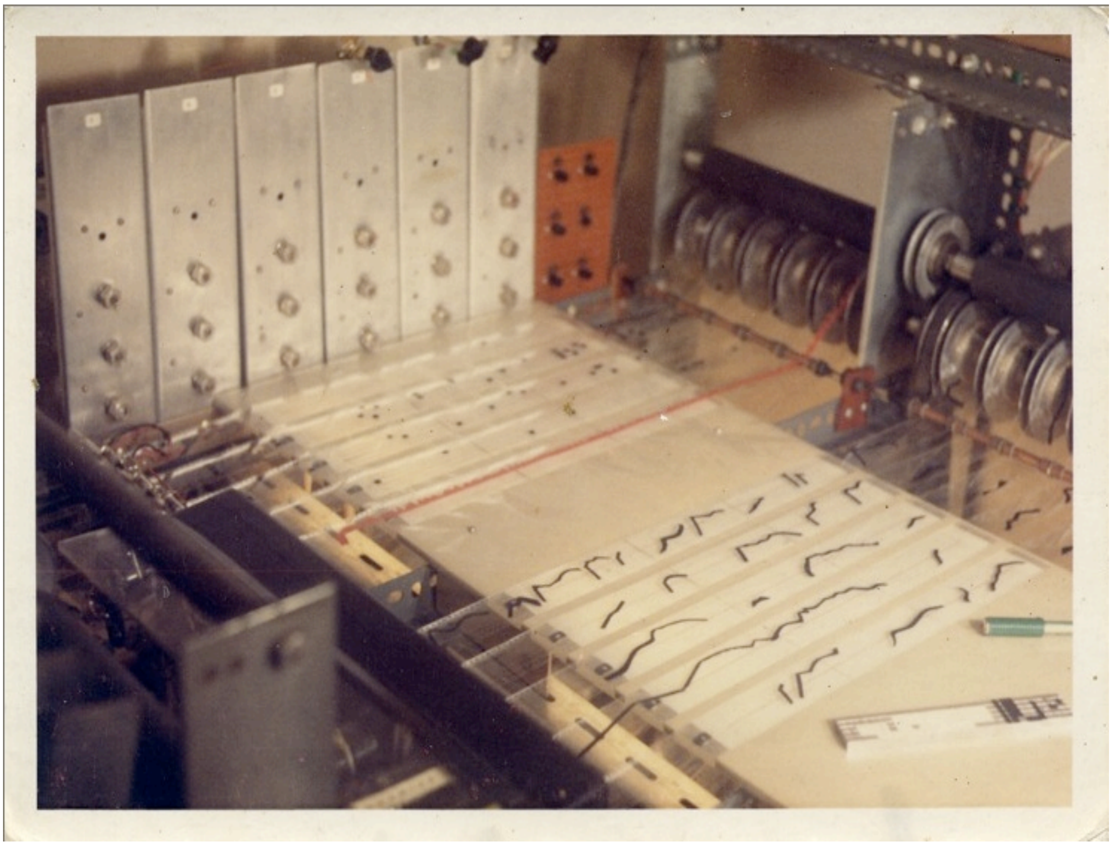

Fig. 3: The Oramics programmer with digital and analogue film tracks clearly visible.

The final stage in the process was a form of automated mix-down, in which a further five tracks of synchronised clear 35mm film were used to draw the dynamic contours (volume over time) of the four waveform outputs, as well as the amount of reverberation applied to the final mix. In the case of the dynamic contours, each waveform or timbre had its own continuous volume graph drawn onto one film track, which in turn would be detected using similar technology to the vibrato control and used to control output amplifiers, which then fed a final summing mixer.

This summed output would be fed both to a final output as well as an effects loop (in this case a reverberation room), which subsequently would also be fed into the final mix. The amount of signal fed to the reverberation room was again controlled by a drawn graph on the last 35mm film track, again using similar technology to the vibrato control.

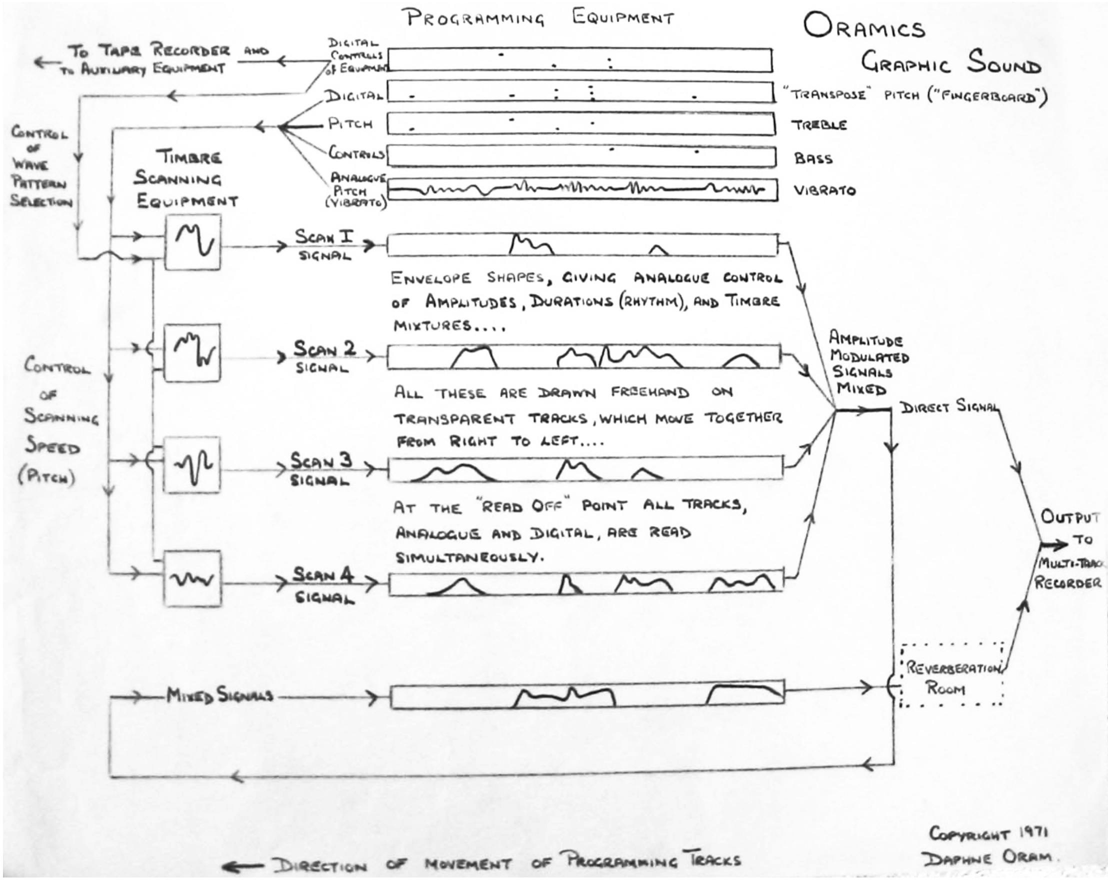

Fig. 4: The block diagram of the Oramics Machine from Oram's book *An Individual Note*

Differentiating Oramics from Contemporaneous Technologies

The Oramics Machine allowed the composer a very detailed level of control in the shaping of every musical note, and this approach in the construction of electronic music contrasted sharply with many of the other techniques being developed at the time, many of which relied on subtractive synthesis, processing simpler waveforms with filters, modulators and so on, and utilising much simpler forms of audio envelope control. However in terms of post-concrète (tape manipulation) techniques, it was possibly quite painstaking to use, requiring multiple drawn symbols to lay down one note, let alone a simple melody, and it lacked any provision for the live control of sound. That said, the Oramics machine was developed at a time when computer music was in its infancy, and Oram certainly would have argued that her methods were simpler, quicker and more intuitive than the programming methods being used by her contemporaries in this related field in the mid 1960s.

In her final report to her funders, the Calouste Gulbenkian Foundation on the 9th June 1966 she wrote:

> As you will know from the "New Scientist" article which we sent you last year, much work is going on in the U.S.A in developing computer music. But, as far as we can tell, the difficulties, which the composer experiences in programming a computer, have not yet been overcome. We have high hopes that the Oramics equipment will prove to be the answer.[3]

[3] Oram 2007, ORAM/01/02/070

Background: Oram's Evolving Profile

In a period when many researchers are working hard to redress the gender balance and re-integrate numerous female scientists, technologists, and artists into written histories, it should come as no surprise that the life and work of Daphne Oram has attracted more attention of late than she perhaps received in later life, as her career slowed down and was eventually curtailed by ill health.

With the re-emergence of her legacy and increased public profile since the 2008 South Bank symposium[4], her archive being accessioned by Goldsmiths Library Special Collections and the subsequent *Oramics to Electronica* exhibition at the Science Museum, much has been achieved to restore Oram's name to the history books.

In this context it is of importance that Oram's legacy should be treated with an even hand and dispassionate eye. There is a potential risk of 'wishing something into being', in this case for me or any other researcher to overstate Oram's case for support and recognition, or indeed to jump prematurely to the conclusion that she has been written out of history entirely because of her gender. It would be easy to fall into the realm of unqualified hyperbole. Was Oram 'the unsung pioneer of techno' as Giles Wilson in his 2003 BBC Obituary dubbed her?[5] It seems unlikely Oram would have appreciated this title, having never really shown any real interest in popular music[6]. In fact even to assert that she was unsung is extremely misleading; she may have previously received very little credit from the BBC[7] for her pioneering experimentation in the late 1950s, and she certainly was not a household name at the time of her death, but she made her mark in electronic music in her 1960s heyday and she received the attention to match, from both the press and the public, and she was also received and acknowledged as an expert in electronic music by many of her academic peers in the field.

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[4] 27 June 2008, 12:00 - 22:00 at London's South Bank Centre, organised by Goldsmiths College and Sonic Arts Network (now Sound & Music)
[5] Wilson, G: Obituary *Daphne Oram, the Unsung Pioneer of Techno*
[6] This could be seen as somewhat ironic, as it turned out rock/pop musicians were to become early adopters of commercial synthesisers. Oram did work with a local rock band *The Electrons* in the course of producing commercial sound commissions, however, it would be difficult to argue that she was a fan of pop music more generally.
[7] This was in accordance with BBC Policy, Oram and her fellow studio managers were not classed as musicians and would either not have been credited, or later would have been credited collectively as the BBC Radiophonic Workshop.

Why then did Oram's career dwindle and fall into obscurity? Why since then, has Oram's name once more come to the fore? Why has her standing been posthumously elevated? Why is the Oramics Machine suddenly of interest again when it could so easily have become a forgotten and failed innovation slowly deteriorating in a barn in France?[8] These questions have necessarily and constantly been borne in mind during the process of researching and writing this thesis.

Oram is not only seen as a forgotten and underrated female innovator. Currently many electronic musicians are turning their backs on software based EM systems and interfaces, and returning to hardware such as modular synthesisers, hand built noise machines and effects units, as well as some hybrid systems such as *Patch Blocks* where embedded software gives the impression of a hardware interface. A proliferation of internet communities such as Hackspace, Dorkbot, Electronotes and Muffwiggler have sprung up, giving a voice and opportunities for knowledge sharing to electronic music DIY communities. It is in this context that Oram is very much celebrated as a DIY hero, whether or not she might have seen herself in this light.

Another factor that should not be underestimated when attempting to examine and analyse evidence relevant to these questions, is the fact that both public and academic perceptions of electronic music have changed beyond all recognition between 1944, when Oram started out her career at the BBC, and 2017 as this body of research is being finished. Throughout the 1950s and to a large extent through the 1960s in the UK, a common perception of electronic music was of a somewhat minority interest, even a passing fad, and much of the press coverage questioned whether it should be deemed music at all, as illustrated by the following press cutting.

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[8] After Oram's death in 2003, the Oramics Machine was donated to Martin Newcombe's Museum of Synthesiser Technology, it was then sold to Peter Forrest, author of the A-Z of Analogue Synthesisers who moved the machine to France where it was tracked down by Jo Hutton (now Langton) and found to be in quite poor condition.

INTERESTING—BUT MUSICAL MADNESS

After hearing the first composition in a concert presented in the Freemasons' Hall last night, one member of the audience clapped, some laughed, and others stared in bemused bewilderment. For this was no ordinary concert.

This unusual electronic recital presented by Miss Daphne Oram can undoubtedly claim to be the weirdest offering of the Festival. Instead of an orchestra on stage there was a conglomeration of tape recording equipment and electronic devices, looking something like a George Orwell fantasy. If this really catches on, musicians will soon become redundant.

The performance was technically very interesting. There were some wonderful sound effects—the tune of "Little Brown Jug" was obtained by varying the pitch of a single tap on a milk jug with a spoon.

There are those who claim that these electronically conceived compositions are the natural development of modern music forms. While there may be a certain amount of art-form in the experimental effects, the claim can hardly be entertained seriously. This was musical madness.

UNUSUAL SOUNDS

The trouble with this type of sound is that the listener himself has got to be on the right wavelength: he's got to be "with it." The compositions seemed to be generally made up of grunts, moans, running water, sudden emissions of steam, gongs, doors shutting, and other unusual sounds. What a cacophony!

The programme would have baffled any "spot the tune" panel game expert, and it was difficult for the layman to discern what was intended by the various sounds.

One inspired member of the audience tapped his foot right through Kotonski's Study for One Cymbal, but when the foot continued to tap during Miss Oram's oration it became evident that no significance could be attached to it whatsoever.

If any listener had blown his nose, scraped his feet, or rustled a sweetie bag, it would have been difficult to say whether the sound came from the sound-track or not. Strange indeed!

No Miss Oram is not mad; in fact this former B.B.C. music balancer is obviously a very gifted woman. But as one member of the audience whispered as he shuffled out half-way through: "This eerie stuff's all right for cranks and beatniks."

Perhaps his summing-up was a bit unfair, but it wasn't difficult to see what he meant.

Scots Wife's Child Will Be Adopted

Mrs Esther Brown, 39-year-old Scottish mother of three children who last night appealed for someone to take her fourth unborn child, said in Wolverhampton today, that she has now arranged to have the child privately adopted.

Mrs Brown, who went to the Midlands from Fallin, a few miles from Stirling, explained that her husband had left her and she could not afford another child.

Fig. 5: Press cutting (newspaper unknown), referring to Daphne Oram's performance at the Edinburgh Festival in 1961. Oram 2007, ORAM06/04/002, (Oram's Edinburgh Festival Documentation).

Oram and Music in a Feminist Framework

> Recovering the history of women's achievements has now become an integral part of feminist scholarship in a wide range of disciplines. However, as the extent and intransigent quality of women's exclusion from science became more apparent, the approach gradually shifted from looking at exceptional women to examining the general patterns of women's participation.[9]

In terms of musical composition, the fact that Oram's recognition died down significantly from the mid seventies - when many of her male peers have subsequently retained legendary status, could be seen as part of a much wider and unfortunately still present problem, where women are extremely under-represented in music (and a host of other subjects); both in terms of actual numbers participating, and also in terms of the proportion and quality of coverage they are given when they do. The fact that women who succeed in music are often treated in terms of novelty or even relative sex appeal,[10] rather than straightforwardly as artists and practitioners, is still adding to the problem. Only when female musicians are treated as just that: musicians, and are consistently given merit based, non-gendered criticism and promotion, will the other problem; that of numbers, start to be resolved. Tara Rodgers[11] raises a striking example, citing the prominent 1998 feature length electronic music documentary *Modulations*[12]. In this film numerous electronic music practitioners of different generations are interviewed, and not even one of them happens to be female. How is it possible that the researchers of the film failed to even stumble upon the works of Pauline Oliveros, Eliane Radigue, Delia

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[9] Wajcman 1991, P2
[10] Regarding 'relative sex appeal' this problem is much more endemic in electronic pop / dance music than in academia or experimental music, however many young composers start out in these areas so it can still be deemed relevant to this subject matter. In classical music there has been a recent trend for the sexed up packaging and marketing of young female musicians, which is worrying not only as a backward step in what was previously perhaps more of a meritocracy, but also for the sidelining of equally deserving musicians who don't make the cut for this artificially imposed glamour quotient. Regarding novelty, the term 'woman composer' itself illustrates this problem, as you do not ever hear the term 'man composer'. Specifically in Daphne Oram's case there has been a tendency to refer to her as 'Daphne' rather than 'Oram', when people don't tend to refer to Stockhausen as 'Karlheinz' or Moog as 'Bob'.
[11] Rodgers, T. 2010. P14
[12] Lee, I. 1998. (Director)

Derbyshire, Bebe Barron, Laurie Spiegel, Laurie Anderson, Doris Norton and other musical innovators? Certainly then, Daphne Oram takes her place as part of an unevenly documented and a contested history where women have been, and are still, regularly undermined or celebrated for the wrong reasons.

In terms of research beyond this thesis, a comparative examination of Oram's innovations in the framework of theories of gendered technology[13] would be a most welcome addition to literature about Oram and the development of music technology more generally. The sharp contrast of Oram's *super-analogue* hand drawn approach to the varied approaches of her mainly male peers could surely provide the basis for another doctoral thesis or academic paper. Oram's unique conspiratorial tone in her writing style is also at odds with much of the contemporaneous literature on electronic music techniques; the fact that she made no attempt to shape her individual voice to fit in with the dry and academic *house style* of contemporaneous electronic music literature speaks of her individuality, confidence, and tenacity.

This body of research however is not a specifically feminist account of Oram's life's work - it is beyond the scope of this project to form a feminist critique of the wider social, technological, and cultural construction of what would become electronic music as we now know it: in a broad sense the omnipresent music of our time, and one that is still often characterised by a *boys and their toys*[14] culture whether specifically in academic music, or within society more generally. It clear from reading Oram's 1995 article *Looking Back to See Ahead*[15] that Oram herself felt that her career had been negatively affected by the male dominated and sexist atmosphere of her chosen profession.

In this meritocratic and techno-historical account, it is also necessary to explore which other factors are important to Oram's career trajectory and historical legacy. We should not forget that except for being female, Oram had every advantage; born white, in the West, to a supportive middle class family, privately educated, and as luck would have it,

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[13] See Wajcman, J, 1991
[14] Musician, composer and roboticist Sarah Angliss, gave a lecture at the AHEM conference held at the Science Museum (see research outcomes). She told the audience in the Q&A, that she uses a male avatar when on internet synthesiser forums, to avoid aggressive or patronising responses of the other forum members. In other words just to have a 'normal' user experience.
[15] Oram D. 1994

she came of age just as women were filling the technical posts left behind by the soldiers of World War Two. It is very likely that had it not been for the war, Oram may not have been able to enter a technical profession at all, and that her research may never have gone in the same direction[16].

In the context of re-examining past practices of electronic music, there are many other examples of misleading or forgotten histories of extremely talented and productive people, left outside the canon of dominant western document due to ethnicity, geographic location, personality, even disillusionment and withdrawal. The history of electronic music is constantly being re-written as forgotten or sidelined works and practices come to light. It is very likely that the Egyptian composer Halim El Dabh[17] was using concrète technique before Pierre Schaeffer coined the term Musique Concrète, Hugh Le Caine and Myron Schaeffer in Canada were using voltage control before Robert Moog in the US, and a Evgeny Sholpo and whole host of Soviet inventors and practitioners were advancing optical sound synthesis derived from film soundtrack technology, simultaneously or ahead of Norman McClaren, Rudolf Pfenniger, Oskar Fischinger and others in the west[18].

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[16] In fact WW2 also had a major impact on two of the technologies Oram later utilised in her work, magnetic tape recording was developed by the Nazis during the war, and the radar technologies which inspired Graham Wrench's wave scanning CRT oscillator designs were also developed and improved in the UK during WW2.
[17] Holmes, T, 2008, P156
[18] Smirnov, A, 2013

How Daphne Oram Positioned Herself and Her Work

Defining Oram's fields will necessarily become a part of this thesis, as Oram herself positioned her research in a very particular manner, very much situating herself within the musical avant-garde, but simultaneously rejecting or criticising the fashionable aleatoric and serialist music-technology research of the 1960s as 'music by slide rule' or 'music by the yard' - expressions she used frequently in both public and private sentiment. See for example her appearance in the documentary film *The Same Trade as Mozart*[19] and also her personal correspondence with the New Zealand composer Douglas Lilburn[20]. In short she rejected the fashionable serialist and aleatoric approaches in electronic/computer music, and although she embraced concrète technique at first, building her career on it, her drawn sound research was to take her away from this in terms of a group affiliation[21]. It is yet to be demonstrated what impact this individualistic approach may have had on her career; to what extent did the fact that she distanced herself both physically and ideologically from these aesthetic groupings cause her to become isolated or side-stepped?

Oram's departure from the BBC to work outside any institution meant that she had to undertake commercial work to survive financially and continue her research. Although it is remarkable that she managed to create much of her income through the production of commercial sound commissions, advertising jingles and the like, these categories might not have been regarded as what an 'avant-garde composer' ought to be doing. Conscious of this potential compromise to her ambitions, Oram preferred giving lectures, demonstrations and performances to undertaking this more commercial work[22]. Many of her contemporaries whose names remain more familiar now, managed to find much more consistent institutional support for their composition and research, and there are few others in Oram's field who managed to maintain such a portfolio career while

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[19] BBC TV. 1969. *Horizon: The Same Trade As Mozart*

[20] Oram 2007: ORAM/09/04/064

[21] In fact the BBC also wanted to distance their experiments with the electronic manipulation of sound from the term Musique Concrète, despite the fact they were in discussions with Pierre Henri and Pierre Schaeffer as well as other influential EM figures. They initially settled on the term 'Electrophonic' effects, but it was then discovered that this term had previously been used to describe the phantom sounds 'heard' by subjects of electro-therapy. When this was discovered the BBC chose the term 'Radiophonic' effects' instead.

[22] See Scales 2012 and Oram 2007, ORAM/01/02/047

simultaneously being lauded for their compositional and innovational achievements. She therefore presents a difficult model for comparison; Raymond Scott in the US perhaps deserves closer examination in this context.

Aside from written history having a fickle tendency to privilege some over others, on occasion it also has a tendency for over simplification. Take for instance another electronic music pioneer to be examined in this thesis: Peter Zinovieff expresses regret[23] that he is mainly remembered for developing the VCS3 analogue synthesiser, when he would rather be remembered as a pioneer of computer music. Whatever view you might take on Zinovieff's musical output, there is no disputing that he set up (with the assistance of several highly skilled technicians) the very first computer controlled music production studio in the UK, and one of the first worldwide. Perhaps this is more noteworthy than being the co-designer of a relatively simple analogue synthesiser, however elegant its design, and however iconic it may have now become.

[23] For example in the film 'What the Future Sounded Like' Dir Matthew Bate, 2006

Innovational Competitors

Whilst Oram was developing the Oramics Machine she kept her eye firmly trained on the competition as she saw it, yet less high profile (but highly relevant) technological developments were under way, or had already come to pass. Away from the Columbia Princeton Electronic Music Centre and Bell Laboratories, away from the RTF and WDR, unbeknown to Oram, works and designs that were in fact technologically closer to the development of her Oramics Machine were progressing in institutions such as organ manufacturers' workshops and seismographic research laboratories. The story of her patents therefore deserves further detailed examination and is by no means as simple as stated by Douglas[24] that "the [Oramics] apparatus is protected by worldwide patents". Oram, after ascertaining whether the Calouste Gulbenkian Foundation would claim any intellectual copyright of her designs (they replied in the negative[25]) applied for UK, US, and Japanese Patents. Both the US and Japanese patents applications were rejected and the UK one was accepted. The US and Japanese rejections cited numerous similar technologies, the most notable being that of an oscilloscope based function generator illustrated by David E Sunstein (US), in the February 1949 issue of *Electronics* magazine, which is in fact identical to the wave scanning technique conceptualised by Oram, and realised by Graham Wrench around seventeen years later.

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[24] Douglas, A. 1973. P97 (statement remains in second edition 1983, by which time the Oramics Machine was no longer functional)
[25] Oram 2007, ORAM/01/02/066

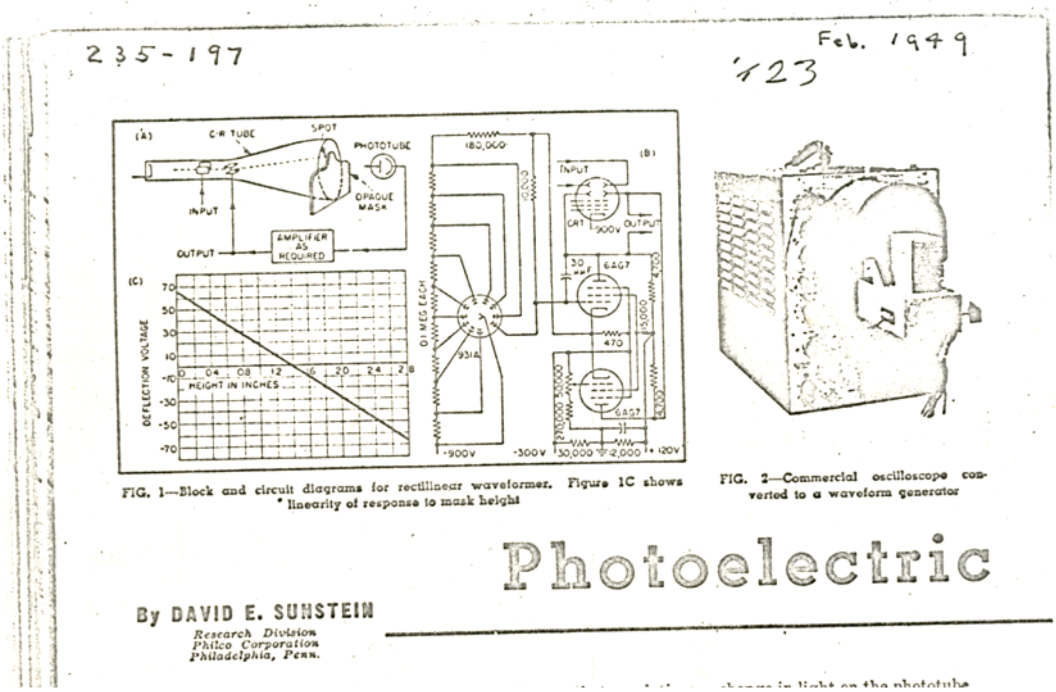

Fig. 6: Oram's photocopy of the 1949 Sunstein function generator article. Oram 2007, ORAM/01/03/009

After some re-drafting, her US patent was eventually accepted, but in fact only the claims related to the opto-digital control of pitch remained. It has not been possible to find any evidence that she ever held a Japanese Patent for Oramics, and it appears Oram gave up on these efforts, instead choosing to strongly imply that her work was protected internationally, at the same time as keeping the specific technology employed very much under her hat (one factor which has made the later analysis of her technology that bit more difficult due to the lack of complete technical drawings and circuit diagrams).

Despite Oram having been an absolutely avid researcher and correspondent, in her era, it would have been very difficult to keep abreast of all the possible rival developments to her research. Her archived correspondence[26] is peppered with exchanges and promotional material from names such as Max Matthews, Robert Moog, Lejaren A Hiller, and Hugh le Caine. The Daphne Oram tape (audio) archive also contains numerous recordings of the sonic experiments of such composers and technologists. All the same, it can be argued that she perhaps was not as aware as she might have been, had she not limited her research of potential competitors to what she might have perceived as the technological/musical avant-garde.

[26] Oram 2007, ORAM/09/04 Notes and Correspondence

This revelation about the originality of Oramics, and its having so many other precedents in the US and Japan (even if Oram knew nothing of them at first) means that we need now to adjust how we think of the Oramics Machine. It needs to be re-appraised, not as an under-appreciated musical invention, but rather as an alternative conceptual innovation, a system design which is more than the sum of its parts, where the overall vision, and the sophisticated combination of elements, is more relevant to historical progress than the individual elements themselves.

That said, it does seem very likely that her method for the digital optoelectronic control of pitch over time, developed with Graham Wrench, is very likely to have been a technological first, and the significance of this should not be underestimated. This was also something Oram changed several times in the process of developing her composition system.

CHAPTER 1.2: METHODOLOGY

Establishing the Research Areas

There are several limiting factors that affect the current understanding of Daphne Oram's technological innovations. Outside this research, both the Oram Archive and the Oramics Machine have yet to be researched in any great detail and much of the recent literature on Oram and her work has focused heavily on anecdotal evidence. Oram herself was understandably protective of her research and did not share detailed specifics about the technologies she developed. Her patent specifications do not go into any real detail about the specific methods she employed, and they represent only an early technical overview of the system she created. There is still no really detailed and balanced account of Oram's technological achievements in the field of drawn sound/electronic music, and to date no researcher has accurately isolated which of the electronic systems she incorporated into her compositional tools can truly be considered technological firsts (if any). It follows therefore, that it is very difficult to effectively compare her work with that of others, or to accurately situate and contextualise her innovational achievements in a wider sense.

This body of research is an attempt to address some of the limiting factors outlined above, as well as to draw some initial conclusions from the information gathered in the process. A secondary outcome of this research will be to provide access to far more detailed schematics and photographs of the Oramics Machine than those currently available.

In order to extend the existing knowledge of Oram's work in the field of music technology it has been necessary to utilise a number of research and analysis methods.

Sourcing Appropriate Literature

The main subject areas deemed relevant to this project have been defined as Music Technology, Electronic Music History, Science and Technology Studies (including feminist readings of technology). In this project the secondary literature sources can be divided into those directly addressing Oram and her work, and those that deal with the broader context of electronic music history and the (sociological) study of technology. In this case, some relevant (contemporaneous) secondary literature has been identified through Oram's own research notes and correspondence.

The prescribed primary literature and research materials for this project are: the Daphne Oram Archive and associated audio archive held within Goldsmiths Library Special Collections, as well as the Oramics Machine itself, held in the collection of the Science Museum London. Supplementary to these primary resources are relevant files from the BBC Archives in Reading.

Further information has been sought through interviewing some of Oram's colleagues and acquaintances as well as others involved in designing musical technology of the same era. The format of these interviews has been contextually derived (depending on the relation of the interviewee to the subject matter) and they have in no way been an attempt to form a qualitative survey with one particular question in mind, rather a way of gathering information and opinion, and opening up further potential research avenues.

Gathering and Organising Information

This study began with a fairly open ended approach: to expand upon the current understanding of Daphne Oram's innovations. As such, in many respects the line of questioning has developed from the early archival research in combination with the background reading in Electronic Music History and Science and Technology Studies (STS).

Work in the Daphne Oram Archive began with examining the files explicitly concerned with the development of the Oramics Machine. Detailed notes were kept for subsequent categorisation and analysis. Simultaneously work in the tape archive commenced, listening to and digitising the tapes and keeping notes.

The process of organising the initial research when preparing exhibitions and talks based on the preliminary reading and archival evidence led directly to the line of questioning outlined in the Research Questions and the introduction to the Practice-Based Research.

The empirical research conducted on the Oramics Machine itself, has been a process of systematically investigating and documenting the various electronic modules present in the overall system architecture, drawing up detailed circuit schematics in the process (where possible). In addition, two mechanical engineers have been consulted with regard to the mechanical operation of the machine.

There is a separate methodology and justification for the practice-based research in Chapter 5 *Re-Imagining Mini Oramics* on page 152 of this thesis.

Analysis

Finally the broad collection of information, sonic media, and expert opinion gathered in the course of this research will be cross referenced and situated comparatively, and then examined within the framework of the *Social Construction of Technology* [27] (SCOT) model of STS, as outlined in the Theoretical Framework chapter (P31), which has also guided the line of questioning employed. The aims of this concluding analysis are not designed to be a comprehensive survey of Oram's life and work, but a detailed and specific evaluation of the technologies she designed and employed, as well as a creative and speculative exploration of the lost potential of Mini Oramics.

[27] Bijker, W. Hughes, T. and Pinch, T. Eds. 1989.

CHAPTER 1.3: THEORETICAL FRAMEWORK

Oram, Electronic Music Technology, and the SCOT Model in STS.

Oram was a multifaceted character, having diverse professional activities and research interests, and those who have chosen to write about her in the last ten years have all brought their own emphases to the table, whether technological, musical, philosophical, feminist, sociological, or even paranormal. The content of this thesis will be no exception; I should state at this point that with a background as an artist, musician and a designer and maker of electronic musical instruments, the aesthetic and technical aspects of Oram's research, innovations and career form the main focus, framed by the broader history of electronic music technologies. As Graham Wrench[28] points out however, Oram would perhaps not have made such distinctions, having had a singularly holistic vision of arts, science and philosophy. *An Individual Note of Music, Sound and Electronics*[29] Oram's sprawling, idiosyncratic yet fascinating account of her own philosophy also bears this out. The only possible retort is, that the more individuals that bring their own perspectives to her story, the less likely it is that Oram will end up being pigeonholed. This particular account is an exploration of artistic and technical innovation, and the desire for a less compromised interface for making electronic music, at a time when the genre was still being invented.

This particular research then, is primarily a study of relative success and failure in the aesthetic, technical and commercial domains, thus it is appropriate to form this research within the theoretical framework of Pinch and Bijker's Social Construction of Technology[30] or SCOT model. This research framework primarily states that the principle of symmetry should be applied, approaching the study of successes and failures in a given field, using the same parameters for each, as opposed to following a somewhat triumphalist or 'genius based' approach to success, and more social-rejection based approach to failure.

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[28] In a private email to the Author 11th November 2012
[29] Oram, D. 1972
[30] Bijker, W., Hughes, T. and Pinch, T. Eds. 1989

> …the SCOT model of describing technological artefacts by focusing on the meanings given to them by relevant social groups seems to suggest a way forward. Obviously, the sociocultural and political situation of a social group shapes its norms and values, which in turn influence the meaning given to an artefact. Because we have shown how different meanings can constitute different lines of development, SCOT's descriptive model seems to offer an operationalization of the wider milieu and the actual content of technology.[31]

Oram herself was very much aware of the inherent shortcomings of attributing a given invention solely to an individual *genius* and perhaps it could be argued that she was an early proponent of this mode of analysis:

> I have just said that it is not much more than 25 years since electronic music began. But I must hasten to qualify that statement, for surely we can trace its history back far earlier than the last war. Do not let us fall into the trap of trying to name one man as the 'inventor' of electronic music. As with most inventions, we shall find that as certain changes in circumstances occurred- as certain new facilities became available - many minds were, almost simultaneously, excited into visualising far-reaching possibilities. New developments are rarely, if ever, the complete and singular achievement of one mind. Yet, when we speak of an invention, we seem to delight in persistently naming one man as the originator ...[32]

The principle of symmetry demands that we examine success and failure in the same terms, and in keeping with this method, alongside an in depth technical and aesthetic analysis of the Oramics Machine, will be comparisons with parallel developments in electronic music technology, some of which have now become iconic, whether or not they initially succeeded commercially.

Crucial to the application of the principle of symmetry is the idea of interpretive flexibility, where the same invention, theory or principle can and will mean very different things to different social groups and end-users - in the case of electronic music, the Roland TB303 is a case in point, categorically failing within its target market as an electronic accompanist for acoustic musicians, yet later gaining legendary status within the techno community as a lead instrument, one which was absolutely pivotal to the development of the genre, and one which spawned a whole new strand of simple synthesiser/sequencer products we now know as 'Groove-Boxes'.

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[31] Bijker, W., Hughes, T. and Pinch, T. Eds. 1989, P46
[32] Oram 1972, P111

The SCOT model encourages us to examine technology from a social perspective, examining developments not only with simple pragmatic questions – Does it work? Does it solve a significant problem? Is it economically viable? But also to examine more subtle socio-political issues which might interrupt or complicate the route to success or failure for a given innovation, for instance one factor which determined the eventual success – or *closure* of the TB303 was that they were unwanted and available cheaply second hand at thrift stores and yard sales, at a time when a new genre of electronic music (Acid House) was being invented, largely by somewhat disenfranchised young black men in the post-boom deprivation of Detroit in the mid 1980s. So in this simple example we can see that it was certainly as much by accident as by design that the TB303 won its place in history.

The principle of closure represents the final acceptance by relevant social groups, the limited but effective consensus that a product or theory has answered its brief and solved its problem. This phenomenon is also referred to by Bruno Latour[33] as 'becoming a black box'; when something is finalised in this sense it is no longer scrutinised in the same way, and it is taken as a final unit and employed widely by a relevant social group, whether it be a scientific theory or a new consumer product, the principal of closure can be applied. Of course closure is very rarely permanent, even the black boxes of Newtonian physics were eventually opened and pulled apart by Einstein, who proved that they only work within certain constraints.

The Oramics Machine can be read as a failure in terms of the SCOT model of STS, never having achieved closure in any of its three main incarnations: Oramics, Mini Oramics, and Computer Oramics. It provides an interesting challenge for techno-historical evaluation, not least because so many of the concerns of the relevant social groups in this case are philosophical and aesthetic, and therefore completely subjective. In Oram's case, although there is evidence that she attempted to commercialise and democratise the Oramics system, for example she was in correspondence with Moog and Philips in regard to collaborating on the further development and commercialisation of her technology[34], there is also evidence that she was unable to really let go enough to

[33] Latour, B. 1987

[34] Letter to Robert Moog: Oram 2007, ORAM/09/04/063. Description of visit from Jack Boyce, Philips representative: Oram 2007, ORAM/01/04/002

do so: she stated herself that 'I shall never want to call it finished'[35]. This duality of purpose in Oram's approach requires careful further analysis, and the question of why Oram never received further significant backing (despite continued interest[36]) after her two grants from the Calouste Gulbenkian Foundation, will remain at the core of this research project.

Interpretive flexibility applies not only to end users but also to those innovators attempting to understand and design around a given problem[37]. They will all interpret a given problem in different ways and design accordingly, influenced by numerous social, political, financial and technological factors. To put things very simply, in the case of Oram and her contemporaries in the late 1950s, *the problem* could be seen as the limitations of tape manipulation for the production of electronic music: the fact that noise was added every time it was bounced down, the meticulous and time consuming nature of cutting it up and splicing it back together and the fact that there was no visual indication of where a sound started or finished (Chinagraph pencil markings excepted), not to mention the fact that pitch and tempo were inconveniently and inextricably linked. Oram, Zinovieff, Olsen and Belar, Max Matthews, Robert Moog and a host of others all designed around *the problem* completely differently. How and why these different treatments came to pass, and then fail or succeed is the core of what will help us to understand and contextualise Oram's innovations and decipher the web of influences and events which led to her particular concept for the evolution of electronic music dwindling, despite it having uncannily similar aspects to what is now the standard for almost all recorded music production: the software based digital audio workstation or DAW.

It is arguable that on paper at least, Oram's music production system had many advantages over the technologies of some of her rivals, notably voltage controlled analogue synthesis and related sequencing hardware (Moog, Buchla, ARP, EMS etc), and also the early stages of computer synthesis/sequencing techniques which were being developed (Bell Labs, EMS etc) as Oram developed the Oramics Machine. Oram's system presented the end user with a far less abstract interface than either rival

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[35] Oram 2007, ORAM/09/04/064
[36] After the publication of her book *An Individual Note* in 1972, Oram received a flurry of new enquiries about her research and the Oramics project. Oram 2007, ORAM/09/04. Notes and correspondence.
[37] MacKenzie and Wajcman 1999, P40

technology (initially) and especially compared with computer generated/controlled music composition systems. Far less specialist technical knowhow would have been required (in theory). The Oramics system also allowed the composer more direct flexible and nuanced timbral and dynamic control within a composition, especially bearing in mind that as Oram set out with her project, even very basic attack and decay type envelope shapers were not in common use[38]. This leads to a key issue examined within the SCOT framework, that of early adoption, as outlined by the following quotation:

> Technologies often manifest increasing returns to adoption. The processes of learning by doing and using discussed above, and the frequent focus of inventive effort on removing weak points ('reverse salients') from existing technologies, mean that the very process of adoption tends to improve the performance of those technologies that are adopted. This gives the history, especially the early history of a technology considerable significance. Early adoptions, achieved for whatever reason, can be built into what may become irreversible superiority over rivals, because success tends to breed success, and rejection can turn into neglect and therefore permanent inferiority. The history of technology is a path dependent history, one in which past events exercise continuing influences. Which of two or more technologies eventually succeed is not determined by their intrinsic characteristics alone, but also by their histories of adoption.[39]

In this context, and despite its merits, Oramics can be described as an evolutionary dead end in the history of music technology, and the early adoption of rival products by musicians, studios and educational institutions is at least as important to this account as the inherent advantages and disadvantages of each system. Whilst Oram continued to develop her system, the rival products which were available for purchase, superior or not, were the systems being adopted and therefore invested in and improved upon, whilst Oram continued without going to market, and in relative isolation. Her attempts to miniaturise and commercialise the Oramics Machine with Mini Oramics bore little fruit, and in fact she never released a commercial version of Oramics in any form. As she never gave the EM market the chance to adopt her methods, it is not at all surprising that Oramics did not catch on or become a significantly documented part of the history of music technology. So in examining Oram's innovations in the context of the history

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[38] See Wrench, G, 2013 and Douglas, A 1962
[39] Mackenzie, Wajcman 1999, P19

of music technology, the pertinent questions are in fact those surrounding why Oram never brought a product to market, rather than those surrounding why her technology was not generally adopted.

In the context of the SCOT model, Oram's failure to commercially launch an Oramics interface, also begs the question: *Who are the relevant social groups?* If we are to compare commercially available products to Oram's research prototypes, how can we evaluate them on the same terms? So the SCOT model is used to inform research questions and arguments in this thesis, but within the context of this practice-based PhD project it is possible to extrapolate further. Contemporaneous experimental musicians, academics, and technologists were the relevant social groups for Oramics, but in addition we can also speculate on the *potential* of an Oramics product and the potential users of this product. In essence the re-imagining and construction of Mini-Oramics allows for a hybridisation of the SCOT model. Through hands-on research and a subsequent user study we can also make informed guesses as to what the response to a commercial Oramics product might have been, given that this practice-based research gives renewed access to an Oramics user experience. This additional *what if?* methodology, is further justified and explained at the beginning of Chapter 5.

In essence the SCOT model has been used to inform the shape and direction of this research project in its earlier stages, and it is hoped that the practice-based research with its own justification and methodology can add to significant further arguments, especially when discussing the potential of the Oramics user interface.

It should also be stated that within the SCOT model it is easy to name something a 'failed technology' when, in a broader context, it is not necessarily fair to do so. Imagine for instance that Oram had developed the Oramics Machine within an academic setting. To that institution it would be a great success: valid research with material outcomes, whether or not it was then commercialised and/or patented. The fact that Oram got as far as she did without this kind of affiliation is testament to her vision and determination, and it should be noted that in this thesis, when referring to 'failure' in the context of SCOT, it is meant purely in the commercial sense of widespread adoption and proliferation, and eventual profitability.

These factors form the background for the main research questions of this thesis but before examining further relevant literature and outlining the main research questions it would be prudent to outline some of the criticisms of the SCOT theoretical framework.

Criticisms of the SCOT Research Model

There are some compelling critiques directed at this approach to the study of technological development by scholars such as Langdon Winner[40], who accuse the SCOT model of failing to address collateral fallout from ideas products and innovations, i.e. its fine to illustrate the web of events, cultures, ideas and actors which have led to the eventual closure of an idea or innovation, but what of the consequences of that closure, what are the knock on effects? Who decides which are the relevant social groups, and are those indirectly or negatively affected by *progress* not also to be deemed relevant? However as Winner also points out it does provide a convenient framework for smaller scale case studies, and in this case there is no intention of following the widespread knock on effects of the invention of the op-amp for instance, except where deemed directly relevant to the trajectories of Oram, her immediate peers and relevant technologies. The extrapolation of the wider socio-economic consequences in this branch of technology are beyond the scope of this project and so although whilst taking on board the limitations of the SCOT model, as outlined by Winner and illustrated by Adam Curtis, Graham Harwood and others[41], it should provide a sufficiently inclusive and convenient theoretical framework to shape this body of research, and one in which it is possible to encompass a broad range of factors which were instrumental in shaping Oram's career progress.

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[40] Winner, L. 1993

[41] The Adam Curtis Film *All Watched Over by Machines of Loving Grace* Pt 3, BBC 2011, describes how the desire for consumer technology contributes to war in the Democratic Republic of Congo (DRC). *Tantalum Memorial*; an artwork by Harwood, Wright, Yokokoji, 2008 reminds us how telephony and the Coltan Wars (also in the DRC) are inextricably linked.

CHAPTER 1.4: LITERATURE SURVEY

Recent Writing on Daphne Oram

There is not a vast resource of contemporary literature specifically about Daphne Oram and her work, however there is a small and committed group of scholars who have over the last few years contributed enormously to the understanding of Oram and her legacy, notably Peter Manning, Jo Hutton (now Jo Langton), Dan Wilson, Tim Boon and Mick Grierson. In addition a collection of recent PhD theses on the history of electro-acoustic and electronic music have also provided vital contextualisation and a variety of approach and emphasis to the subject matter, and some of those who include chapters on Oram and her work are: Nicola Candlish, Rob Mullender, Fiorenzo Palermo, Holly Pester, Jo Langton, and Laurie Waller.

Whilst much of the recent literature mentioned above gives a good general picture of the Oramics Machine and Oram's research practice(s), in terms of detailed technical specifics and accurately dated development stages there is still much more to be learned about the Oramics Machine, and even more to be learned about its other incarnations *Mini Oramics* and *Computer Oramics.* This thesis will also only briefly touch on Oram's computer work, but it is hoped that the other knowledge gaps in the technical understanding of the Oramics Machine and Mini-Oramics will be largely filled in and contextualised within this body of research, and to do so it will be necessary to concentrate more on empirical research examining the Oram Archive, the BBC archives and the Oramics Machine itself, as well as utilising contemporaneous literature and recordings to further contextualise Oram's outlook and achievements.

The Daphne Oram Archive

The Daphne Oram Archive, accessioned by Goldsmiths, University of London in 2007[42] represents an enormous resource, not only for those studying the life and work of Oram herself, but also for anyone looking at the history of electronic music more generally. It is also valuable in terms of illustrating the cultural zeitgeist in the UK and beyond in the mid to late twentieth century. The archive contains a huge amount of material related to Oram's research and development of Oramics: press cuttings, diaries and technical log-books, correspondence with technical associates and component suppliers, and with her main sponsors, the Calouste Gulbenkian Foundation. These sources can be used to identify and date many of the technical successes, challenges and setbacks that Oram experienced, and to examine her approach to technical problem solving.

The archive also contains much of Oram's personal correspondence, only a small proportion of which is directly relevant to Oram's research and development of Oramics, but in which can be found information on life events which could certainly be deemed relevant to Oram's career trajectory. This account is by no means a biography, and will in no way attempt to delve deeply into Oram's personal life, but if we are to approach the development of Oramics using the SCOT framework, some of these factors will necessarily have to be incorporated. It is demonstrable that Oram's personal and family relations can be directly linked to her progress in certain instances: factors such as the early financial support she received from her parents, the death of her mother, and her falling out with her brothers and her electronics engineer Graham Wrench, in all likelihood had a material influence on the design, and (as will be argued) most crucially, the timescales for the Oramics Machine and her subsequent work in EM technology.

The Oram Archive also contains over 500 1/4'' audiotapes, of which approximately 50% have been digitised. The tapes contain a wide variety of material and are not restricted to the works of Oram herself; she recorded many musical works from the

[42] Initially the archive of written materials and 1/4'' tapes was passed by Oram's heir Martin Cook, to Hugh Davies, a British composer and lifelong friend of Oram's, when Davies died in 2005, the archive was passed on once more to the Sonic Arts Network (now Sound and Music) who then passed it on to Goldsmiths Library Special Collections in 2007.

radio as well as other programmes she had an interest in. In addition she sought musical examples from many of the other EM and sound research studios of the era and many classic early pieces are represented in the collection, and are useful for establishing details of Oram's awareness of contemporary practice. For this thesis, the tape archive is most useful in examining the output of the Oramics Machine itself, and many unpublished examples of Oramics sound are present. These tapes are useful not only to illustrate what the Oramics Machine sounded like in comparison to contemporaneous EM technologies, but also in analysis of the machine against Oram's own design brief, clearly outlined by Oram at the beginning of her project[43]. Using examples from the tape archive, it is possible to construct arguments pertaining to the success of her project and to what extent Oram fulfilled her own brief for drawn sound composition.

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[43] Oram 2007, ORAM/01/01/018 a page entitled *Written Sound Waves* January 1961. See P. 87

The BBC Archives

The BBC archives in Caversham contain several files useful in examining the development of resources for the electronic manipulation of sound toward and beyond the establishment of the BBC Radiophonic Workshop in 1958. Other researchers have also closely examined these resources: notably Louis Neibur and Nicola Candlish[44]. That said the different emphases of this particular project certainly justify re-examining these archives in their primary form. The circumstances of Oram's departure from the BBC and her choice to continue her research outside any institution are most certainly crucial factors in this account. These records contain minutes of the Radiophonic Effects Committee (formerly the Electrophonic Effects Committee) who were charged with the task of improving BBC facilities in electronic sound production. The records also contain logbooks and research scrapbooks from Oram's brief time at the helm of the Radiophonic Workshop, and these are illuminating in that we can see how much time was devoted by whom to any given work in those early days of the workshop, as well as uncovering details of many sources of inspiration to Oram and her colleagues.

The Daphne Oram Archive and the relevant BBC archives are both invaluable resources, but unfortunately neither appears to be complete. There are numerous notable absences in both archives, and in fact Carolyn Scales[45] has stated that her mother (Oram's sister in law) went through Oram's papers and destroyed numerous documents before the material was passed into the public realm. One glaring absence is an envelope marked 'Graham's Circuits'[46] that contains absolutely nothing. Martin Cook[47] stated that there were several break-ins at Tower Folly after Oram was hospitalised with a stroke in 1995 and it is possible some crucial audio materials recorded on to cassette tapes were lost at this time, as there are no cassette tapes in the archive, yet, tantalisingly, Oram refers to having recorded her computer generated music onto cassette in her notebooks from that era[48]. In terms of the BBC archives, there are documents referring to notes of Oram's, which do not appear in the relevant files and it

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[44] Neibur, L. 2010 and Candlish, N. 2012.
[45] Scales, C. 2012
[46] Oram 2007, ORAM/01/05/167
[47] Cook, M. 2013
[48] Oram 2007, ORAM/02/003 on a page dated Feb 20th 1988

is difficult to assess whether these missing documents were exactly the same as the early research notes present in the Oram Archive.

In examining the archives outlined above as well as some more general histories of electronic music, the research has led to various contemporaneous resources, many of which Oram herself referred to in her correspondence, writings, and notes. Two sources of particular interest are *Electronic Music Review* and the catalogue for the ICA's *Cybernetic Serendipity* exhibition. These resources in particular, simultaneously examined new technological developments as well as critically examining trends in EM composition and computer music, and contain writings by a wide variety of Oram's peers. It is documented that Oram read them and commented on what she found, and hence these sources have become vital resources in the contextualisation of Oram's work and broader motivations.

Hugh Davies and Associated Archives

Hugh Davies (1943-2005) and Daphne Oram were initially acquainted when Davies wrote to Oram regarding his interest in electronic and experimental music whilst he was still a music student at Oxford University in the mid 1960s[49]. Soon afterwards they met in person at Oram's studio. They remained in touch for the rest of Oram's lifetime, and after she passed away in 2003, Davies assisted Martin Cook (Oram's friend and heir) with sorting through and organising her archive and personal effects. After Davies died in 2005, Oram's archive was passed to the *Sonic Arts Network* (which was later assimilated into *Sound and Music*), and then to Goldsmiths Library Special Collections.

Davies was a key figure in electronic and electro-acoustic music in the latter half of the 20th century. Like Oram he was a prolific musician, researcher, teacher, and musical instrument designer/builder. Soon after graduating he became Stockhausen's assistant[50] and was instrumental in the production of several of Stockhausen's works. Shortly afterwards Davies compiled the seminal *Repertoire International de Music Electroacoustiques* (RIME), an exhaustive catalogue of electronic music works and associated studios which was published in *Electronic Music Review* Vol. 2 in 1967, a collaboration between Moog Music and MIT press. He was a key member of the experimental group Gentle Fire. He was the founder of the Goldsmiths College Electronics Music Studios, and later became a lecturer in Sonic Arts at Middlesex University.

Davies wrote the definition of *Drawn Sound* in the *Groves Dictionary of Musical Instruments*[51] where he succinctly traced the concepts and technologies employed, from early optical sound experiments based on film technology, through to Oramics and beyond.

Like Daphne Oram, Davies' contribution to the field has recently started to be re-evaluated, and contextualised: primarily by Dr S.F. Palermo at Middlesex University (a former student of Davies) who recently completed his PhD thesis[52] on Davies work, and

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49 Oram 2007, ORAM 01/02/050
50 Oram 2007, ORAM 01/02/050
51 Sadie, S. ed. 1984
52 Palermo, S.F. 2015

Dr J. Mooney at Leeds University, who has published several papers, as well as organising a symposium and concert series.

Davies position on electronic and electro-acoustic music is not easy to synopsise, due to his prolific and diverse output and research interests. His musical output and instrument designs were inextricably linked and, generally speaking, could be characterised as improvised in nature. He often utilised household objects, which were combined with contact microphones and magnetic pick-ups to create new amplified sonic palettes, and the potential for new forms of live improvisation.

Davies' archive, for the last few years has been divided between two collections. The first is held at the Science Museum, and consists mainly of electronic equipment and computers, as well as some hand-made electronic instruments/sound processors. The second is in the British Library, where Davies' collection of recordings as well as some papers and correspondence are kept. More recently, (early 2017) a further collection of Davies' instruments, books, catalogues and ephemera was donated by his widow, Pam Davies, to Goldsmiths, University of London. The author of this thesis was to an extent involved in the initial review of this material, which is currently in the process of being accessioned. This newly gifted collection promises to be at least as valuable as the other archives, and probably more so, given that many pristine and working examples of Davies' electro-acoustic instruments are present. It also appears that, as Davies was in possession of the Oram Archive at the time of his death, some of the papers in this new collection may have originally belonged to Oram or may have been gifted to Davies before Oram's death. This new material was donated too late to contribute to this particular PhD thesis, and is not yet available for examination at the time of writing.

Overall, Davies' archives are a rich resource for the researcher of electronic and experimental music and art, and will become more so as the new material becomes more accessible. In terms of this thesis, Oram's correspondence with Davies, kept at the British Library is the most pertinent, and can help to illustrate Oram's aspirations and frustrations during the long process of creating the Oramics Machine. This material was mostly explored through discussions with Dr Palermo, regarding his exploration of the Oram/Davies relationship, and in fact the Douglas Lilburn and Calouste Gulbenkian Foundation (CGF) correspondence was found to be illustrative of very similar concerns in this regard.

The Davies Archive within Science Museum collection was examined to see if any of the electronic or computer equipment held had in fact belonged to Oram. These visits were with the specific purpose of ascertaining if Oram's Apple 2 computer or her associated custom made computer audio-interface (see Fig. 47 in Further Research), or a lost Mini Oramics prototype, had survived and been mixed up with Davies equipment. It turned out not to be so, and unfortunately these items have not been located in the process of this research.

An Individual Note of Music, Sound and Electronics

Oram's own book[53] *An Individual Note of Music, Sound and Electronics* provides insight into her philosophy of sound and the human condition more generally, but in fact in this work Oram deliberately pulls her punches, leaving her reader to examine and evaluate for themselves the long list of readings and musical recordings referred to in her book.

> Perhaps the works that I have listed in the Appendix may help you to embark on an individual exploration. I do not wish to impose upon you any preconceived ideas of what you must hear or how you should listen, so I prefer to leave the exploration to your personal whim ... merely use my suggestions if you feel you must have some guidance.[54]

Her personal opinions of rival technologies and musical approaches are more frankly expressed in her private correspondence, some of the best examples of which are to be found in her airmail exchanges with the New Zealand composer Douglas Lilburn[55].

Oram's book of course outlines her work with the Oramics Machine and an introduction to musical electronics more generally. However the level of detail given in either case does not really illuminate the detailed workings of the Oramics Machine to the reader, nor allow one to gauge the sophistication of Oram's command of electronics (although it amply demonstrates that she had a firm grasp of musical physics). It is evident of course that she understands the basics of analogue electronics, but in fact where circuits are drawn or described, it is often as an analogy of aspects of the human mind or body rather than as a practicable example.

Chapter 11 of Oram's book[56] provides a design brief for the Oramics Machine, where in layman's terms she sets out the reasoning behind her design, and also, how she sees it as a more immediate and expressive interface than some alternatives; especially the mathematical approaches of additive and subtractive synthesis which at that time were strongly associated with *Elektronische Musik* and the Cologne school of electronic

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[53] Oram, D. 1972
[54] Oram, D. 1972, P110
[55] Oram 2007, ORAM/09/04/064
[56] Oram, D. 1972, P131

composition. Earlier on in the book she articulates the challenges of using computers for sound generation and makes convincing arguments:

> No wonder composers of digital computer music have had some qualms when faced with the problem of controlling the quality of the sound. 20,000 numbers to specify every second! How does the poor composer know which are the right numbers for a particular sound? Well he is gradually discovering methods of defining the necessary digits. . . but he now runs up against another problem. Generating music from a computer takes time, and time is money. He may easily take 20 computer hours to produce one minute of sound. As the average cost of computer time for this work is approximately £100 per hour, the composer needs to be a rich man or to be financed by a rich institution!
> Building fascinating timbres and intricately moulding individual notes, with a digital computer, needs so much time and money that few can attempt it. The composer usually finds that it is more realistic to devise computer programs which concentrate on the control of pitch, volume and duration, and just make use of the ordinary electronic timbres such as sinewave, squarewave, white noise) which the studio oscillators and generators provide.[57]

Of course these critiques, and this Oramics design brief were written after the construction of the Oramics Machine, so can be read as a defence of her research and practice, rather than a proposal for it. However the book was written just as Oram was starting to develop Mini Oramics, and to that end can be deemed relevant to the practice-based element of this thesis, illustrating Oram's public facing attitudes to her research, and that of her contemporaries, as she set out to re-invent her interface.

An Individual Note is a vibrant, diverse, and overwhelmingly enthusiastic illustration of the depth and breadth of Oram's research and interests as well as her personality, but within the specific remit of this particular thesis it is a somewhat limited resource, perhaps most useful as a milestone, illustrating what she knew by 1972. For instance she makes brief reference to Murzin's ANS Synthesiser[58], a technology in which the design principles are not too far removed from her own. When trying to determine *Precedents, Technology and Influence* however, knowing what Oram was aware of is more useful if we can also date when she became aware of it, and in that regard, again, going back to the archive and a more empirical approach is of more value.

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57 Oram, D. 1972, P89
58 Oram, D. 1972, P109

The literature and resources briefly outlined above, when examined in combination, can certainly add significantly to the existing understanding of Oram's work with drawn sound technology. Recent literature on Oram and her works has drawn heavily on anecdotal evidence, mainly from Oram's own accounts, and to some extent from some of her colleagues and friends. A more empirical approach can certainly help correct some inaccuracies and misconceptions about Oram and her work, as well as adding significantly more detail about the specific technicalities of her machine. There are however, still knowledge gaps to be filled in which perhaps lie outside the potential of these sources alone, and one enormous resource yet to be examined in any detail until this research project is the Oramics Machine itself.

The Oramics Machine as a Research Resource

For this project, the author was given privileged access to the Oramics Machine, both whilst it was exhibited at the Science Museum and afterwards. This level of access allowed the temporary removal of certain parts, and the use of tools such as a multimeter to be employed, whilst under the supervision of a conservator. Unfortunately, due to its aging components, and the presence of some asbestos parts, it was not possible to try and switch any part of the machine on or test any circuits using an electrical supply.

Initial examinations of the Oramics Machine raised a number of questions and alternative possibilities to the existing understanding of its operational principles, especially with regard to the operation of its analogue tracks (timbre mix, reverberation and vibrato controls). Oram herself often stated that it was a perpetually evolving entity, and close examination bears this out.

It would be easy to assume that the machine could only provide evidence pertaining to how it operated in its final state. Yet, it has become apparent that in the course of its many adaptations and modifications, much was added but very little taken away, and various seemingly redundant electronic and mechanical elements are still present, which have allowed the examination of various stages in its evolution.

The process of cross referencing the machine with Oram's dated log books and personal notes has enabled a much more detailed description of its optical, digital and analogue features, and a more accurate timeline of its evolutionary stages. This has in turn facilitated a much more complete contextual and comparative survey of the technology.

There is one aspect in which the empirical study of the Oramics Machine cannot help us with. One of the major difficulties this study presents is that there are very few people who are still alive and have experienced the Oramics Machine operating first hand. The memories of the few people with direct experience of Oram demonstrating the machine are somewhat imprecise and this is not surprising given that it has not been operational since the late 1970s[59] and in accordance with the Science Museum's conservation policy it unfortunately will never run again. This is due to the high proportion of components that would need to be replaced with modern alternatives; it would effectively have to be re-built.

We are able to hear some of its sonic output thanks to the tape archives held at Goldsmiths, however we will never be able to assess the Oramics Machine by using it. It is for this reason that, in addition to the close study of the existing machine, central to the practice based element of this PhD research project is the construction of a hardware version of *Mini Oramics*. While not the same as having the Oramics Machine operational again, it has allowed this researcher to make comparative evaluations, to gain understanding of what it is like to compose music in this fashion, as well as gaining real experience of some of the technical challenges Oram faced in the process of constructing such a device.

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[59] Peter Manning, John Emmett and Carolyn Scales have all described their impressions of the operational Oramics machine in the course of this project. Attempts were made to speak to the composer Thea Musgrave with regard to her collaborations with Daphne Oram, unfortunately this meeting never came to pass. Graham Wrench's memories are also somewhat uncertain and pertain only to an early prototype of the Oramics Machine.

RESEARCH QUESTIONS

Main Questions:

- How did the Oramics Machine function, and to what extent did it fulfil Oram's own brief?
- How did the Oramics Machine evolve over time, and which changes were implemented to miniaturise and commercialise the concept with Mini Oramics? Which of these changes were pragmatic and which conceptual?
- What factors prevented Daphne Oram from bringing Mini-Oramics to market?
- Had Mini-Oramics been launched commercially with the right timing and financial backing, how might it have fared compared to rival products?[60]

Background Questions:

- How did her responses to her contemporaries and the musical/technological fashions of the time influence her decisions and the above outcomes?
- How did Oram's technical ability and her reliance on others affect these outcomes?
- How did Oram's departure from the BBC influence these outcomes?
- How did Oram's interpersonal style affect these outcomes?
- In what ways were Oram's competitors ahead or behind at key points in EM history?
- How did UK cultural policy influence these outcomes?
- How did the aesthetics and functionality of the existing Oramics Machine affect these outcomes?

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[60] Any conclusions given in regard to this question of course will only be conjecture. It is effectively unanswerable. Yet it is still hoped that, whilst the information to be derived from analysis of the Oramics Machine and relevant archival material should justify a contribution to knowledge, attempting a response to this *unanswerable question* will still add to the texture of written EM history and give rise to further debate, discussion and perhaps further research.

CHAPTER 2: THE EARLY DEVELOPMENT OF THE ORAMICS CONCEPT

Early Conceptions

> If you are curious to know what such a machine could do that the orchestra with its man-powered instruments cannot do, I shall try briefly to tell you: whatever I write, whatever my message, it will reach the listener unadulterated by "interpretation." it will work something like this: after a composer has set down his score on paper by means of a new graphic notation, he will then, with the collaboration of a sound engineer, transfer the score directly to this electric machine. After that, anyone will be able to press a button to release the music exactly as the composer wrote it - exactly like opening a book.
>
> Edgard Varèse 1939[61]

Much of what has been written about the Oramics Machine's early influences can be attributed directly to an autobiographical article Oram wrote for *The Composer* in 1962[62]. The foundations of Oram's interest in electronic music as told, are mainly concerned with quotes from Kurt London and Leopold Stowkowski,[63] both of which have much in common with the seminal writings of Varèse from the 1930s.

Another common anecdote derived from an interview Oram gave in 1983[64], concerns the occasion of a BBC technical training course at their facilities in Evesham, where she first conceived the 'reversed oscilloscope' principle of waveform generation. On seeing the waveforms of sound from a microphone displayed on an oscilloscope, Oram enquired as to whether the process might be reversed, thus planting the seeds in her own mind of the drawn sound principle she went on to make her life's work. This has all been covered before and there appears to be scant empirical evidence to further support or comment upon this formative experience in regard to the inspiration for the Oramics Machine. For the purposes of this thesis it is necessary to examine more closely the

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[61] Varèse, E. 1936-1962.
[62] Oram, D. 1962.
[63] Both are referred to in Wilson, D. 2011 and Hutton, J. 2003.
[64] Oram 2007, ORAM/09/006. Interview notes for Oram's interview by Roy Curtis Bramwell whilst he was researching the book, *The BBC Radiophonic Workshop: the First 25 Years,* which he co-wrote with Oram's former colleague Desmond Briscoe.

notes and correspondence held in the Daphne Oram archive, bringing in other relevant material where it is justified.

Most of Oram's drawn-sound research and development notes in the archive date from rather later than 1944 (when she was aged just 18), when she states she first read Kurt London and Leopold Stowkowski. By the mid to late 1950s however, it is clear that Oram had started to grasp some of the technical challenges of her drawn sound concept. In a file Oram herself labelled *Oramics - Early Conceptions*,[65] there is a wealth of notes, drawings and correspondence pertaining to her earliest ideas for drawn-sound technique.

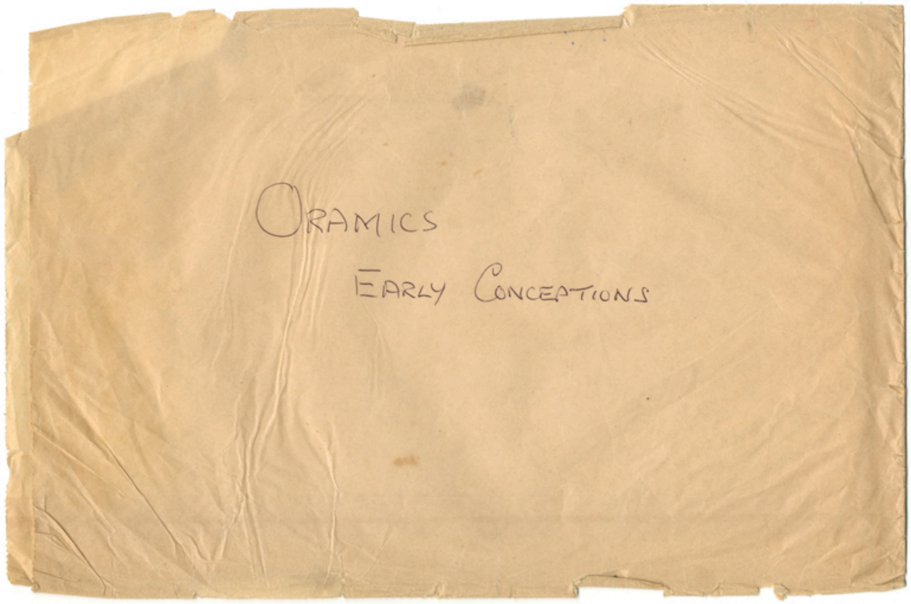

Fig. 7: Manila envelope in which Oram filed her earliest ideas on drawn sound. Oram 2007, ORAM/01/01/001

Perhaps slightly at odds with Oram's Evesham anecdote, her initial ideas and designs did not involve the CRT wave scanning technique, which was eventually to form the core of the Oramics sound generation apparatus. Some of her ideas did not involve an optical sound generation system at all, although in all of her early ideas, some kind of system to incorporate drawn parameters in the process of sound production was included. It is unclear whether Oram kept the idea of the CRT scanning oscillator in the back of her mind, whilst keeping things within her own technical capabilities in the initial research phase of Oramics, or whether she was somewhat embellishing her own

[65] Oram 2007, ORAM/01/01 Oramics Early Conceptions

history with the later anecdote. In either case, the earliest explicit, dated and contemporaneous reference to a CRT scanning oscillator present in the relevant Oram archive files, is from her first annual progress report to the Calouste Gulbenkian Foundation in April 1963[66], although there are also some undated photographs of an experimental CRT scanning oscillator[67] on the billiard table at Tower Folly, which may well date from slightly before this according to Carolyn Scales and Alan Sutcliffe[68].

Peter Manning of Durham University has written the most detailed account of the development of the Oramics Machine available to date[69]. In his paper he refers to many of the same archival resources, and has already to an extent, covered much of the material in this chapter. The account in this thesis differs in emphasis to Manning's however, in taking a somewhat more forensic and technically analytical approach, as well as interrogating further Oram's contemporaneous resources, with an emphasis on when, and what she knew about relevant developments in electronic music technique. In terms of Oramics precedents, it concentrates on those deemed the most pertinent as a result of this body of research: specifically those that are demonstrably an influence to Daphne Oram as she developed her unique graphical music machine.

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[66] Oram 2007, ORAM/01/02/030

[67] Oram 2007, ORAM/07/04/053 and ORAM/07/04/061 See Fig. 16, P. 94

[68] Scales, C. 2012, and Alan Sutcliffe in a private conversation with Tim Boon 2011

[69] Manning, P. 2012

Oram's Early Ideas for Drawn Sound

Oram's early ideas for a drawn wave oscillator; the sound producing part of her conceived electronic music production system, can be divided into two types. Firstly, those that adapt tape technology to generate audio frequency signals and secondly, those using varying light levels in conjunction with photoelectric cells to similar end. In both instances mechanical means were proposed to create the necessary movement in pitch/time, and it should become clear to anyone with a reasonable grasp of physics, that her initial proposed techniques had some innate drawbacks, which go a long way to explain why they were not subsequently adopted in the Oramics Machine. Although all the principles Oram proposed for the generation of oscillations are fundamentally sound[70], in both cases her designs rely in the changing speed of an electric motor or gear mechanism to control the pitch of the oscillations. Apart from the difficulties associated with controlling the speed of a motor reliably and accurately enough to create precise musical intervals, using the speed of a spinning object to control pitch in this manner would have been limited to a finite rate of change; restricted by the forces of momentum and inertia. This would have created an inherent and unwanted glissando (pitch slide) effect when moving between musical notes.

[70] In the case of one proposed optical scanning technique, unknown to Oram, the principle had already been successfully demonstrated by E.G. Richardson in 1940. See Manning, P. 2012, P139

Oram's Tape Based Drawn-Sound Technique

Having developed considerable expertise in the manipulation of quarter inch tape in the course of her duties (and beyond) at the BBC, it follows that one of Oram's early ideas for a drawn sound technique proposed utilising the same medium. Oram devised a method whereby the user would draw a waveform by hand on paper, and then trace this outline with an adapted slide potentiometer, thereby creating slowly varying voltages. This slow AC signal would then be recorded onto a rotating drum of tape. The whole course of the wave-tracing process was to take place in exactly one revolution of the tape drum (presumably a mechanical system could have been implemented to ensure that one 'reading' of the drawn waveform would spin the drum once).

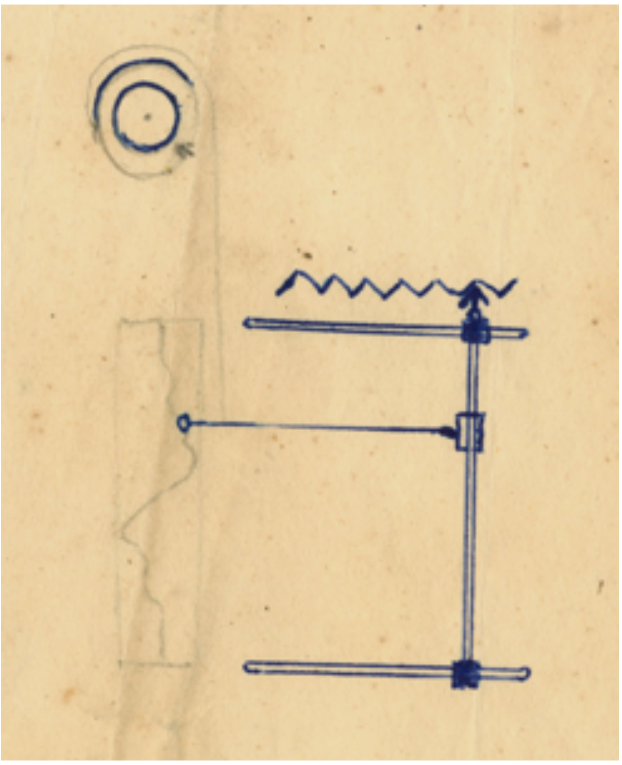


Fig. 8: Detail of a drawing by Daphne Oram, showing the transfer of a freehand drawn waveform to a potentiometer, to record varying voltages on a revolving drum of tape. Oram 2007, ORAM/01/01/002

Once a waveform had been transferred, the drum would have been spun at constant speed using an electric motor. When a playback head was then applied, the repeated waveform would have been detected and output as a tone, keeping the drawn contours of the wave-shape and offering different overtone structures depending on the drawn waveform.

Oram suggested that multiple parallel waveform recordings could be stored on one rotating drum, and that multiple playback heads could be used to access multiple wave-shapes. Her notes also indicate another possibility afforded to the user, whereby moving the different playback heads to varying positions around the axis of the rotating drum, would enable different phase relationships to be achieved when the different timbres were eventually combined.

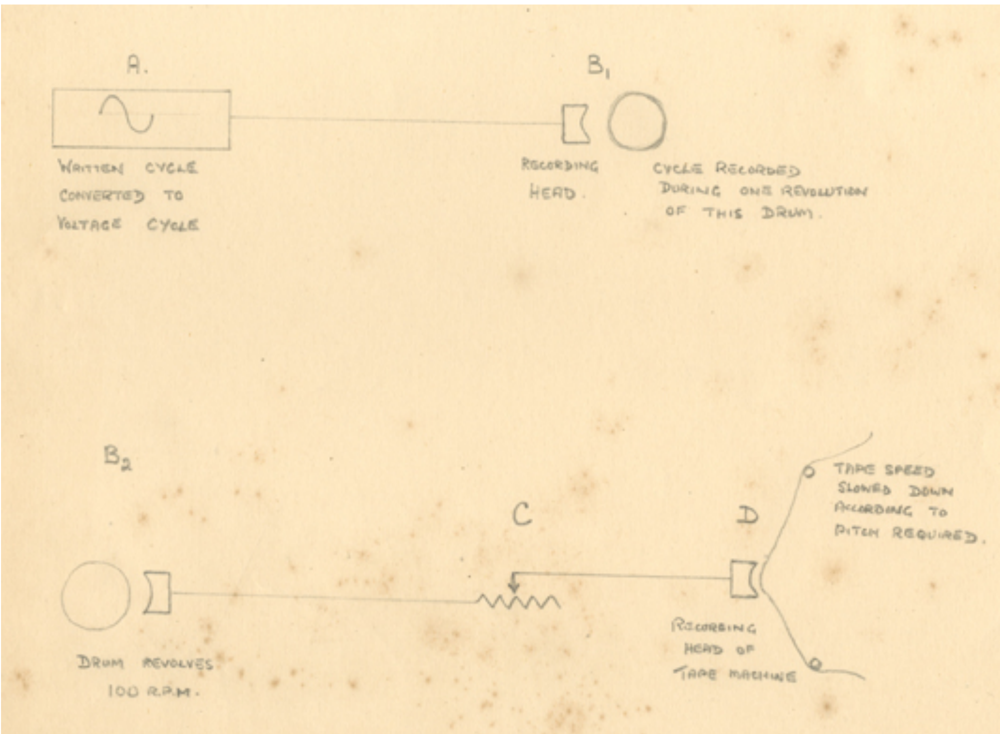


Fig. 9: Drawing by Daphne Oram describing how a revolving drum of tape could be used to construct pitched sequences of music. Oram 2007, ORAM/01/01/012

The next stage in Oram's tape based drawn sound scheme was to
re-record the sound from the tape drum onto an ordinary spool of tape, controlling the eventual pitch by adjusting the running speed of the tape machine. This would have required an inversed relationship between the desired pitch and the recording speed – slower for high pitches and faster for low pitches. Once the recording had been accomplished, and when played back at constant speed, the changes in pitch would form a line of musical melody.

The recording tape machine in this instance would have been specially modified to accommodate the quick, accurate and wide ranging speed changes necessary. Oram devised a mechanical system[71] to drive the capstan of said machine, where a platter spinning at constant speed would be contacted at varying (hand adjustable) radial distances by a 'cog wheel', whereupon the axle of the wheel would rotate at a speed proportional to its radial distance from the centre of the spinning platter. This axle would then drive the capstan of the recording tape machine. Accompanying this set of plans, are tables of Oram's calculations of rotational speeds and audio frequencies – using a given tape drum speed of 100rpm.

[71] Described at Oram 2007, ORAM/01/01/13 and ORAM/01/01/14

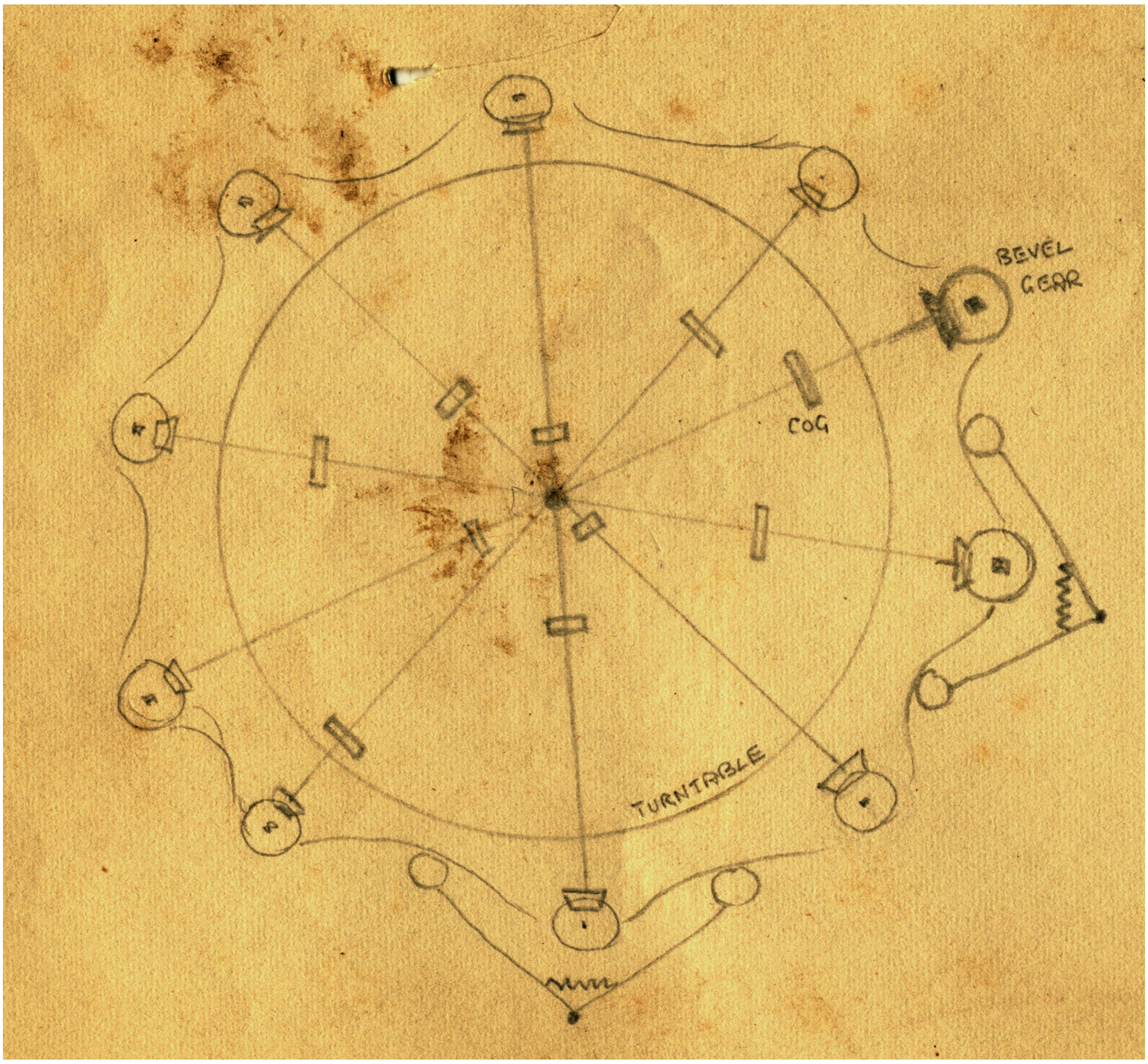


Fig. 10a: Daphne Oram's diagram for a radial tape-drive system (detail).
Oram 2007, ORAM/01/01/10

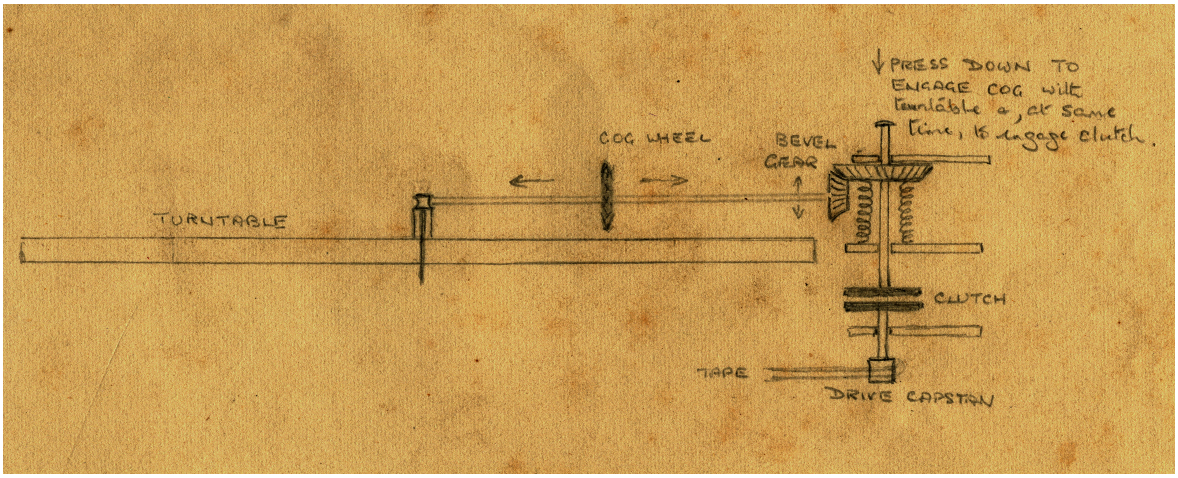


Fig. 10b: Daphne Oram's diagram for a radial tape-drive system (detail).
Oram 2007, ORAM/01/01/10

Oram's diagram of the tape drive system (Fig. 10) included multiple drives from the platter, and also a clutch system to ensure the capstan would only turn when the correct frequency was selected, by moving the contacting wheel to the correct position on the platter. This is suggestive of a stop/start approach to making compositions: select the note, then record the note, stop, and repeat.

This system, in addition to being subject to the issues of inertia/momentum described above would also have been subject to another mechanical problem: that of the varying load on the main drive platter. However accurately the platter was calibrated, the load on it would vary with the number of contacting wheels and their relative distances to the centre, hence it would have been very difficult to keep multiple lines of melody in tune. The system also appears to be incomplete in that there is no prescribed method for timing the notes, which, as described previously would need to vary according to the desired pitch as well as intended duration, hence the laborious consultation of tables would be required to determine the recording time of each note.

It appears very likely that either Oram realised the innate flaws in this system, or that they were pointed out to her by a colleague at an early stage, as work on this design is less complete than her early work on an optical system to create sound from drawn symbols. Although many of the documents and plans in Oram's 'Early Conceptions' file are undated, it is very likely that the tape-based system was dropped in favour of an optical system; the plans for which are much more complete and arguably more practicable than those of the tape- based approach. In the case of the tape-based system, she appears to refer to it in a letter to Dr Alexander (BBC R&D dept.), dated 23rd Jan 1956[72] and this is the best indication of a date for this early design.

[72] Oram 2007, ORAM/01/01/003 and ORAM/01/01/004

Oram's First Optical Drawn-Sound Techniques

The next phase of Oram's research and development took her ideas much closer to what eventually would become the Oramics Machine. She proposed two similar optical wave-scanning devices illustrated below:

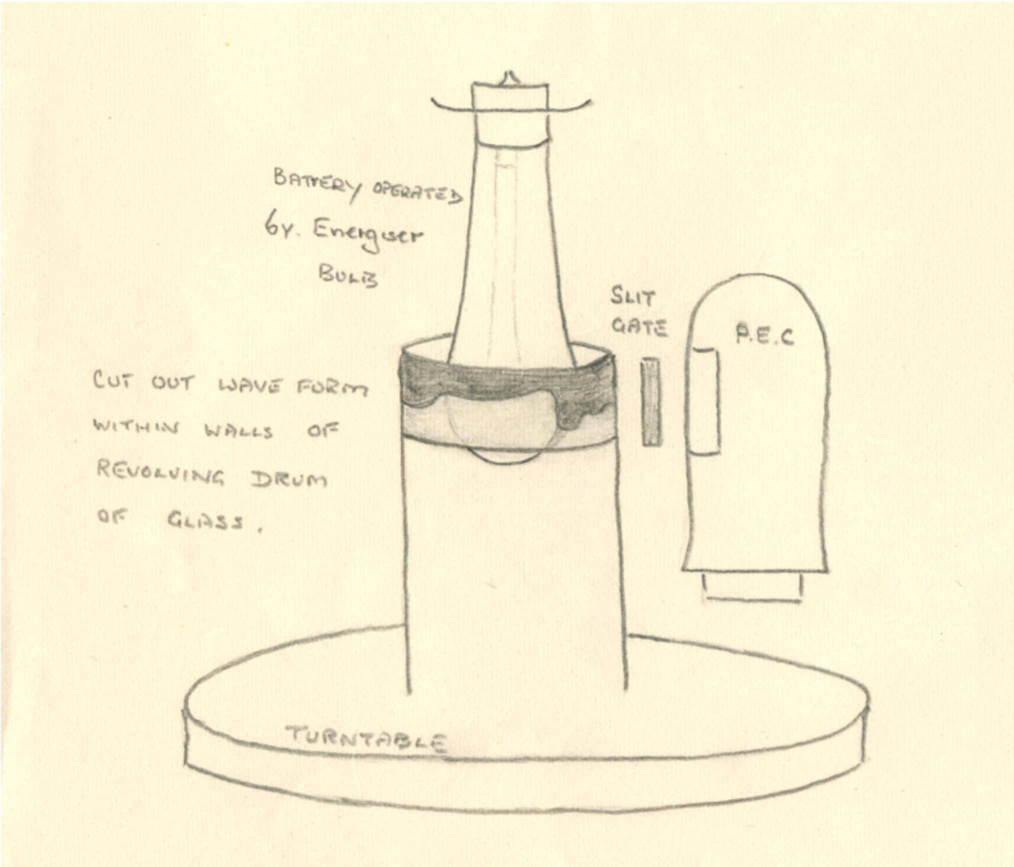


Fig. 11a: Oram's design for two optical wave-scanning oscillators (detail). Signed and dated April 1957. Oram 2007, ORAM01/01/009

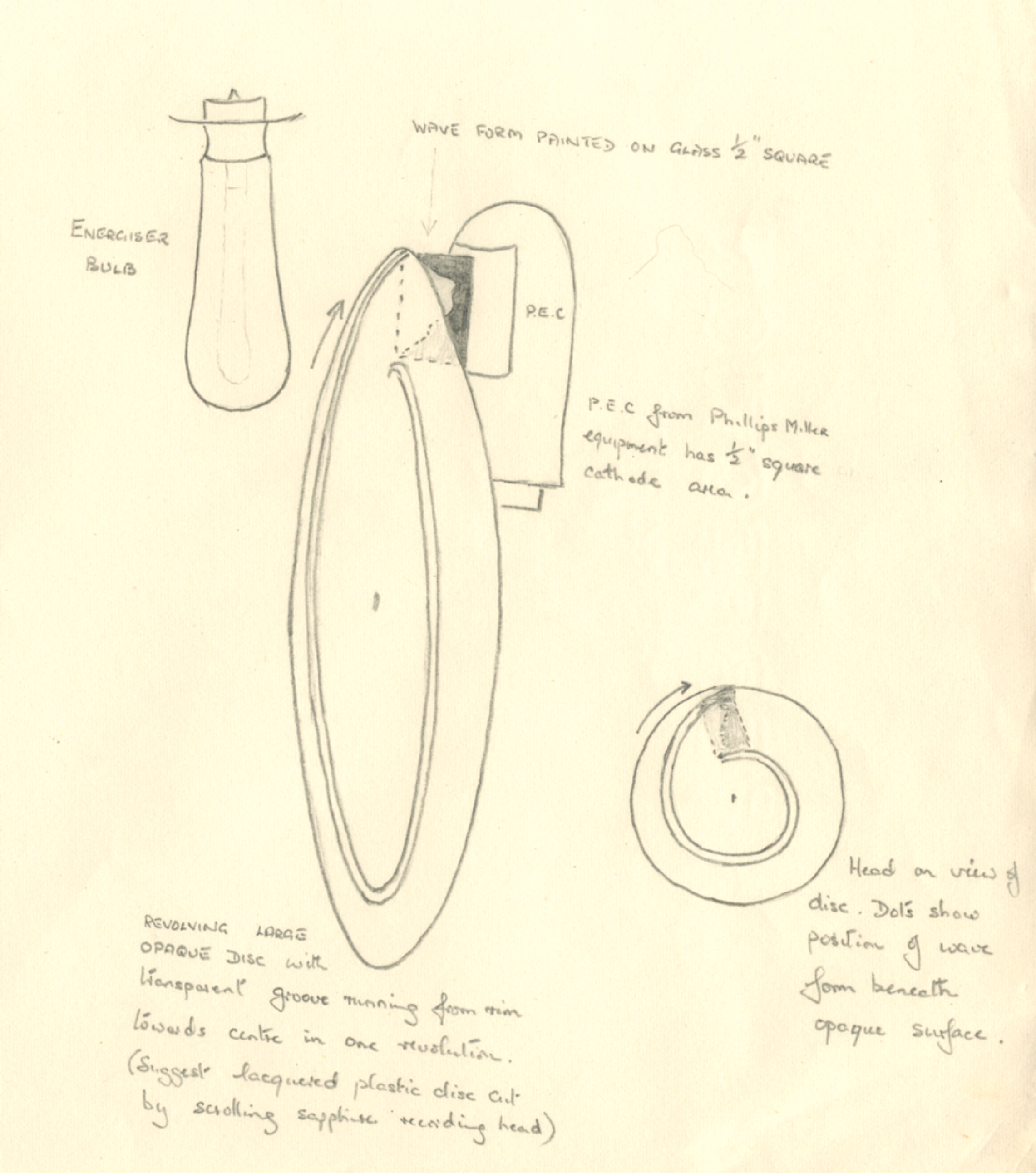


Fig. 11b: Oram's design for two optical wave-scanning oscillators (detail). Signed and dated April 1957.
Oram 2007, ORAM01/01/009

The proposed operational principles are evident from the drawings. Fig.11a shows a waveform drawn onto a clear cylinder, with an electric light bulb inside. The cylinder was to be rotated at speed. Mounted next to the cylinder, a photoelectric cell was to detect the varying light levels through a narrow slot, and convert these levels into varying voltage levels, reading the waveform as it rotated, and outputting an electrical signal analogous to the drawn waveform.

Fig. 11b shows a similar system, where a waveform drawn on a flat glass slide is repetitively scanned by a rotating spiral form, on an otherwise opaque spinning disc. The moving intersection of the clear parts of the waveform and the clear spiral were to create similarly varying light intensities; again to be converted to an analogous electrical signal using a photo-electric cell (PEC), which again was to be energised with an electric light bulb.

In both cases the pitch was to be controlled by electronically varying the speed of the scanning drive motor.

It was at this point that Oram's proposed optical music composition system surpassed that of her earlier tape based system. After settling on the spiral slit-based scanning device, she went on to add features for the control of timbre mix, dynamics and reverberation.

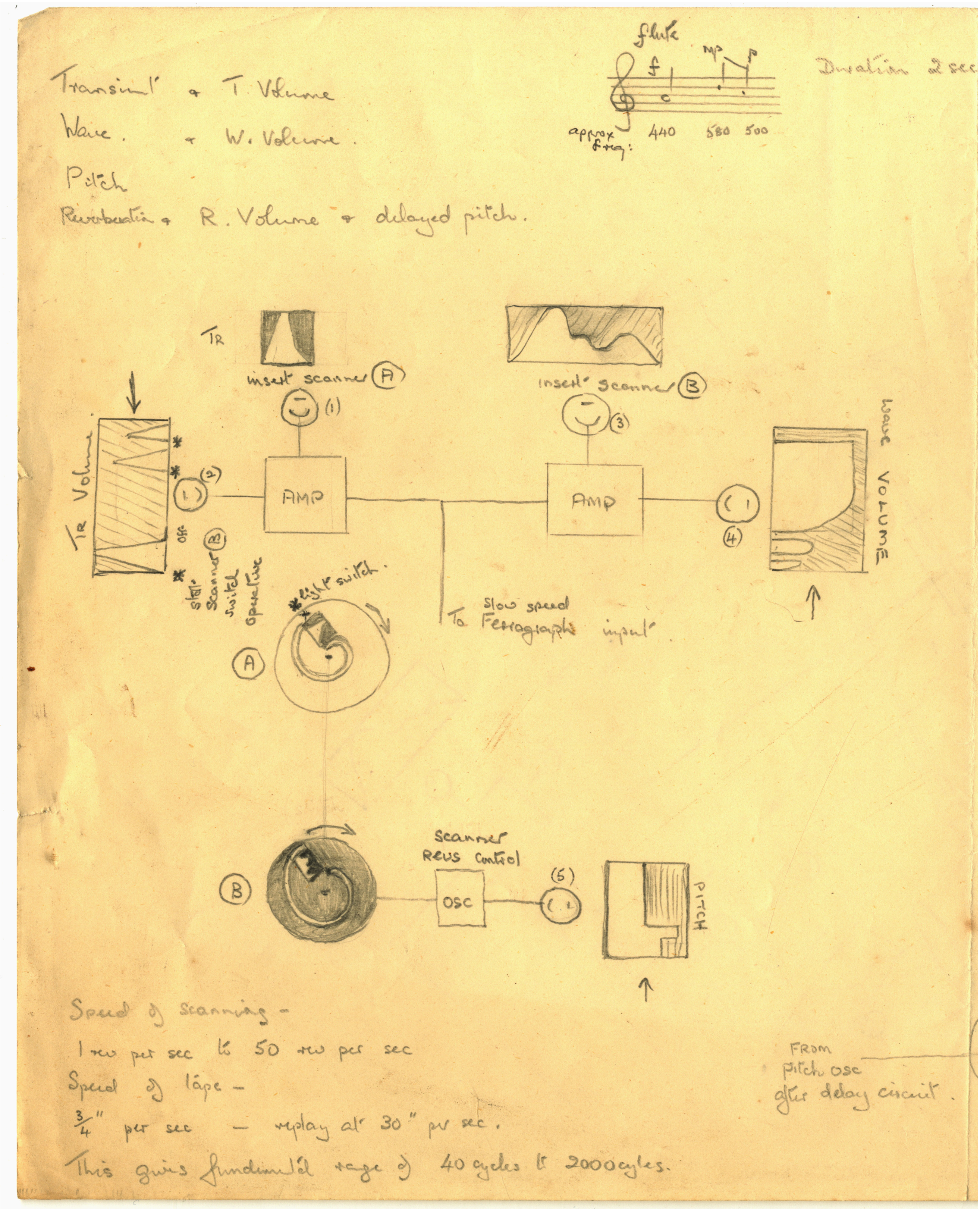
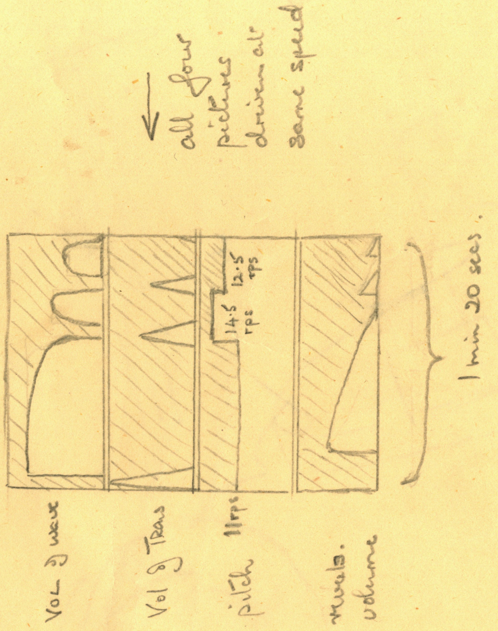
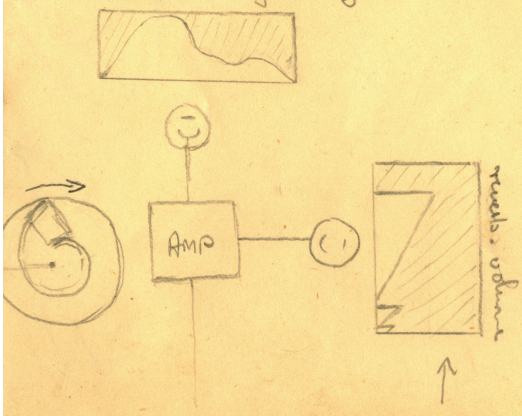


Fig. 12: Design by Daphne Oram, illustrating the overall system she envisaged for the production of music using drawn sound, circa 1957. Oram 2007, ORAM01/01/011



Reverberation-modified original wave.



Oscillator could increase speed of scanner 1 to $6\frac{1}{4}$ while decreasing tape speed from $\frac{3}{4}$ to $\frac{3}{32}$ & this would give same range. (No use with reverberation delay circuit)

In Fig. 12 we are able to see for the first time, evidence of the moving analogue control films that Oram would eventually utilise on the Oramics Machine. In the design, she breaks down a three note phrase for flute into elements of drawn sound: wave volume, transient volume, pitch and reverberation, with the intention of composing by constructing the musical parameters (other than the initial waveform or timbre) graphically on moving film, detecting the masked areas using a similar light bulb/PEC set-up.

At an unknown date in the process of drawing up these plans, Oram outlined her ideas to Alec Nisbett, a fellow BBC studio manager who went on to produce *Horizon,* the BBC's flagship science and discovery programme for many years. It is unclear exactly which notes and diagrams Oram showed to Nisbett, but his written reply,[73] kept by Oram, and now held in the archive, is illuminating but also somewhat confusing:

> My earliest idea on this subject was that if a steady note and harmonics (i.e. a timbre) could be provided by scanning a simple waveform repeatedly, the idea could be extended to other devices for dynamic control, etc, so that the volume of the scanned timbre can be varied in a predetermined way. Each sound to be produced has however, for the greater flexibility, to be provided with a transient, and with means for decay colouration, and also frequency vibrato. And each of these needs some means of control.

In his reply simply dated 'April 1957' Nisbett goes on to describe different possible control options including moving film, multi-track tape, and single track tape of which multiple carrier frequencies are employed to control different parameters. He also finishes the note with his opinion that a manual form of pitch control would be preferable to pre-programmed pitch parameters recorded in the same way as other parameters. A quote from this reply follows on the next page.

[73] Oram 2007, ORAM/01/01/006

> I am rather doubtful of the value of controlling pitch by means of this or any other system of a similar nature. As the projected rate of construction of complex sounds is 1/50th the replay rate, and we are dealing in terms of one row of notes at a time, I think there would be no difficulty in controlling them manually; whereas it would be very difficult to construct a sufficiently accurate device of the type shown in the schematic diagram – Alec Nisbett

The note is a conundrum, in that it refers to a diagram (presumably of Oram's) which must have already had a graphical pitch control element included (such as Fig. 12), as he explicitly refers to it, and quite justly critiques it as impracticable[74]. However it also strongly implies that the ideas of including automated parameter controls for transient waveform, vibrato, and decay colouration were conceived by Nisbett himself. It seems most likely that this exchange happened somewhere in the time between Oram producing the designs of Fig. 11 and Fig. 12, in which case it is possible Nisbett's input had a material influence on Oram's later design (Fig. 12). The fact she kept his reply for many years in her 'early conceptions' folder may also signify that Nisbett's thoughts on her early drawn sound designs were of some importance to her. However, a document[75] Oram sent to Mr Porter and Mr Garrard, her BBC superiors[76] on the 4th April 1957, included explicit reference to very similar parameterised graphical controls and this document was most likely sent with the optical scanning oscillator designs (Fig. 11) of the same date. The following extract from the document illustrates that Oram had already envisaged using a total of four parameters to enable the composition of single lines of melody using multiple waveforms:

> […] A modified form of the timbre wave (probably the higher harmonics altered somewhat) is scanned in the same way as timbre and transient waves except that pitch variations are somewhat delayed. Dynamics given by the colouration & decay dynamic control P.E.C. are probably similar to the timbre dynamic control except they are delayed and uniformly reduced.
>
> All dynamic control films and the pitch control film move past their slits at the same speed. Those illustrated would take one minute and twenty

[74] Also described in Manning, P. 2012, P141
[75] Oram 2007, ORAM/01/01/008
[76] Mr Porter was Asst. Head of Central Programme Operations, and Mr Garrard was Organiser of Studio Operations.

> seconds. The speed of the ferrograph tape would be 3/4''per sec if replay could be 30'' per sec; 3/8'' per sec if replay at 15'' per sec.
>
> [signed] Daphne B Oram [dated] 4.4.57

The parameters Oram proposed to control with moving film are essentially three different waveforms of the same fundamental frequency, each drawn differently to extrapolate differing overtones (referred to by Oram as: timbre, transient, and decay colouration), plus accommodation for programmed changes in pitch. The document also states her intention to record the oscillations from the wave scanners onto tape at a rate of 1/40th the eventual replay speed. This difference in recording and playback speed (referred to slightly differently as 1/50th replay rate in Nisbett's notes) mean that the recording would also take place at 1/40th the frequency of the eventual work. This fact dispels a misconception about Oram's proposed technique:

> '[…] It is scanned according to the pitch required at a speed between 1 rev per sec and 50 revs per sec. This gives a range of the fundamental between 40 cycles per sec and 2000 cycles per sec' (Oram 2007: 1.2.004). It can be deduced from these specifications that forty complete cycles of the waveform had to be coded for each revolution, a challenging prospect in terms of drawing the functions entirely by hand.[77]

Here Manning quotes Oram, but takes a leap too far in his subsequent deductions. Oram never intended to draw each waveform forty times per cycle, she merely intended to speed the eventual recording up by forty times. Why Oram chose to slow down the recording process to this extent might seem unclear; perhaps to enable greater accuracy when determining the relative timings of events, or to be able to codify much shorter notes beyond the fingering skills of acoustic musicians? Her motivation for this decision seems more likely to be to compensate for the upper speeds available on an electric motor. If we take her upper figure of 50 revolutions per second we get a pretty realistic 3000 RPM as the upper motor speed. This rotational speed is much more feasible than that of a one to one ratio system, eventually requiring a fairly fantastical upper motor speed of 120000 RPM, even to maintain a quite limited 2000Hz audio bandwidth (not taking into account inherent drawn overtones which would enable significantly higher pitches to be reached). So, arguably Oram's decision to slow down the recording of tone

[77] Manning, P. 2012, P140

to tape by a factor of forty was to *avoid* having to draw forty identical waveforms per oscillator.

Her proposed system might seem an arduous prospect in today's terms, but in fact, a forty to one ratio of construction against playback time would have been positively quick, when compared to achieving equivalent musical constructions of combined waveforms using 'traditional' tape splicing techniques.

Oram's Early Designs in Context

In summation of Oram's early drawn sound schemes, though they are not without technical flaws as outlined above, it is evident that by the latter part of her time at the BBC, she had progressed her designs to a point where the construction of a prototype seemed within reach.

Oram was singularly determined to pursue new research in electronic music in the framework of her ideas for drawn sound. She also discussed her work with colleagues, and took their advice where it fitted with her individual agenda. Oram herself gives particular mention to a Dr Alexander in the BBC R&D team for having been helpful and supportive of her ambitions.[78] In addition to Alec Nisbett's contribution which has already been mentioned, Oram also sought information outside of the BBC, having (with her colleagues Alec Nisbett and Madeau Stewart) had some discussion and visitation with a Dr W. H. George, professor of Physics at Chelsea Polytechnic[79] regarding the photography and subsequent analysis of sound waves using oscilloscopes.

Accurately attributing credit for influence on her ideas in this period is difficult, and is perhaps unlikely to ever be more much more than conjecture. Certainly she sought feedback and advice, and sometimes she acted upon it. Her designs from this period are the result, not only of her individual work, but also stem from ongoing discussions with her colleagues about possible alternative electronic music techniques. What perhaps set Oram apart from many of her BBC colleagues at this time was her singularity of vision, her commitment to the notion of a drawn-sound technique, and also to the objective of pure musical research.

This forward looking ambition and excitement was, unfortunately for Oram, far from being in line with the thinking of her BBC managers, who pragmatically and tentatively, were seeking ways to extend capabilities in electronic sound production, toward a highly specific outcome: extending the sound production techniques within avant-garde

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[78] Oram, D. 1962
[79] Oram 2007, ORAM/01/01/015 and ORAM/01/01/016.
Chelsea Polytechnic is now Chelsea College of Art and Design, University of the Arts London.

radio and TV drama. The role of the Radiophonic Workshop was to evolve considerably over the years to come, but when it was founded, it was with this specific remit. This was necessarily so, as the BBC music department was in firm opposition to the formation of an electronic music studio for pure musical research in the model of Cologne or Paris.[80]

A research visit to the Brussels World Fair in 1958 also must have served not only as inspiration to Oram, but also as a stark contrast with her experience at the BBC. Many of the composers and researchers in the field of EM whose work she experienced in Brussels, had institutional support for their musical research. If one compares the enthusiastic and inspired tone of Daphne Oram's summarising report after her visit to Brussels[81], with the dry, sardonic and cynical report of her boss Pip Porter[82], who reserved particular vitriol for John Cage's aleatoric lecture and piano performance which was '…surely the ultimate in phoney business…' it is not difficult to imagine how her ideas might have been received by some of her BBC superiors whose agendas were so very different to her own.

It is worth remembering that Oram was a relatively junior member of staff (studio manager) when compared with those who finally brought about the instigation of the Radiophonic Unit, and finally the Radiophonic Workshop, notably Douglas Cleverdon and Donald McWhinnie, both feature producers at the time.[83] In the firmly stratified institutional environment of the BBC, Oram was perhaps regarded by some as a noisy upstart trying to punch above her weight[84], rather than as a senior expert in electronic music production, regardless of her proven artistry with magnetic tape. Indeed, when the Electrophonic and then Radiophonic Effects Committee was formed in 1956, as a first step toward instigating an electronic music studio, neither Oram, nor any other

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[80] Neibur, L. 2010, P8, P16, and P36
[81] Oram 2007, ORAM/03/03 BBC/Brussels Expo 58
[82] BBC Archives: R97/11/02
[83] Neibur 2010, P35
[84] A view supported by Alec Nisbett, who stated that he had been in general supportive of Oram's role in the RW (especially as it was a role he had no interest in for himself). Nisbett also stated that Oram was seen by some in management as 'having ideas above her station'. Nisbett, N. 2014

studio manager was invited to attend, despite the fact her work was frequently discussed at the meetings.[85]

Perhaps unsurprisingly given the context outlined above, Oram's designs for the production of drawn sound were not eventually given any support by the BBC, even as she was initially charged with much of the sound production work for the RW[86].

A dispute about being given credit for sound works was also the cause of much consternation to Oram who wrote to her mother Ida on the 19th February 1958:[87]

> There is still a terrific battle raging as to whether or not I get a credit in the announcement of Winter Journey. It's all a lot of petty nonsense. Of course it's too late now for a credit in Radio Times but the producer is fighting hard for one in the closing announcement. I think my name will pretty definitely be on the screen for the TV show. [Amphitryon 38]
>
> All this sort of thing makes me more and more determined to form a private company…

In a subsequent letter to her mother, Oram mentioned a similar fight for credit with *Private Dreams and Public Nightmares*[88] and stated that Val Gielgud, then the BBC head of drama, had been petitioning on her behalf, only to have his requests to credit Oram cut off by higher BBC management.

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[85] BBC Archives: R97/07/01

[86] Ibid. By 1960 Desmond Briscoe, having been promoted to Senior Studio Manager was included in the REC meetings.

[87] This letter more was more recently donated to the Oram Archive by Carolyn Scales in 2012 and has not been given an accession number as yet.

[88] BBC Radio Play by written by Frederick Bradnum.

Oram's decision to leave the BBC and go it alone after fifteen years of employment in January 1959 can be seen as inevitable for a number of reasons. Firstly she was initially very disappointed with the 'second hand, second rate' equipment installed in the RW and the fact that her proposals for the workshop had been patently ignored. Secondly the letters to her mother prove that she was vehemently seeking credit for her work, in opposition to the official BBC policy not to credit 'technicians'. Finally and perhaps most importantly, Oram wanted to compose. To some, including herself, she was composing, and yet she worked in an environment where it was not acceptable to deem her works music, despite the fact that she was completing highly accomplished exercises in concrète technique both within and outside the BBC.[89]

On the 11th July 1958 Oram wrote to her mother Ida[90] and told her that she had been commissioned to produce a soundtrack for a production some Oxford University students were taking to perform at the Edinburgh Festival. She also mentioned that she had permission to do the work from Pip Porter, her boss, on the condition that it wouldn't interfere with her BBC duties. In the Radiophonic Workshop logbook[91] from the same time, it is clear Oram in fact spent quite a few hours composing the piece in BBC time.

A few weeks later on the 31st August 1958, Oram again wrote to her mother:

> I'm being taken off Radiophonics from Sept 8th - Nov 1st for a 'rest'. I'm furious. Desmond [Briscoe] who works with me (since July 1st) has also been told that he will be taken away on Nov 1st. He's furious too. I think they have a policy not to let either of us get important, have any publicity, or get the running of things in our hands. If the bosses keep changing us round and don't let our names be known the bosses will still be the bosses although they don't know anything about Radiophonics. It makes us livid. There is not a thing we can do 'cos the orders come from four grades up and to fight our case up to that level is impossible.

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[89] By this time Oram had been invited to undertake electronic soundtracks at Eaton School and Oxford University, both for theatre productions.
[90] This letter more recently donated in 2012 to the Oram Archive by Carolyn Scales has not been given an accession number as yet.
[91] BBC Archives: R97/23/1

Although it was not possible to corroborate Oram's statement from the records held in the BBC archive, another document[92] does refer to Desmond Briscoe being temporarily taken off Radiophonic Workshop duties 'to avoid battle fatigue'. Other former members of the Radiophonic Workshop, for instance Dick Mills at the Science Museum's electronic music symposium in September 2012, have also recalled this policy in the early years of the RW, to rotate staff on the basis that this new specialised work might lead to some kind of detriment to health. However judging by the content of the letter to her mother, Oram clearly did not see it in the same light, and took it as a personal affront.

This combination of grievances with her BBC employers, combined with the added confidence gained from having her skills sought externally, provided the necessary tipping point for Oram to resolve to continue her work and research outside of the BBC.

Having briefly described the conditions surrounding the divergent agendas of Oram and the wider BBC position on provision for electronic sound production, and having noted the osmotic yet highly focused nature of Oram's own drawn sound designs, it is at this point pertinent to consider two technological developments more specifically attributable to influencing Oram's progress, before moving on to examine the development of Oramics in the period after Oram left the BBC.

[92] BBC Archives: R97/7/1

Precedents: The Parametric Artificial Talker

The Parametric Artificial Talker (PAT) was a speech synthesis machine developed through the 1950s at Edinburgh University Phonetics Dept. This applied research was initiated by Walter Lawrence of the Ministry of Supply, a telecommunications engineer seeking a method to enable the transfer of speech over telephone lines using a far lower bandwidth than the standard analogue transmissions of the time. This was with the hope of maximising the potential usage of expensive cable infrastructure, especially undersea cables[93].

James Anthony at Edinburgh University built the second version of the machine. It was featured on the BBC's *Eye on Research* programme in 1958[94]. The machine was a marked improvement on the Pattern Playback machine developed by Haskins (Phonetics) Lab at Yale University, because, in addition to the nuanced control of overtones to emulate vowel sounds[95], PAT had the ability to provide filtered white noise to the eventual mix of signals in order to articulate consonant sounds. The BBC documentary was titled *The Six Parameters of PAT.* According to the film, the six parameters it used to construct artificial speech were: underlying pitch, volume, noise, and the three vowel overtones.

As Wilson states[96] it is certain that Oram was aware of PAT, and it is very likely her interest in it was sparked by the BBC documentary. PAT used loops of transparent material with drawn graphs to control enough separate envelope and filter characteristics to produce intelligible artificial speech[97]. These looping graphs are

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[93] Coincidentally the same idea was instrumental in the final collapse of London based synthesiser company and research establishment EMS. An American entrepreneur wanted to use their vocoder technology to similar end, unfortunately for Zinovieff et al, after extending their credit to develop the project, a large cheque from the developer bounced, finally bankrupting EMS. See also Pinch, T. and Trocco, F. 2002.

[94] *Rees, A. Prod. 1958.*

[95] Pierre Delattre of Haskins Lab was eventually so familiar with the spectrograms that turned light into intelligible speech on the Pattern Playback machine, that he could draw sentences freehand which could then be understood when 'spoken' by the machine.

[96] Wilson, D. 2011

[97] Further research is required to establish exactly how this process worked. Dan Wilson in an email to the author has stated that he no longer believes this was controlled optically, but rather electrically, utilising conductive ink.

visible in the first few minutes of the programme, and to a researcher like Oram who was seeking ways to turn graphical information directly into sound, it must have been very exciting to witness.

In August 1959 Oram wrote to her mother Ida, from Edinburgh.

> "Lunch with Tony of the University. Spent afternoon seeing the artificial talking machine. Great welcome from everyone in the Phonetics Dept… Gleaned a lot of useful information. Seeing them again tomorrow." [98]
>
> Edinburgh, 27th August 1959

Oram was clearly impressed by the artificial talking machine. This view is endorsed by the fact that after the visit, she used audio examples from it alongside excerpts from avant-garde electronic compositions of the time in her lectures and demonstrations. Shortly after her visit to Edinburgh to see PAT in action, she also wrote to David Abercrombie,[99] then the head of phonetics, requesting further audio recordings from the machine, as she had only managed to take one rather obscure recorded sentence during her visit: '*what have you done with it?*' [100].

PAT undoubtedly represents a significant inspiration and influence for the Oramics Machine, and it is very likely that witnessing a machine capable of processing graphical information and turning it into sound, gave Oram added confidence that her more musically oriented project was technically feasible.

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[98] This quote is from an as yet un-accessioned letter held in the Oram Archive. Another letter discussing the visit between Oram and David Abercrombie – then the head of Edinburgh University Phonetics Dept, is held in the archive: Oram 2007, ORAM/9/04/103

[99] Abercrombie's reply can be found at Oram 2007, ORAM/06/01/028

[100] Oram 2007 (Audio), DO225

Precedents: The Hamograph

The Hamograph was a musical event sequencer and envelope shaper, designed and built by Myron Schaeffer (in consultation with Hugh le Caine) at the University of Toronto electronic music studio in 1960. The Hamograph was primarily designed as a tool to precisely and automatically mix down the six audio channels of their bespoke automated multi-track tape recorder, which was developed by Hugh Le Caine. Despite its comparatively limited functionality, designed as a studio building block, rather than a holistic music production device, it has many similarities with the audio event control system of the Oramics Machine, and is certainly worth examining in terms of Oramics precedents.

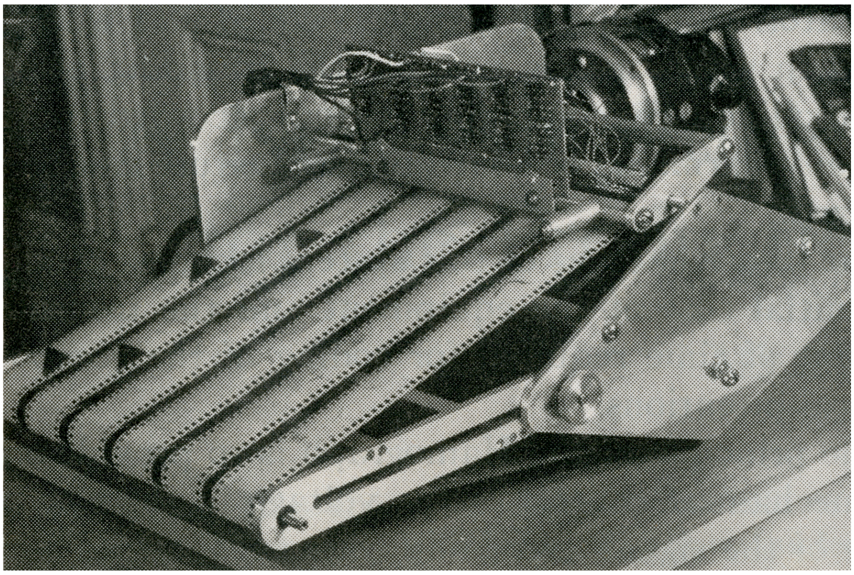

Fig. 13. The Hamograph, detail taken from the promotional leaflet in the Oram Archive.

A promotional document dated from 1962 summarising the functionality of the Hamograph is held in the Daphne Oram Archive[101]. The device as described in the leaflet, had six 35mm film loops that ran synchronously, driven by an electric motor. Each film loop was applied with conductive tape in the form of amplitude graphs, and these graphs would run under a series of electrical contacts, which in turn fed a resistor network. Depending on how many of the brushes were simultaneously touching the

[101] Oram 2007, ORAM/01/05/174. The document was reprinted as a promotional document by Schaeffer et al, and was originally printed in IRE Transactions on Audio, Vol AU-10, No 1, Jan-Feb 1962 (Institute of Radio Engineers).

conductive tape (the height of the graph), the resistor network created varying voltages in a series of nine small steps, which were in turn used to control voltage controlled amplifiers (VCAs). The VCAs then controlled the relative amplitudes of the six audio signals.

A later version of the Hamograph replaced this 'stepped' volume control technology[102], with a more fluid optical graph reading technique illustrated below in this extract from *Electronic Music Review Volume 4*[103] published by Robert Moog from his Trumansberg synthesiser factory.

The " Hamograph " of Myron Schaeffer is a device in which a hand-drawn envelope is imposed upon sound material[4]. Schaeffer used loops of clear 35 mm. motion-picture film upon which masks cut from black " Mystik " tape were stuck. 16 mm. single perforation film may be used; it gives half an inch of useable width. Paper charts may be marked with india ink or pencils. A photoresistor reader suitable for use in any of these arrangements is shown in Fig. 10. Half the case has been removed to show the six photovoltaic cells used with an inch-long aperture (for 35 mm. film). The resistors arranged as shown in Fig. 10 give a nearly linear relation between the length of slot exposed and the voltage developed. This leads to a nearly linear relation between the level in dB and the length of slot exposed.

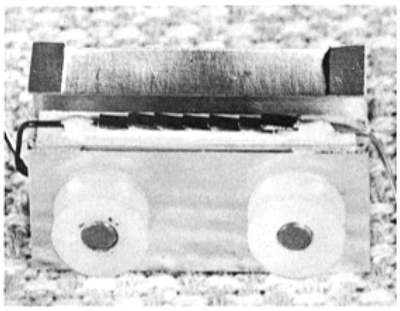

Fig. 10. Optical envelope shaper for 35 mm. motion picture film used in Myron Schaeffer's Hamograph.

OCTOBER 1967 29

Fig. 14. Details of the Hamograph, explained by Hugh le Caine in EMR Vol. 4.

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102 On examining the circuit diagram and accompanying text in the promotional document, it is clear that in the contact reader/amplifier arrangement, the voltage steps were smoothed into gradients with an adjustable capacitor, a design reminiscent of glissando controls or slew limiters in later voltage controlled analogue synthesisers. This capacitor would also have smoothed out any voltage glitches from the contact mechanism itself.

103 Le Caine, H. 1967

This later development into optical audio-envelope control, makes the Hamograph even more similar to the automated audio mixing section of the Oramics Machine. The article is dated 1967, but in fact this later optically controlled version of the Hamograph was completed before Myron Schaeffer died in 1965, whilst the Oramics Machine was still in development.

Schaeffer and his colleagues found the Hamograph most useful when working with loops of material with constant amplitudes, supplied by the multi-track tape recorder. This method meant that the sonic output followed precisely the contours of their drawn graphs. It enabled the musical output of the device to exactly match their conceived constructions in musical dynamics, and changes in timbre over time. These loops of constant tones can be read as directly analogous to the four wave scanning oscillators in the Oramics Machine.

It is clear then, that the Hamograph was technically and conceptually similar to the Oramics Machine. What is less clear, at least from the evidence to be found in the Oram Archive, is how much Oram knew about it, when she knew about it, and how much it might have influenced the development of the Oramics system. Certainly Oram was aware of its existence in the early 1960s as she began work on the Oramics Machine.

On the 11th July 1961 Myron Schaeffer wrote to Daphne Oram[104], enclosing audio examples and a description of the Hamograph. He explains the device as having been conceived (along with Le Caine's Multi-Track) to eliminate the need for countless tape splices in electronic music composition. In the letter Schaeffer explains to Oram how the Hamograph was used on a collaborative composition entitled *Project A.*

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[104] Dennis Patrick of the University of Toronto Music Dept kindly supplied numerous scans of archival documents held in their filing cabinets. The letter from Schaeffer to Oram is one of those documents.

> The point of technical interest is that there is not a single splice used in the melodic fragments nor in the fragmented section described above as number 2. I know of no other way of accomplishing this without numerous splices which explains why the Hamograph was undertaken.[105]

This letter is useful in identifying the exact date Oram became aware of the technologies being developed in the Toronto lab. It proves beyond doubt, that nearly a year before she received her first Calouste Gulbenkian Foundation grant in April 1962, and five years before a working Oramics prototype was in existence, Oram was aware of the similarities of the Hamograph to her concept for a 'Sound Wave Instrument' as she initially described her proposed research to the Calouste Gulbenkian Foundation. It is unlikely the detailed document describing the Hamograph held in the Oram Archive is the same one Schaeffer enclosed with his letter of 1961, as the dates do not tally. However we can be sure Oram was aware of the existence and operating principles of this invention before the main period of construction commenced on the Oramics Machine, and also that she kept up her correspondence with Schaeffer and the Toronto music faculty. Hence we cannot rule out the possibility the Hamograph provided an influential point of reference in the eventual design of the Oramics Machine. Furthermore it is likely, due to the innate similarities of the operating mechatronics, that it had as much or more of an influence on Oramics than the RCA Synthesiser (Olsen Belar, 1955) as mooted by Manning,[106] or a host of other devices referred to as possible sources of inspiration to Oram, as she developed her system for drawn sound composition.

It should be noted that in the cases of both the Hamograph and PAT, whilst they can be thought of as influential to Oram's technical progress, she had conceived the basic elements and an overall block system design for a drawn sound music production device before discovering either technology. Thus any influence they had on what was to become the Oramics machine, was limited to technical nuances rather than overall design concepts.

The similarities of the audio envelope shaping aspects of the Hamograph and the Oramics Machine also changed over the development period of Oramics, and these

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[105] Ibid
[106] Manning, P. 2012, P144

changes in the types of moving amplitude graphs employed, and the relation to the various optical sensor technologies utilised by Oram and her technical designers, are discussed in detail in chapter 3 - *Oramics Post BBC*, which focuses on what can be deduced from the examination of the Oramics Machine in its current state, having been stabilised and conserved by the team at the Science Museum.

Both PAT and the Hamograph can be seen as materially influencing Oram's research and development and it is problematic to assert that:

> Beyond this instance of a material external influence on the design of one aspect of the control system for Oramics [the RCA Synthesiser, Olsen Belar 1955] it is very hard to identify any other features that were specifically derived from the work of other pioneers other than of a purely coincidental nature.[107]

Oram did visit the Columbia Princeton Electronic Music Centre, home of the RCA Synthesiser in February 1964[108] as the elements of Oramics Machine were starting to come together with the assistance of Graham Wrench and her brother John, and it is certainly possible that the digital pitch control system eventually implemented with Oramics was inspired somewhat by the punch card digital pitch control of the RCA Synthesiser. However Oram's familiarity with the technologies of PAT and the Hamograph and her extended correspondence with their respective inventors, indicate that these technologies were in fact more instrumental in the development of Oram's research, especially given the much earlier timescale involved.

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107 Manning, P. 2012, P138
108 Oram 2007, ORAM/01/02/032, P9

CHAPTER 3: ORAMICS POST BBC

To understand and assess Oram's progress with the development the Oramics Machine through the 1960s and early 1970s, this chapter closely examines a number of pertinent sources. It comprises examination and cross-referencing of the Oramics Machine itself, Oram's own research and development log-books, and her Calouste Gulbenkian Foundation (CGF) correspondence. Oram's attempts to patent her technology are also re-appraised, and the Oram tape archive is used to provide sonic examples of the Oramics sound at different stages of development between 1966 and 1972, and to provide additional evidence with regard to how the Oramics Machine operated. Supplementary information from interviews is also used.

These various resources each play their part in the Oramics machine's overall narrative, and in fact the strongest evidence of how this narrative unfolded is in the later period of Oramics development between 1968-1972 when Oram kept a detailed chronological and highly technical log of her progress. The precise chronology of technical progress previous to that is more difficult to discern for two reasons: firstly the machine itself was changed considerably after the departure of Oram's brother John and her engineer Graham Wrench from the project, therefore the actual machine is a less useful resource for this time period. Secondly the most detailed evidence in this period is from Oram's correspondence with the Calouste Gulbenkian Foundation. This correspondence was necessarily kept free of real technical detail as she was essentially describing her work in layman's terms for the benefit of the CGF staff. Oram also spent much of this communication extolling the potential uses of her as yet unfinished machine, rather than giving precise specifics of technical developments.

This chapter is a more chronologically and technically accurate survey of the Oramics Machine and its further developments, with regard to electronics, mechanics and sonic output than has been undertaken in previous research. This updated development timeline and new assessment enables more accurate comparative conclusions to be drawn about Oram's many achievements and setbacks when examined against rival technologies.

The Beginning

Oram bought Tower Folly[109] in the mid 1950s whilst still working for the BBC and living in her rented flat in Wellbeck Street in London. After leaving the BBC in January 1959 she moved full time to Tower Folly and set about creating her own company for the commercial production of electronic music, and to further her drawn sound research. After registering the name *Oramics* as a trademark, *The Electronic Studio Supply Company Ltd* was incorporated on the 5th Feb 1959, with her brother John Oram named as Co-Director.

It is evident that at this pivotal stage in her career, Oram received help and support from her parents. In the course of the upheaval of moving her life to Kent and starting up as a freelancer, she wrote:

> …you know I could do none of this without you sitting firmly in the background supporting even my wildest whims. Bless you both I'm so grateful to you.[110]

In the same letter she also refers to her parents writing her a £100 cheque to help with the start-up of the company (approximately £2000 in 2016 terms). She also thanked them for acting as guarantors for a loan on a car. So with support from her family but also on a somewhat limited budget, Oram set out to make the new business pay.

Oram's first year at Tower Folly was spent establishing herself and her studio in her new venture. She did remarkably well at gaining commercial commissions and also established herself on the lecture circuit, and this is how she initially survived financially. She also took in some lodgers and taught a summer course in electronic music for Morley College in the summer of 1959.

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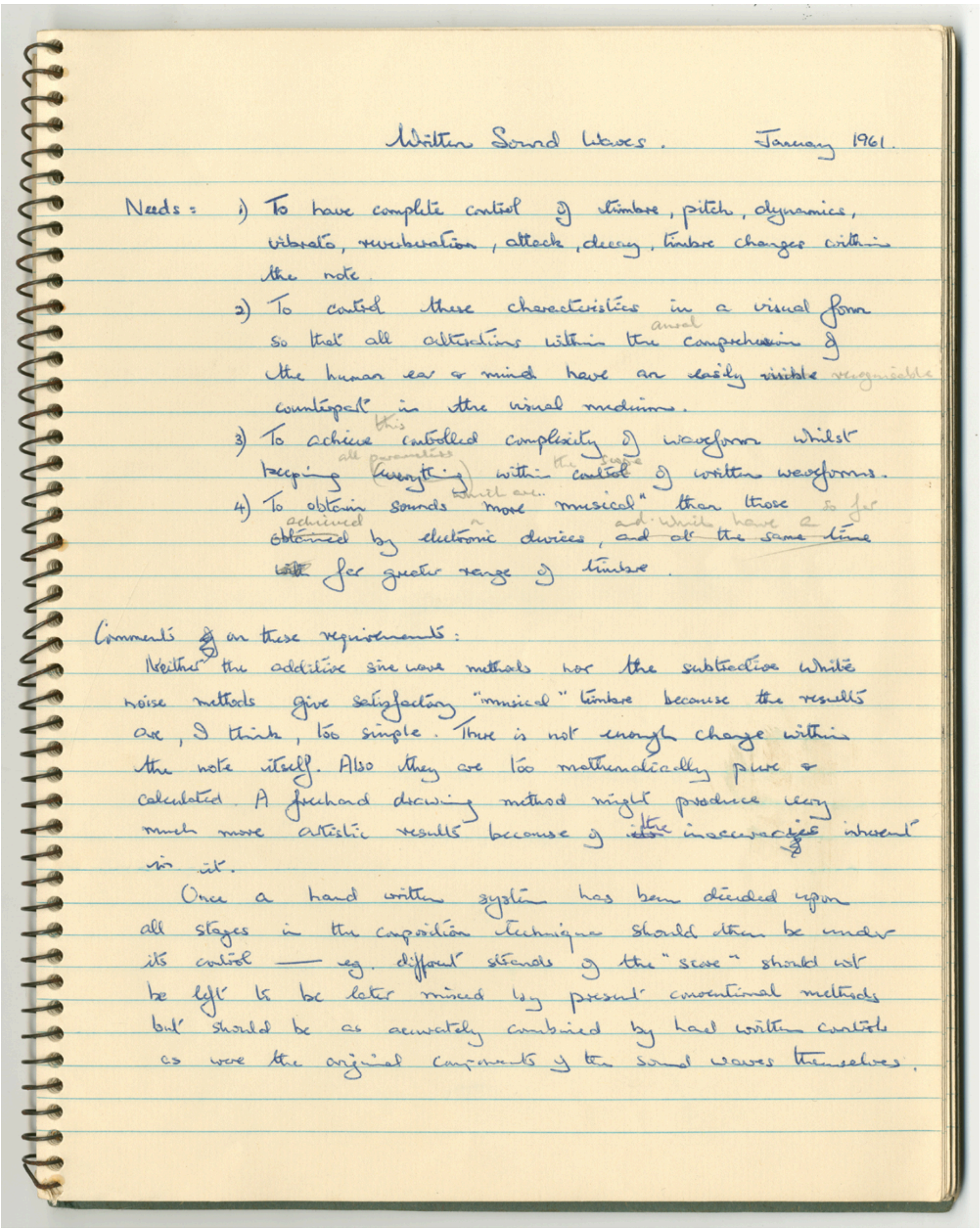
[109] The former Oast-House in Wrotham, Kent where Oram lived and worked for the rest of her life until she had a stroke in 1994.

[110] This letter is in the Oram archive but is yet to receive an accession number as it was donated later than the initial accession.

The Oramics Design Brief

By late 1960 Oram had established herself sufficiently to be able to return to spending part of her time on her ideas for drawn sound research. As she started to compile her thoughts in the process of applying for funding, Oram wrote the following design brief, a scan and transcript of which follow.


Written Sound Waves. January 1961.

Needs: 1) To have complete control of timbre, pitch, dynamics, vibrato, reverberation, attack, decay, timbre changes within the note.

2) To control these characteristics in a visual form so that all alterations within the aural comprehension of the human ear or mind have an easily visible recognisable counterpart in the visual medium.

3) To achieve this controlled complexity of waveform whilst keeping all parameters within the scope of written waveforms.

4) To obtain sounds which are more "musical" than those so far achieved by electronic devices, and which have a far greater range of timbre.

Comments on these requirements:

Neither the additive sine wave methods nor the subtractive white noise methods give satisfactory "musical" timbre because the results are, I think, too simple. There is not enough change within the note itself. Also they are too mathematically pure & calculated. A freehand drawing method might produce very much more artistic results because of the inaccuracies inherent in it.

Once a hand written system has been decided upon all stages in the composition technique should then be under its control — eg. different strands of the "score" should not be left to be later mixed by present conventional methods but should be as accurately combined by hand written controls as were the original components of the sound waves themselves.

Fig. 15. 1 Page of Daphne Oram's notebook (Oram 2007, ORAM 01/01/018)

A complete transcript is included on the following page.

Written Sound Waves January 1961.

Needs:

1) To have complete control of timbre, pitch, dynamics, vibrato, reverberation, attack, decay, timbre changes within the note.

2) To control these characteristics in a visual form so that all alterations within the aural comprehension of the human ear and mind have an easily recognisable counterpart in the visual medium.

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Once a hand written system has been decided upon all stages in the composition technique should then be under its control – e.g. different strands of the "score" should not be left to be later mixed by conventional methods but should be accurately combined by hand written control as were the original components of the sound waves themselves.

If the action of bow on string is thought of in slow motion it would seem that the string, in adjusting or readjusting to a certain speed of vibration, must give off a glissando sound which is too quick for the ear to recognise as such & which we just term "attack". With a slow motion technique this might well be produced far more accurately than any "gating" circuit can do it.

These few short paragraphs again illustrate how Oram wished to concentrate her efforts on both the timbral and dynamic quality of the sound of her potential device, as well as the immediacy of the interface. At odds with the precise and mathematical approaches she perceived in contemporaneous EM research (Bell Labs, EMS, Columbia Princeton, etc), she actually advocated the inaccuracy of a hand drawn parameterised approach and saw the inherent inaccuracies of this approach as potentially producing far more *musical* results. This is a crucial aesthetic and technical difference, and is arguably still relevant to music technology and contemporary innovation.

Within the Daphne Oram Archive, the short text transcribed above appears to be the closest document to a formal design brief, so for the purposes of this thesis it will be treated as the benchmark for the evaluation of Oram's later results as she went on to create the Oramics Machine with the assistance of John Oram, Fred Wood, Graham Wrench and others.

First Approach to the Calouste Gulbenkian Foundation

On the 27th October 1960, Oram wrote to the Calouste Gulbenkian Foundation (CGF) seeking financial support for her drawn sound research[111]. In this letter she clearly sets out the framework for her research as well as her ethos for the pursuit of new sounds through electronic means.

> In my humble opinion, "music by slide rule" will never be worthwhile, except maybe as an interesting acoustic exercise, because the human mind does not fit to the pattern of these mathematical formulae which some composers are trying to force upon it.[112]

This letter sets a stylistic and aesthetic precedent, which Oram continued throughout her correspondence with the foundation (and others). A conspiratorial tone, clearly setting her ambitions and research avenues apart from those of other composers and research establishments; especially those utilising serialist or aleatoric approaches to electronic music.

In this early correspondence Oram also detailed her wish to be somewhat free from her commercial sound production work, in order not only to develop her studio and drawn sound equipment, but also to teach and lecture more frequently – a sentiment that Oram's niece Carolyn Scales confirmed in her 2012 interview[113]. Scales views Oram's desire to prioritise pedagogy and research over commercial sound production, to be indicative of her wish to be seen as being at the forefront of research in the musical/technical avant-garde, as opposed to being viewed primarily as a commercial sound producer.

In this correspondence Oram also refers to the Edinburgh University PAT project as a useful resource, further demonstrating how influential Oram found it, with regard to her own research.

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[111] Oram 2007, ORAM 01/01/002. Oram's first letter to the Calouste Gulbenkian Foundation
[112] Ibid
[113] Scales, C. 2012

As Oram developed her funding application she kept detailed notes and drafts of all her correspondence with the Gulbenkian Foundation and there are many useful passages that illustrate her design ethos.

> For the study of sound, and in order to compose music outside the scope of present day orchestral instruments, it is intended to build an electronic device (here called the "sound wave instrument") which will convert drawn information into sound. The composer will draw, by hand, some dozen or more patterns which will give the electronic device not only the basic complex tone colours but also the information on how they are to be blended, reshaped, pitched, phrased, dynamically controlled and reverberated. The result will be one "line" of musical sound recorded on one track of a multi-track recording machine. Numerous lines can be built up in this way and later combined to make the final composition, which will, therefore, be in the form of a recorded tape.

Throughout the process of applying to the Gulbenkian foundation, Oram stated her intentions clearly, yet she did not at any point in this process intimate in any real detail how she envisaged her proposed device might work: she proposed a system of drawn parameterised controls for the electronic production of sound/music, but at this point she kept her options open with regard to the potential technical solutions of her given approach, despite having started her designs several years earlier while still employed at the BBC. It can be surmised therefore, that she did not feel her earlier efforts were necessarily the solutions she was looking for, and that all technical options remained on the table at this point.

Perhaps slightly at odds with the perception of Oram as having had a suspicion of computer technology[114], at one point in her musings she actually considered using some form of digital memory to store parameter values.[115] Oram also later joined the Computer Arts Society[116]. This complicates the issue of Oram's attitudes to the new digital computers that some contemporaneous researchers were working with. It illustrates that Oram's objection to these technologies was not the technology itself, but rather some of the methods in which it was being put to use; especially within the realms of computer generated or chance based scores.

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[114] Manning 2012, PP147
[115] Oram 2007, ORAM01/02/011 Oram's CGF Correspondence.
[116] Oram 2007, ORAM/05/04. Oram's Computer Arts Society documents

Looking back at this point in her career, especially from a contemporary perspective, it becomes evident what is going on with Oram's self perpetuated dichotomy; that of the Human versus the AI composer, the Varèsian *extension of the composer's arm*[117] versus algorithmic, serialist and aleatoric approaches. What Oram was in fact doing, was privileging the user interface and the eventual sound quality, over conceptual approaches to composition using electronics and computers, even if she did not yet know exactly how she was going to achieve this ambition.

[117] Oram 2007, ORAM/09/04/064, Letter from Oram to Douglas Lilburn, July 1968

Funding Awarded

Between October 1960, and January 1962 there was a flurry of correspondence between Oram and the Calouste Gulbenkian Foundation[118]. In this initial correspondence were various requests for further information from Oram, requests for further clarification about the exact research to be undertaken, as well as a request to considerably reduce the overall budget in order to maximise the likelihood of an award.

On the 4th January 1962[119], Oram received confirmation from Mr George Christie that her project would be funded by £3500 over three years. As Manning notes[120], this was only around half the amount Oram had initially requested, but also quite remarkable, in that individuals were rarely funded by the foundation[121]. It is estimated that £3500 in 1962 would equate to around £55000 in 2016, so a generous award yes, but certainly not enough to entirely free Oram from other commitments, or enough to employ anyone full time for the whole three year funding period. It must also be borne in mind that discrete electronic components (especially solid state components) were proportionally perhaps ten to twenty times more expensive in 1962 than they are in today's markets, and the very early integrated circuits that were just coming onto the market at this time, were more expensive still.

Many institutions, if applying for a such a research fund, might already have been equipped with some of the test and measurement equipment that would have been necessary to get started. However, Oram's application budgets, and her first interim report to the Foundation, suggest she had to spend a good proportion of her first year's budget on oscilloscopes, signal generators, amplifiers, mixers and the other ancillary equipment that was necessary to begin making any real progress.

In this first interim report to the Calouste Gulbenkian Foundation (dated 13th December 1962[122]), as well as outlining the progress of the electronics laboratory she was

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[118] Oram 2007, ORAM 01/02
[119] Oram 2007, ORAM 01/02/021 Letter from George Christie at the Calouste Gulbenkian Foundation
[120] Manning 2012, PP142
[121] In the course of writing this thesis, the author made several attempts to contact the Calouste Gulbenkian Foundation with regard to any documentation they might have about the Oramics project, or about their funding criteria around that time. Unfortunately they were unable to assist.
[122] Oram 2007, ORAM 01/02/023

developing, Oram described the development of 'playback circuits that will be associated with the conversion of the drawn information to a modulating voltage, the storage of this varying signal and its replay' that were to be built by her part time electronics technician Fred Wood. In this report she also mentioned for the first time the role her brother John would take with respect to the development of the mechanical system that was to be employed.

Attempting to discern Oram's exact progress with Oramics at this key time in the early 1960s is difficult, and there are various sources of information that are not always in complete agreement. As will be outlined later in this chapter, it becomes clear that Oram's reports to her funders were sometimes understandably a little over-optimistic about her progress. Alan Sutcliffe[123], who attended Oram's 1959 summer school in Electronic Music at Tower Folly, described[124] seeing a drawn wave-scanning contraption at this time: quite early by most estimates. An undated photo (included below) from the Oram Archive seems to show a scenario similar to the one he described with a CRT tube and photo-multiplier set-up on the billiard table at Tower Folly, however this is more likely to be from 1963 when Oram stated that she had demonstrated an operational wave scanning prototype to Mr Thornton of the Gulbenkian Foundation[125]. Peter Manning states that at the beginning of the funding period in 1962, Oram was still attempting to create her device using rotating optical discs,[126] and although this seems quite unlikely, as all her technical correspondence and notes from this time seem to concentrate on electronic means to achieve her intentions, it is also impossible to rule out. If she did start out this way she certainly very soon dropped this approach, as in her first annual report[127] to the foundation she describes her intention to employ a CRT based scan system, the *reversed oscilloscope* of her later biographical testimony, and this is the very first explicit contemporaneous reference to her use of this specific technology that has so far come to light. In this report Oram stated her intention to employ a company called Datran of Hitchin to produce her CRT wave scanning oscillators, as serendipitously, they had recently been contracted to develop a similar technology for a government contract.

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[123] Founder of the Computer Arts Society, and former Co-Director of EMS.
[124] He mentioned seeing this set-up in a private conversation with Tim Boon in the run up to the 'Oramics to Electronica' exhibition at the Science Museum 2011.
[125] Oram 2007, ORAM 01/02/32. Oram's second annual report to the Calouste Gulbenkian Foundation
[126] Manning 2012 PP143
[127] Oram 2007, ORAM 01/02/30. Oram's first annual report to the CGF.

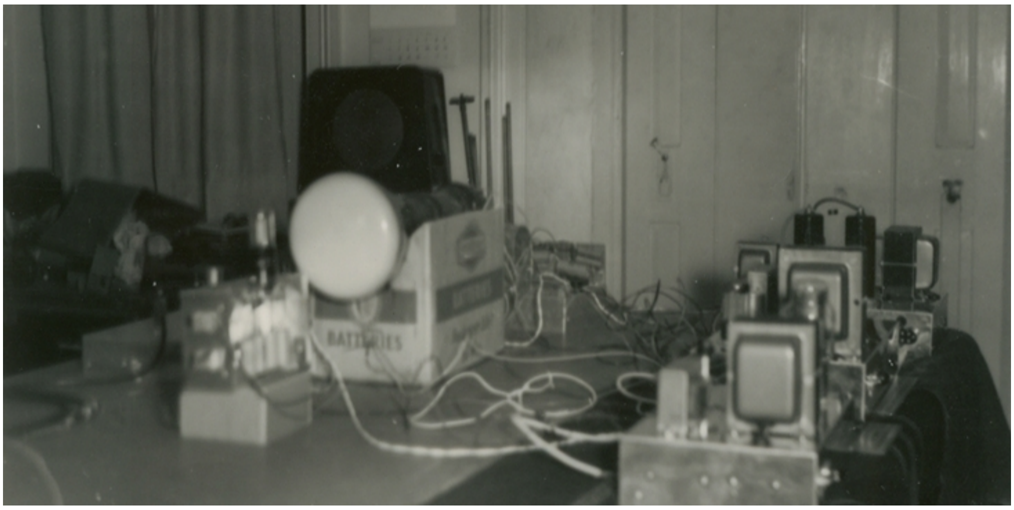

Fig. 16. Experimental Wave Scanner at Tower Folly, Early 1960s. Oram 2007, ORAM 07/04/053

In the rest of this first interim report to the CGF, Oram described how she had gone about initiating the research. She describes how her brother John Oram was commissioned to produce the mechanical aspects of the machine, including the multi-track tape mechanism, and how Fred Wood, whilst still employed in a technical capacity at the post office, worked weekends with her to try and build the necessary electronic circuitry. As with much of her correspondence with the CGF, Oram concentrated on the potential future uses of her device; detailing her intentions to use it to study the potentially harmful or beneficial effects of sound on both human and animal subjects.

The early development of the mechanical aspect of the Oramics Machine has not been thoroughly covered by earlier research, and again it is difficult ascertain the details with much certainty. Both Graham Wrench (Oram's electronic engineer 1964 – 1966) and Oram's niece Carolyn Scales, have stated that many of the design discussions between Oram and her brother took place over the telephone, so unfortunately much of the detail on this topic has been lost to time. However there are a few small clues which lead to the tentative conclusion that the original mechanical framework delivered to Oram was significantly altered to become the one she later used, and that is now in the collection of the Science Museum. One of these differences is that the machine was originally fitted with film spools for non loop-based operation. There are two sources of evidence that support this theory. The first, again within the CGF section of the archive[128] includes details of 11'' film spools. Graham Wrench[129] was also adamant that the machine had

[128] Oram 2007, ORAM 01/02/047 typed report about the Oramics project.
[129] Wrench 2013.

feed and take-up spools when he was working on it, and that John had modified the mechanics since he (Wrench) had ceased to be involved in the project. In fact it is unlikely that John made these modifications as he parted professional company with Oram around the same time as Wrench, and it is more likely a Mr Harris[130] undertook this work. A small note found in the archive[131] refers to him making adjustments to the mechanical transport system circa 1968.

The other main mechanical (and electronic/optical) difference between the transport-mechanism as John delivered it, and the one we are able to see today, is the number of programming channels, which changed from fifteen down to an eventual ten. There are three sources of evidence to support this assertion: the first is Oram's second annual report to the CGF[132] which confirms that John was building fifteen channels on the device. The second is contained in Oram's technical report and notes which formed part of a second and later (C1964) potential funding bid[133]. Finally, the third is a channel diagram[134] which was almost certainly sent by Oram to her brother John with regard to the layout of the machine's transport system. This diagram is in a graph paper pad which includes a note that reads 'sent to J.A.O. 21/06/63', and this diagram sets out a channel description from top to bottom. Each channel has a functional description, and also a short description of the optical sensors to be employed on that specific channel. The sensing devices described either define a number of ORP60 light dependant resistors, or in some cases, channels which require a 'C.R.T. & P.M.' – in all likelihood a small cathode ray tube and photomultiplier pair - to be used as an analogue optical line follower. These optically linked (mechanically opposite) pairs were to be used in a similar fashion to the wave scanning devices also employed in the Oramics Machine.[135] A transcript of the diagram is included on the following page.

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[130] Mr Harris was a live in handyman who did not last long at Tower Folly and who is also referred to in Manning 2012 and at Oram 2007, ORAM09/04/016 and in Wrench 2013

[131] Oram 2007, ORAM 01/05 Oramics technical drawings and correspondence.

[132] Oram 2007, ORAM 01/02/033 Oram's second annual report to the CBF.

[133] Oram 2007, ORAM 01/02/047 detailed report on Oramics, and also Oram 2007, ORAM 01/02/033 hand written notes.

[134] Oram 2007, ORAM 01/05/044, a graph paper notebook of Oram's, C1963

[135] A system that was eventually employed on all six of the analogue parameter channels as will be discussed later in this chapter.

Oram's Parameterised Control Channel Layout (circa June 1963)

- Extra (-)
- Extra (-)
- Delay CRT selection & VOL and waveform selection (5 x ORP60)
- Recorder Controls (8 x ORP60))
- Waveform Selection (6 x ORP60))
- CRT selection and volume (3 x ORP60))
- CRT selection and volume (3 x ORP60))
- Attack No. of Cycles (10 x ORP60))
- Pitch Thousands (4 x ORP60))
- Pitch Hundreds (9 x ORP60))
- Pitch Tens (9 x ORP60))
- Pitch Units (9 x ORP60))
- Vibrato % change & rate of change (C.R.T. & P.M.)
- Overall volume (C.R.T. & P.M.)
- Delay Volume (C.R.T. & P.M.)

This parameterised diagram presents a previously unknown picture of an interim stage in the design of the Oramics Machine; a missing link between the early designs from Oram's time at the BBC, and the eventual design discussed by Wrench, Boon & Grierson, Hutton, Manning, and Oram herself in her 1972 book *An Individual Note.* Here we can detect the remnants of Oram's earlier *attack and transient* waveforms*,* which would later evolve to simply become four different waveforms (or timbres) to be deployed in the mix at the composer's will. It is also one of the earliest indications of the decade-based universal pitch control system, yet one which specifies and eventual range of 0-4999hz rather than the 10khz range described by Wrench in 2009.

The significance of this diagram is clearly within the realm of illustrating Oram's thought process rather than in the analysis of the machine itself, as there is no evidence to suggest this particular parameterisation system was ever employed, and it is unlikely that it ever was. However it does contribute to a body of evidence which suggests that the transport mechanism did in fact start out with fifteen tracks.

The system outlined in the diagram would have been impossible to implement on some of the channels, due to the fact the ORP60 light dependant resistor arrays would have been wider than their respective 35mm film strips. Each ORP60 component was 5.2mm wide[136], so an array of ten would be at least 52mm wide even without any space between components. Realistically six or perhaps seven units would have been the maximum for one strip of film.

Within the framework outlined, Oram devoted eight sensors to the control of the multi-track tape device that she hoped to integrate into her machine. It does not go into detail as to how this might have worked (nor does it on any of the other tracks), but utilising this much precious optical sensing 'real estate' for said purpose, clearly demonstrates the amount of priority she gave this system at the time, despite the very real challenge of getting the machine to first create the single lines of musical melody she described in her own brief.

Both Carolyn Scales and Graham Wrench have described John Oram as having had some difficulty extracting a specific mechanical design brief from his sister. The 'extra' tracks included in this interim parameterisation system appear to confirm this, and can be read as a kind of technical contingency plan, to satisfy any as yet unforeseen additions that might have become necessary as the design progressed.

Overall this outline design is indicative of a project still in flux, inelegant, and with some fairly obvious shortcomings. It may well be something Oram used in order to help her brother finish the transport mechanism before she knew exactly how the optical/electronic systems would integrate with it.

It is unfortunately impossible to assign a precise date to this diagram, as it is entirely possible that it did not form part of the notes in the same pad, which were dated June 1963. However, it is very likely that it dates from either just before Graham Wrench became involved in the project, or just after. This is because the decade-based pitch system, which it is known Wrench helped to develop, is present, but not in its eventual, more component-efficient (if less intuitive) binary coded decimal (BCD) format. The BCD format only requires four bits, or in this case four light sensors, to represent any number between 0-9 whereas in this diagram each digit is assigned one light sensor, a system which not only requires more sensors, but would also have required much more complex circuitry to actually control the pitch as intended. A fact that became

[136] ORP60 component dimensions accessed here: http://www.radiomuseum.org/tubes/tube_orp60.html

inconveniently apparent and one of the most difficult aspects of the practice-based project of re-imagining and building a version of Oram's later *Mini Oramics* design, which required a prioritised single selection of response to an array of light sensors in a very similar manner to the non-BCD pitch control outlined above. A description of the practical and technical challenges involved in designing such a logic system is detailed in Chapter 5.1 (P167).

Graham Wrench Joins the Oramics Project

In Oram's second annual report to the CGF[137], dated May 1964, she introduced the addition of Graham Wrench to the Oramics design team, especially with regard to the CRT wave scanning units, as the quote that had come back from Datran of Hitchin had been far too expensive. Wrench soon quit his job in medical electronics in order to work on Oramics full time,[138] unlike Fred Wood who had kept his technical position at the GPO and worked with Oram at weekends. Wrench also clearly had an understanding of electronics which surpassed that of Wood in some areas, especially analogue systems, and his arrival appears to have hailed a renewed optimism on Oram's part, despite the fact her funding period was to end only eight months later. An extract from this report follows:

> i. in London a young engineer, Graham Wrench, has taken over for me the final research stages of the high speed scan equipment and is delivering the prototype , assembled and working, during June-July
>
> ii. at my brother's laboratories in Leighton Buzzard all the mechanical parts have been designed and made for the 15 track programmer and the 12 track tape recorder, and assembly is well underway'
>
> iii. here in Kent the 12 way electronic mixer unit has been built and tested, the playback amplifiers have been designed and are now being built.

In this report Oram also referred to a prototype 'high speed scan unit' as having been witnessed in operation by Mr Thornton (of the CGF) in August of 1963. This is significant in specifically dating this important milestone in the evolution of the Oramics Machine. It also makes it possible that this first prototype was devised by Fred Wood, before Wrench joined the project, as he is not mentioned in any of the CGF correspondence before this report of May 1964. However Oram also reported two major problems with the first experimental unit: it could not hold pitch well due to interference from mains voltage fluctuations, and also the relatively slow fly-back of the CRT spot produced unwanted overtones in the output waveform.

In the report Oram goes on to describe the design by Graham Wrench of a newer prototype, which Wrench had described as follows: "the waveforms have very good

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[137] Oram 2007, ORAM 01/02/32
[138] Wrench 2012

stability over a continuous fundamental frequency range of 40 cycles to 4000 cycles with an inter-scan period short enough to have no appreciable effect on the generated audio waveform".

Oram also mentioned that she had been to visit several other EM research centres including 'the Electronic Music Studio of Columbia University' where she was given a warm welcome. It seems very likely then, that she had seen the RCA Synthesiser on this visit, already quite late in the Oramics funded research period and therefore that the RCA Synthesiser was in all likelihood less of an influence on the project than PAT and the Hamograph as described previously.

By February 1965 – toward the very end of the CGF funding period, it is clear that Graham Wrench has had a remarkable impact on Oramics, in terms of technical progress on one hand, but also with regard to the theoretical and philosophical background to the project. Oram refers to Wrench warmly in her next interim report to the CGF[139], and when discussing the project even refers to 'we' instead of 'I'.

> We see Oramics as a means of combining the "Two Cultures" Science and Art. We feel that this is a very important concept at a time when the two cultures appear to be drifting further and further apart – indeed a strange and senseless suspicion has grown up between them. We wish to show that Science can assist the Arts without inducing, cold, calculating, lifeless, mechanical results. We also wish to show that machines, however complex they may be, have not of their own accord produced – and we believe they never will be able to produce – a work of Art which has that indefinable difference – the stroke of genius. This is a product which stems from an inner inspiration that we trust no machine will ever fathom. However, we feel that machines can provide new ways in which that inner inspiration can express itself; they can help to give a greater understanding of the medium and can aid the study, in minute detail, of the stimuli and sensations produced – for it is our belief that by a greater knowledge of the result we may better appreciate and respect the tremendous unknown – inspiration.

This document reads like a manifesto - even more so than her earlier reports, espousing the potential alternative (non-musical) uses for the technology, which after Wrench's involvement, Oram then considered to be 'modular' in nature. Although the renewed excitement in her words seems genuinely heartfelt, the problematic fact looming in the background was that the funding was ending, and the Oramics Machine was not yet

[139] Oram 2007, ORAM01/02/039 Interim report to the CGF dated February 1965

finished. In this period whilst Wrench was finessing the required circuitry, Oram was evidently trying to find a way to get additional funding for Oramics, and she started to cast the net a bit wider than the CGF, whilst simultaneously priming them for another request for money. Indicative of Oram's tenacity; rather than merely seeking a few more thousand to finish the Oramics Machine, Oram started to make ambitious plans for an Arts-Science research centre[140], complete with its own building in Kent, in which Oramics could find a home with herself and Wrench salaried to pursue their common research objectives. Oram submitted these plans to the MPs Joan Vickers and Jennie Lee, Kent County Council, and of course, the CGF. Unfortunately for Oram, it appears that she did not get any positive responses, save one from the CGF[141], who intimated that they might consider some further funding.

Oram's April 1965 report to the CGF[142], which included precise details of her proposed Arts/Science Research Centre, is also very interesting in that Oram goes to some length to explain to the CGF how 'the competition' at various institutions in the USA were progressing with their own strands of music technology research. Oram mentions MIT, Bell Laboratories, The Columbia Princeton Electronic Music Centre, The Argonne National Laboratory, and Yale University. In this document, she cleverly frames these other technologies as having almost caught up with her own Oramics research. It seems Oram hoped this time imperative would be good leverage, to encourage the CGF to continue to finance Oramics. As supporting evidence to her claims, she described a visit from James Seawright of the Columbia Princeton Electronic Music Centre, who had visited her studio (in summer 1964) and was impressed with her progress.

In a follow-up letter from Oram to the CGF in June[143] she expressed her desire that the Oramics Machine should have been completed:

> ….in a polished style to international standards….hence my request for full salaries and expenses. [re the Arts/Science Research Centre]

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140 Oram 2007, ORAM01/02/45 through to ORAM01/02/49 are all documents pertaining to Oram's proposed research centre.

141 Oram 2007, ORAM/01/02/056 Letter from Mr Rye at the CGF to Oram indicating further finding will be considered.

142 Oram 2007, ORAM01/02/50, Oram's annual report to the CGF April 1965.

143 Oram 2007, ORAM01/02/054. Letter from Oram to the CGF. 24th June 1965

She goes on to say:

> However, I can quite understand that the trustees might well like me to complete, first of all, the more utility "Heath Robinson" working model (which is now shaping very well) so that they could see it in operation, before assisting me in accepting the American challenge. This can of course be done.'

This letter forms important evidence that even as early as 1965, Oram did not want the Oramics Machine to be the final manifestation of her concept. This is a point that doesn't appear to have been properly addressed in other recent research and press coverage about the Oramics Machine. The fact that Oram saw her machine as a prototype for a more slickly engineered (future) device, further illustrates the significance of her later work with Mini Oramics and her computer research. It also contributes toward an explanation of why she didn't launch Oramics more publicly, when her prototype became operational soon afterwards.

Luckily for Oram, by October 1965, after indicating financial problems to the CGF[144] and having had some rather ominous correspondence with her bank manager regarding her overdraft, the CGF came through with an additional £1000 grant for her to finish the project.[145]

In the Oram ¼" tape archive is an Oramics recording which gives a good impression of Oram's progress at this time.[146] In this recording entitled 'Scanner Oct 1965', the beginnings of the distinctive Oramics sound are clearly audible. It sounds as if the waveform-mask in the wave-scanner was being moved around by the operator, subtly adjusting the timbre of the sound.[147] In this recording a noticeable pitch bend is also audible, although it is difficult to ascertain whether the vibrato function is being employed, or whether the operator is simply adjusting the master tuning control by hand, but, given the date, the latter seems more likely.

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[144] Oram 2007, ORAM01/02/058. Letter from Oram to the CGF indicating financial worries.

[145] Oram 2007, ORAM/01/02/059 Letter from CGF to Oram confirming £1000 additional funding, 20th October 1965.

[146] Oram 2007, (AUDIO) DO163 'Scanner Oct 1965'.
INCLUDED MEDIA 001

[147] Ibid (4'30")

1966 A Working Prototype

On the 9th June 1966, Oram wrote again to the CGF, a few months after her one year funding extension, but with good news[148].

> We are delighted to tell you that we have succeeded in proving that graphic information can be converted into sound. We can draw any waveform pattern and scan this electronically to produce sound. By varying the shape of the scanned pattern the timbre is varied accordingly. The speed of the scanning is controlled by digital information written on the clear 35mm films of the programmer, and this determines the pitch of the sound produced. A number of scanners can be controlled for pitch in this way.
>
> By writing information on the other films of the programmer the following parameters are controlled – duration of each note; timbre mixture; the overall volume envelope of each separate waveform which is contributing to that timbre mixture; reverberation (either on the timbre mixture or on a selected waveform of the timbre mixture); and vibrato.
>
> […]
>
> We believe that no similar piece of equipment exists anywhere else in the world. As you will know from the "New Scientist" article which we sent you last year, much work is going on in the U.S.A in developing computer music. But, as far as we can tell, the difficulties, which the composer experiences in programming a computer, have not yet been overcome. We have high hopes that the Oramics equipment will prove to be the answer.

It is unlikely the Oramics Machine that Oram announced to the CGF in 1966 bore much resemblance to its later/current form. As discussed earlier, the mechanical aspects were soon to be quite radically altered. Graham Wrench is positive that he only made one scanning oscillator in the time he worked on the project, and several archive photos[149] appear to show the frequency switching circuits uncased, and laid out on a table. Oram's later notes confirm that the frequency switching circuits were not fitted into the old radiogram cabinet until much later. Nevertheless the operating essentials were functional, and a ¼" audio-tape[150] labelled *Scanner Oramics May 1966* from the Oram audio archive demonstrates how Oramics sounded in this early operational stage. As is often the case with Oram's recordings, her preference for adding large amounts of reverberation or tape delay make the analytical appraisal of the audio difficult - even

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[148] Oram 2007, ORAM/01/02/070
[149] Oram 2007, ORAM/07/09/049 image of the pitch control circuits C1966
[150] Oram 2007 (Audio) DO219 A,B,C INCLUDED MEDIA 002

impossible. Mercifully, in this instance, sporadically, a few seconds of the recording are left *dry*. In these short fragments it is possible to ascertain that only one wave-scanner (or timbre) was in use. This appears to support Wrench's assertion[151] that only one scanner was in use at this time.

Returning briefly to Oram's final report to the CGF,[152] and also the potential reasons why she did not have a more public Oramics launch, she went on to say:

> However before we give the system extensive publicity, there will be much work to be done in learning its "language". At the moment my own writing technique in Oramics is rather akin to the efforts of a small child, who has just learnt to write "the cat is on the mat"! As this is an entirely new field no one can teach me how to do it - I have just got to work it out myself.

However, before Oram was able to get beyond 'the cat is on the mat' she had some other issues to deal with.

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[151] Wrench 2013 (unrecorded interview)
[152] Oram 2007, ORAM 01/02/070

A Strange Summer

Almost immediately after Oram announced the working prototype to her funders, things started to go awry. The exact facts of what happened at Tower Folly and with Essconic Ltd[153] from June to December 1966 are very difficult to ascertain, and this body of research is not the place for any idle conjecture. Some possible scenarios have presented themselves in the course of the project, but none can be proven and Oram will never be able to give her account of what happened. However, it is safe to say Oram had been under severe stress and was hospitalised for a period of several weeks.[154]. At this juncture the most relevant points in terms of the development of Oramics are that, for unknown reasons, on her return to Tower Folly in late July 1966, Oram abruptly terminated her professional relationship with Graham Wrench[155], and shortly afterwards she also cut ties with her brother John Oram[156] after he resigned as co-director of Essconic Ltd, the company that Oram had formed to further her drawn sound ambitions. In the context of Essconic Ltd, it is evident from the company meeting minutes[157] that the company had been going further and further into the red, with numerous overdraft extensions noted during the course of the time John and Daphne Oram were co-directors.

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[153] The short name for *The Electronic Studio Supply Company Ltd*, the company she owned with her brother John Oram.
[154] DO297 (old numeric ID) (AUDIO) *hospital copy*. Tape in which Oram describes her symptoms to a doctor. Summer 1966
[155] See Wrench 2009 and Wrench 2012
[156] Oram 2007, ORAM 05/09 P39. Meeting minutes of a meeting where JO and DO split their business practices (5th December 1966). Also see Oram 2007, ORAM 01/03/020 (March 1967) Letter to patent agent confirming that Oram and her brother had professionally split, and in Oram's words: 'relations between my brother and myself are somewhat strained at the moment'.
[157] Oram 2007, ORAM 05/09 Company meeting minutes of Essconic Ltd

Oramics Post Funding

Indefatigable, Oram slowly pressed on with the Oramics machine and over the next two years she worked with Fred Wood again, who reverse engineered Wrench's circuits in order to make more copies. In the archive[158] are initial *tag board*[159] layout drawings by Wood, and their subsequent circuit schematics of Wrench's pulse delay unit and JK Flip-Flop designs, which were crucial to the pitch control circuitry. This part of the archive[160] is unfortunately quite chaotic, seemingly incomplete, and jumps around chronologically between the early and later stages of Oramics, and even toward Mini Oramics, which was to be Oram's next foray into drawn sound in the early to mid 1970s. One of Fred Wood's copied schematics is signed and dated however, to October 1966, very soon after Wrench's departure from the project.

The fact that Wood was required to reproduce the circuit diagrams and some of the circuitry is not only indicative of the semi-finished nature of the project at this time, but also may suggest that Wrench took some or all of his drawings with him, as a folder labelled 'Graham's Circuits' lies ominously empty in this part of the archive. A few of Graham Wrench's drawings and notes do survive; clearly recognisable by his spidery handwriting, but these certainly could be not be described as anywhere near a complete design for Wrench's contributions to the Oramics Machine, and Wood's reverse engineered copies, again, only form a partial picture of the overall design.

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[158] Oram 2007, ORAM01/05/012 and Oram 2007, ORAM01/05/020

[159] Tagboard is a type of electronic prototyping board, which allows the experimenter to solder components and wires together without the use of a printed circuit board. It is still used today in some musical electronics, especially classic valve guitar amp circuitry.

[160] Oram 2007, ORAM01/05, Oramics technical notes and drawings.

"Instructions for turning studio on June 1968"

In June 1968 Oram drew up instructions for how to switch on the Oramics Machine[161], and a complete transcript of these pages of notes is included below:

> Turn on Upstairs before downstairs. June 1968
>
> <u>Turning On</u>
>
> 1. TURN NORMAL STUDIO ON- Insert Rubber 13A plug
>
> 2. (Ditto) Programmer <u>Motor</u> & Programmer <u>LIGHTS</u> on at rear of studio rack (13A switches marked)
>
> 3. If lights do not come on see that power pack under programmer is turned on.
>
> 4. Check that films on programmer are free to move. Switch on motor & then clutch & see that all films run together ok.
>
> 5. <u>UPSTAIRS</u> Plug in by fireplace & turn on.
>
> 6. Turn on two 300v POWER PACKS on shelf
>
> 6b . →CROC **CLIP** ACROSS THE 100~ REED SWITCH
>
> 7. <u>WAIT</u> for neons on EHT power packs to strike.
>
> 8. When neons on, turn on shelf EHT
>
> 9. Immediately check that the timebase is functioning otherwise CRT tubes will have bright spots which will burn face of tube. Short GREEN of centre COAX to chassis to make timebase fire.
>
> 10. Wait for tubes to warm up – they will gradually trace wavepatterns but need about ten minutes (only then alter brilliance or Y-amp gain if it is absolutely necessary. The Y-amp on RIGHT looking in at back of scanner cupboard is the amp for the right tube when facing the front of cupboard.)
>
> 11 Adjust volume of listening level on Heathkit amp under chair at end of bench.
>
> 12. With magnet "operate" reed switches to check pitch changes
>
> 13. <u>DOWNSTAIRS</u> – run Programmer with speed pointer just to the right of centre (ie about 3" per sec)
>
> 13B WITH STUDIO VOL OFF connect battery plug to VOL control amplifiers on PROG. Connect output to mixer. See that scanners are plugged to vol amps
>
> 14 <u>UPSTAIRS</u> Turn on DC power pack for Digital.

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161 Oram 2007, ORAM 01/05/201

15. Short delay unit capacitors if pitch changes are "pizzicato".

16. Turn on (UPSTAIRS) EHT for photocells of programmer (having checked that neon is on)

17. Connect up 4 ½ V batteries for Vibrato Bulb

<u>DOWNSTAIRS</u>

18. Plug in 13A plug EHT for CRTs on programmer

19. Plug in 13A plug for BIAS (not used in 1969)

20. Check that spots are following analogue films and that "torch" bulbs are reacting accordingly.

21. Turn up studio VOL

The simple fact that it was a twenty-one step process just to turn on the machine indicates that even at this later stage in the machine's evolution, it was still unwieldy, very much a prototype, and not yet the user-friendly interface that Oram had described in the earlier *Written Sound Waves* document, which formed a key synopsis of her research intentions in 1961. Perhaps it was still the 'more utility "Heath Robinson" working model' that Oram had earlier written to her funders about. For example, this document refers to six separate power supplies (including some battery based supplies) used by the system, which at that stage was spread across two rooms on two floors of Tower Folly. It is not uncommon for complex electronic systems such as this to have a separate subsystem entirely devoted to automating a switch-on/switch-off sequence, to ensure the system comes on correctly without any one part damaging another due to inrush currents and the like, yet Oram had to do all of this manually every time. This is a factor that might go some way to explain the difficulties she later encountered trying to keep the system running. The document also details various things which might well go wrong and their solutions – for instance what to do if the pitch changes were 'pizzicato' (this can be interpreted as only temporarily switching to the intended pitch, rather than latching onto this pitch until the next instruction from the programmer, as was intended), or what to do if the main waveform scanning CRTs were exposed to a lack of output from the main time-base sawtooth oscillator, with the risk of burning out of the CRT screen, with its replacement being a potentially expensive and time consuming result. Overall we can see a picture of a prototype unit that was not yet ready to be moved from her studio in Kent for any form of public scrutiny. This perhaps can start to explain why so few people actually ever used Oramics. It also can be seen as a reason for its fairly limited musical output.

The document has been extremely useful, especially as it was drawn up for Oram's own reference, and therefore appears 'warts and all' for subsequent analysis. It is helpful for drawing conclusions about how the machine operated, and with respect to dating certain photographs (in conjunction with other notes). It is at this point in my account of the development of the Oramics Machine, that evidence from examining the Oramics Machine itself becomes pertinent to the analysis.

At this stage the scanner unit or *synthesiser* part of the system was situated upstairs in Oram's audio studio. The film transport/programmer or *sequencer* part was situated downstairs. Oram later moved the programmer into her audio studio to keep all the equipment together. It is not clear why it was initially downstairs. Perhaps as the mechanism was noisy, or perhaps more likely, that is just where it had been developed, and Oram had always planned on uniting the two sections once it was satisfactorily operational.

At this point the decade system of pitch control was still employed. The document refers to the 100~ reed switch, indicative of a 100hz switch which would fit the 1000s 100s 10s and 1s system and not the other tuning system that she later employed. Oram's later logbook notes confirm that the decade system was still in operation at this point.

At this time it is also very likely that Oram had scrapped the use of any reel-to-reel film system for Oramics in favour of closed loops, despite the reels having been being present earlier. The reasons for this change are not known, but it is possible it was advantageous from a prototyping perspective - one that afforded Oram a simple way to have constantly running control signals whilst adjusting and calibrating the electronics.[162] It is also possible that the reel-to-reel system just didn't ever work very

[162] An approach which was found useful for the same reason in the practice-based part of this project.

well, or alternatively, that as blank film was expensive, this approach allowed Oram to conserve it.

Before delving further into the evolution of the Oramics Machine, and how the system developed into the early 1970s, it seems worthwhile to explain in slightly more detail how the system operated at this key juncture; the point at which Oram started making some progress with using the system for composition.

A brief summary of the workings of the Oramics Machine in 1968

Based on the evidence which has been uncovered in the process of this research, the following is a description of the most likely way in which the Oramics system and its circuitry was implemented in 1968, the time period in which she wrote the instructions discussed above. Some aspects of this system will be discussed and illustrated in more detail later in the chapter, especially those aspects which depart from the pre-existing understanding of how Oramics worked. A summary is necessary at this point so that the reader can better understand the later evolution of the Oramics system, which will be discussed using the evidence found in Oram's technical logbooks which cover 1968-1973, as well as evidence discovered from analysing the machine itself.

Essentially composing with Oramics was a three-step process outlined below:

1. Define a range of 4 timbres or wave shapes by drawing them on glass slides. (Direct Analogue Process)

2. Define the outline melody by drawing groups of black dots on clear 35mm film. (Symbolic Digital Process)

3. Define other analogue parameters (envelope shapes of the 4 different timbres, pitch vibrato, and reverb mix) by drawing graphs on clear 35mm film. (Direct Analogue Process)

The Oramics motorised transport mechanism then moved the films over a variety of light sensitive components, which gave control signals to the equipment, which in turn transformed this information into sound.

In terms of step one: the wave-pattern scanning, the specifics of the system worked exactly as outlined in the introduction. The drawn wave-pattern on a glass slide was inserted in a slot over the surface of the CRT unit. On the other side of the slide was an RCA 931A photomultiplier (a light sensitive vacuum tube component). The X (horizontal) axis of the CRT tube was driven by the main timebase sawtooth-wave oscillator in an identical manner to the adjustable timebase of a standard oscilloscope. This drove the CRT spot repetitively across the screen at the fundamental frequency of the timebase. The Y (vertical) axis of the CRT spot was derived using a feedback amplifier fed from the output of the photo-multiplier, and the nature of the feedback circuitry was such that the CRT spot would follow the drawn contour of the wave pattern. The Y-axis terminal was therefore a pitched electronic copy of the drawn waveform. It was then tapped and attenuated, and this signal became the audio output for that wave-pattern. The composer was able to output four wave-patterns (derived from four wave-scanners built into the radiogram casing, and determine their relative amplitudes later in the process.

In terms of step two - the pitch control system, symbolic digital information in the form of groups of small cut out pieces of black tape, (referred to by Oram as Neumes) were used via LDRs set up as voltage dividers, to optically control a bank of bistable JK flip-flops (discrete transistor based logic circuits). These in turn switched in and out various reed relays (electrically operated switches), which then controlled a resistor/capacitor network determining the pitch of the analogue thermionic valve based sawtooth-wave oscillator. In its current state, the timebase circuit has a fixed capacitor with all frequency variation provided by the switching in and out of a selection of variable resistors, and there is no evidence to suggest it worked any differently in 1968. At this point in time, Oram used four film tracks, each with four LDRs to employ the decade or Hertz-based control system as described by Graham Wrench[163]. This meant that each of four films controlled one decimal place of a 0-9999 Hz frequency control system. Oram later changed this system and re-wired the 'decade [circuit] boards' as she did so[164] and unfortunately any schematics of the decade system have not survived. That said, the operational essentials of the system were in all likelihood very similar, and the probable operation was as follows.

In the pitch control system were four parameters; each represented one decimal place and these were encoded in standard binary coded decimal (BCD) format[165]. Each of the four pitch control films had four LDRs[166] and each of these was connected to an

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[163] Wrench, G. 2009

[164] Oram 2007, ORAM01/04/001 Logbooks: 'Moving Equipment 1969-1970'

[165] Binary Coded Decimal is a standard system for representing the decimal counting system within digital equipment. Essentially the numbers 0-9 are represented as their binary counterparts, and binary numbers representing 10-15, the rest of the four-bit binary system, are counted as invalid.

[166] All 16 of these components are still evident within the machine. Due to the way these components are mounted, it was not possible to isolate them and positively identify them without damaging the equipment, however it was possible to analyse their behaviour using a digital multimeter, and on the basis of their dimensions and ohmic response to light exposure it is extremely likely that these components are Mullard

associated JK flip-flop[167]. Graham Wrench's delay circuit (still evident in the wave scanner unit) was a fixed period monostable circuit, employed to very briefly reset all the pitch control relays at the moment any new pitch instruction was detected. Then the combination of neumes detected would operate the LDR voltage dividers for a slightly longer period than the monostable time constant, and after this brief reset pulse from the delay unit, would be then free to operate the reed relays as required to determine a new given pitch. This delay part of the circuitry would have required some careful calibration in order to allow the inaccuracies inherent with the 'drawn' input, i.e. the time difference between the starting points of each of the four sections of the new pitch specification, to fall within the time constant of the unit, without allowing the new pitch to be misread (in the instance that one of the drawn parameters should fall outside that time constant, therefore resetting them all again). At the same time it had to have been short enough that there was no audible glitch or delay heard at the output. Wrench created this unit to have three switch selectable settings of 10, 20 and 30 milliseconds, which still would have required the operator to have a good level of accuracy when deploying simultaneous neumes, yet this must have been the trade-off necessary to ensure that the change would only ever be heard as a distinct, one-note-to-another pitch change. It is unclear exactly how the BCD pitch control worked to control the RC network of the timebase, due to the re-wired circuit boards, and the lack of any schematic diagram regarding the decimal system employed. Oram's later tuning system, which is still built into the Oramics Machine, will be examined in more detail in due course.

For step 3, the film tracks controlled all the other analogue parameters: overall dynamics, reverberation mix and vibrato. The technology employed has been perhaps the biggest discovery about the operation of the Oramics Machine. It represents an innovative sophisticated and more nuanced interface than the Oramics system has been previously been given credit for. Essentially it worked in a very similar manner to the wave-scanners, with a mini CRT and photomultiplier pair with a feedback circuit, but with the x-axis held static (instead of being swept by a timebase). So on the lower side of the programmer, underneath the films, were 6 mini CRT tubes, and above them were

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ORP60 light dependant resistors, which Oram had referred to having purchased in earlier notes.

[167] The JK flip flop is a universal clocked (edge triggered) bistable circuit and is still a common gate used in computer architecture and digital circuits.

an array of 6 photomultipliers. The films with drawn parameters were then moved between these components by the motor drive, and the CRT spots would then 'follow' the edges of the drawn graphs, allowing the y input on the CRT tube to again be tapped as the signal source. In this case the outputs were slower moving control voltages, to be applied to other control elements of the system. The six sub-circuit units, which can still be seen mounted at the top/rear of the Oramics programmer, are the interfacing circuits for these six optical detector arrangements.

The reason using pairs of CRT/Photomultipliers in this way is superior to using a single LDR and a lamp for instance, is that in the case of the latter, the drawn parameter graphs on the film would have to be filled in and completely opaque to create meaningful control voltages. In the case of the CRT system that Oram employed, the composer could just draw the outlines of these graphs for the system to give a similar output. The significance of this crucial difference should not be underestimated in terms of the relative merits of a drawn-sound interface, as drawing an outline is far more time efficient, and also much easier to erase and re-draw should the results be found unsatisfactory. If we then multiply these factors across the six analogue control channels and consider the savings in time and convenience for the composer, we can conclude that it was a considerably more elegant and efficient approach than, for instance, that taken on the Hamograph. In fact both these control systems were outlined in Oram's UK and US patents, however the main illustrations in both patent documents refer to using filled in graphs with unspecified photo-electric devices to create the control voltages. The CRT/Photomultiplier system, which was actually employed, is referred to in just one brief sentence quoted below.

> As an alternative [to the filled in graph system] that may be preferred a cathode ray tube and photo-electric device can be used as described with reference to Fig 1 to cause the cathode ray spot to follow a curve on the strip 71 and provide an output for volume control.[168]

How were these control voltages then employed? This answer to this question has been fairly elusive in the process of this research, as no voltage controlled amplifier (VCA) circuits were discovered in the examination of the Oramics Machine despite such amplifiers being specified in Oram's patents. The initial assumption that Oram had used

[168] Oram British Patent, lines 95-100. An identical phrase is also included in the US patent.

VCAs raised questions surrounding missing external circuits or equipment that served this purpose. Fortunately recent re-examination of Oram's log-books[169] has provided an answer. In fact the solution Oram applied to the voltage control of volume was remarkably simple in comparison to the sophisticated graphical interface outlined above. The control voltages for the dynamic controls were buffered by transistor based DC amplifiers to light up a group of torch bulbs to the right side of the programmer (all still evident today) and the varying brightness of these torch bulbs then influenced passive attenuation circuits using LDRs to adjust the relative volumes of each timbre[170]. In the case of the volume control circuits - the wave-shape volumes 1-4 and reverberation mix - the varyingly attenuated outputs were all fed into a mixer and eventually amplified and/or recorded onto tape. In the case of the vibrato control a similar system was employed, but in this case the LDR controlled by its dedicated torch bulb was integrated into the RC network of the timebase circuitry, effectively bending the pitch proportionally to the height of the drawn graph on the control film. The wiring for the vibrato bulb is still evident in the timebase unit today and the housing for the bulb/LDR can be seen in earlier photographs of the Oramics timebase unit.

Of course there is one element included in Oram's brief which has been left out of the operational explanation, and that is the mechanically synchronised multi-track tape recorder. This device was supposed to allow the composer to build up harmonies and chords by recording up to twelve individual lines of melody created with the equipment. In theory these lines could later be mixed and recorded onto standard ¼ inch tape to provide a playback copy of the whole polyphonic composition. In terms of the development of this additional subsystem for Oramics, there is plenty of evidence to suggest that Oram considered it a priority in the R&D stages, and also that considerable time and effort was spent trying to integrate such a system into Oramics. Oram often

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[169] Oram 2007, ORAM 01/04/001 through 01/04/003.
[170] Previous to this discovery it had been assumed by the author that these torch bulbs were merely indicators, to allow the composer to see the response of the electronics to the drawn parameters. The passages which describe this process are found at Oram 2007, ORAM 01/04/02 The following is one quote referring to this system: "Weds Nov 27th [1968] Shining torch on 1 cell of track 5 volume gives marvellous fast and loud attack. Cells therefore seem able to take much more light. How about higher wattage bulbs and more amplification? What bulbs in stock? (Need power transistor in feed to bulb)"

refers to it in her CGF correspondence and evidently her brother John Oram was briefed to integrate the system into the operational mechanics. Indeed it is very likely that the proposed twelve-channel recorder had a considerable influence on the eventual mechanical design of Oramics. A relic of this recording system survives today in the form of a large metal drum with a surrounding framework, and this object is part of the group of objects which collectively form the Oramics Machine that is in the Science Museum Collection. *However*, in the course of this research, across all the paper and audio archives, it has not been possible to find a single scrap of evidence to suggest this system was ever operational, and indeed there is strong evidence to the contrary, which is detailed in a passage where Oram describes trying to record Oramics chords using her standard Brenell ¼'' tape recorders.[171] Therefore for the remainder of this thesis, the multi-track recorder will essentially be left out of any discussions regarding the reality of using Oramics, and will only be referred to with regard to Oram's conceptual vision for the system.

[171] Oram 2007, ORAM 01/04/01, 29th January 1971, a description of Oram's attempts to create chords by recording onto two separate Brenell tape recorders.

The Further Evolution of the Oramics Machine 1968-1973

The system that has just been described is a brief explanation of how the Oramics Machine was initially configured and designed to work: a probable theory of operation. In reality, despite having had a really rather elegantly designed system to work with, Oram often had operational issues and recurring faults whilst attempting to compose with Oramics. A comprehensive detailed description of all these technical problems is not necessarily required to underpin the arguments of this thesis. Any researcher wanting to delve deeper into this area can examine Oram's three large volumes of technical log-books that illustrate her technical and creative journey over the period 1968-1973. Instead, a few key moments from these logs will be used to illustrate some of Oram's further successes, set-backs, and creative processes.

In July 1968[172] Oram composed 'Duet for Two Graphs', and in the following month, another piece entitled 'Fanfares'[173]. Fanfares is clearly evident in the tape archive and the sound is fairly simple, reminiscent of the call of trumpets and on listening it seems perhaps a maximum of two of the wave scanning oscillators were used for this piece. The other work, if it is present the audio archive is not referred to as such, but the very similarly titled 'Dialogue of Graphs' is evident in the tape archive[174]. If this *is* the piece Oram refers to in her logbook, the sound is positively remarkable given the time it was composed: complex, reminiscent in parts of violin but with deep bass and more abstract sounds also. On listening it is very difficult to discern if this piece was a single composition using multiple wave scanners or whether it has been overdubbed with tape recording techniques. Both options seem quite plausible, and a more forensic analysis of the audio file would be necessary to discern this. These early works clearly illustrate that the system Oram and her technicians had assembled worked admirably, and when compared to contemporaneous computer music, for instance the early Max Matthews / Bell Labs pieces[175] (which it is documented Oram had listened to[176]), the results are not at all 'cold, calculating, lifeless, mechanical'[177], exactly as Oram had hoped. In the

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172 Oram 2007, ORAM01/04/010
173 Oram 2007 (Audio) DO204
174 Oram 2007 (Audio) DO117 titled *Dialogue of Graphs* (not *Duet for Two Graphs*)
175 For example music recorded on the IBM 7090 computer released by Bell Labs on the 1962 Decca LP 'Music from Mathematics'
176 Oram 2007, ORAM09/04/044. Correspondence with Max Matthews, 1966-1968.
177 Quoted from Oram herself at Oram 2007, ORAM/01/02/039 (CGF Correspondence).

view of this researcher, the organic quality of the drawn sound was also, as desired by Oram, much more reminiscent of acoustic instruments than other available means of electronic sound production at the time.

Despite these early flourishes of success, Oram soon encountered technical problems with the system, and her notes suggest three major issues that slowed her compositional progress in 1968 – 1969.

The first difficulty she encountered was a problem establishing a reasonable range for the vibrato control. Its over-sensitivity and sometime asymmetric response were to become issues that dogged the Oramics Machine throughout its operational life. The following extract is one of many similar notes in Oram’s technical logbooks.

> Tues 25.6.68
>
> Vibrato range is so wide that stuck on PVC tape with straight edge gives pitch change. Stuck on PVC should give ‘ZERO’ and have no apparent pitch change.

To avoid continually struggling with the vibrato and to enable the use of the other functions without its interference, Oram fitted a bypass switch to the vibrato circuitry, which is still mounted on the timebase unit today.

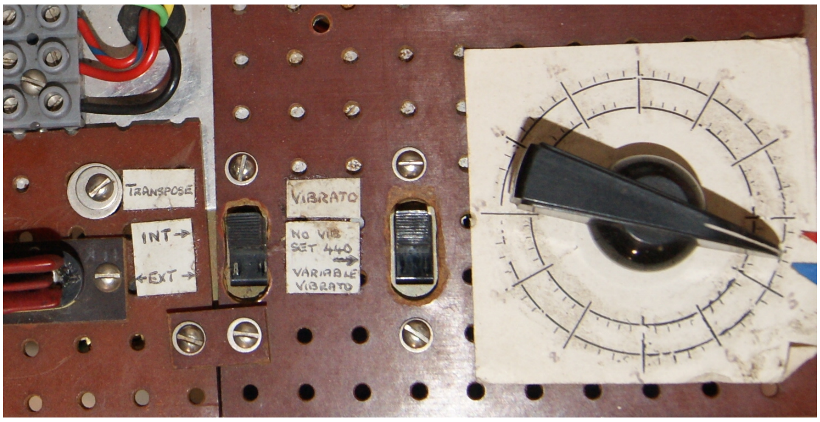

Fig. 17. Oramics timebase controls including vibrato bypass switch, photograph the author.

Another problem Oram encountered was pitch locking, where a certain frequency would lock in and stop responding to instructions from the programmer. On the 10th October 1968 as Oram prepared for a studio visit from an unnamed TV producer, she wrote the following entry:

> ….Later one pitch locked in (About B 998). Turned off DC power pack for about 10 mins & then OK again. (evening) 998? Locked in again for a short time.

Further logbook entries confirm that this problem continued for a number of days.

The other technical problem Oram encountered in this period was that voltage fluctuations in her mains electricity supply would affect the overall tuning of the device. The inability of the power supply units to give a constant output regardless of mains voltage fluctuations was a problem that would go on to plague Oram's progress. On one occasion in March 1969, she described the tuning of Oramics changing when her oil filled radiator turned on. So, not only was the varying mains voltage affecting her machine, the other mains powered devices at Tower Folly were interfering with the tuning of the Oramics Machine.

When examining Oram's log-books, it appears that there were good days and bad days:[178]

> Oct 13th: [1969] Equipment shown to Thea Musgrave. All working fairly well.
>
> Nov 7th: [1969] Vib Lamp is not lighting enough. Only getting 4 ½ V when spot at top of trace. Batteries down to 8V

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[178] Oram 2007, ORAM01/04/02. Oramics log book 1968-1970

Moving and Retuning

From the end of 1969 to mid 1970[179], Oram was moving and re-installing the Oramics equipment within Tower Folly, as well as changing various operational aspects of the device. As was previously discussed, she wanted to move the programmer part of the system upstairs to the main audio studio where the wave scanners were already situated. Many of the logbook entries in this period describe changes to the system which are still evident on the machine today. The most important single change was to the tuning system.

In this logbook[180], between December 1969 and February 1970, Oram wrote several pages of notes that refer to the re-wiring of the decade circuit boards, and she also made the following notes about resistance values and their associated pitches:

¼ tone - 1 meg GRN 500k pot

Min 3rd - 220k YELLOW 100k pot

Tone 330k OR (orange) 500k pot

Semitone 470k PURPLE 500K pot

E 659hz 68K GRN 100k pot

A 440hz 150K YEL 100k pot

D 294hz 270K RED 100k pot

G 196hz 470K BLK 100k pot

Although retuning Oramics to be more like a conventional instrument might seem at odds with Oram's initial intentions, where the decade system of pitch control would give the composer access to any desired sequence of frequencies, it is quite possible to imagine the thought process which might have driven this decision. One can easily imagine how painstaking it might be to have to code every note in hertz rather than a musical pitch, despite the added creative freedom the decade system might allow.

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179 Oram 2007, ORAM/01/04/010 Log book entitled *Moving Equipment 1969-1970*
180 Ibid

Further Adjustments

Throughout 1971 and 1972 Oram made several more major changes to the Oramics Machine and the following written evidence is all sourced from her third technical logbook dated 1971-1972[181].

> Feb 12th [1971] Fine adjustment knob on number two oscillator (now called No1)

This short entry seems to imply that Oram was using less wave scanning oscillators than the system was designed for. On close inspection of the scanner housing of the machine, this theory appears to be confirmed. Despite there being four sets of wiring and connectors for the CRTs Oram used in the scanners (situated underneath the radiogram housing), on the other side (inside the housing) where there should have been four corresponding photomultiplier mounts, there were only two. It also appeared very likely that there had only ever been two, as there were no cable routes which could have been used to facilitate the others (in terms of drill holes and cut outs for access). It is therefore quite possible that the Oramics Machine in its later/current form only ever used two oscillators.

Another logbook entry concerns the extending of the film loops:

> Jan 31st [1972] '40 second loop worked out well'

Oram had extended the loop-length of her machine with a broom handle. This broom handle is still with the collection of objects which collectively form the Oramics Machine. See Fig. 19.

But perhaps the most crucial change Oram made was to the system of analogue parameter controls. On the 1st February 1972 she wrote:

> Mains down to -13 [volts]. Volume tracks hopeless. Am giving up CRT spot following volume tracks in despair – absolutely no use when mains fluctuates like this.

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[181] Oram 2007, ORAM01/04/03

Unfortunately the CRT/Photomultiplier-based graph following circuitry could no longer be relied upon, and Oram decided to resort to the simpler technology of using LDRs and light bulbs instead. As was previously discussed this meant that the analogue tracks would now have to be programmed with filled in graphs rather than ink lines, a considerably more time consuming process and a much less elegant solution. Her following note confirms that she had to remove the photomultipliers from the analogue parameter tracks:

3rd February 1972: Removal of Photocells 931As Programmer

To illustrate this change, the following two photographs show the linear graphs and the later filled in graphs.

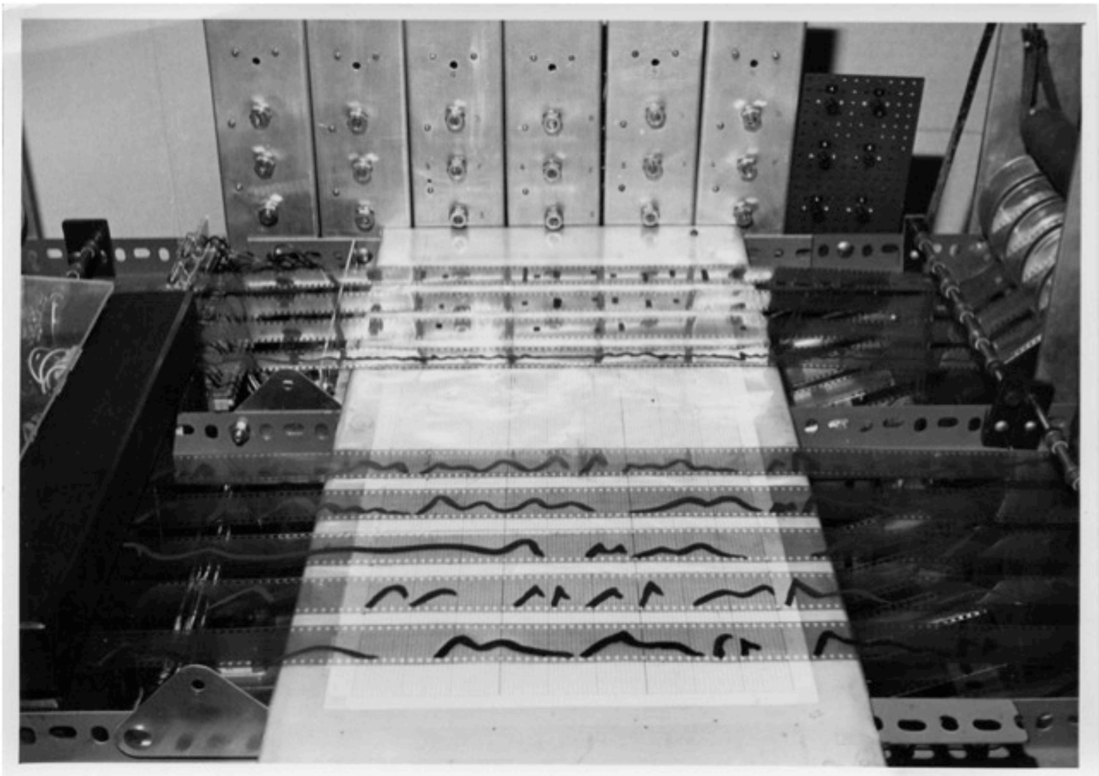

Fig. 18. The Oramics Programmer C1969 with linear graphs for the analogue parameters and black photomultiplier housing shown clearly at the left of the image.

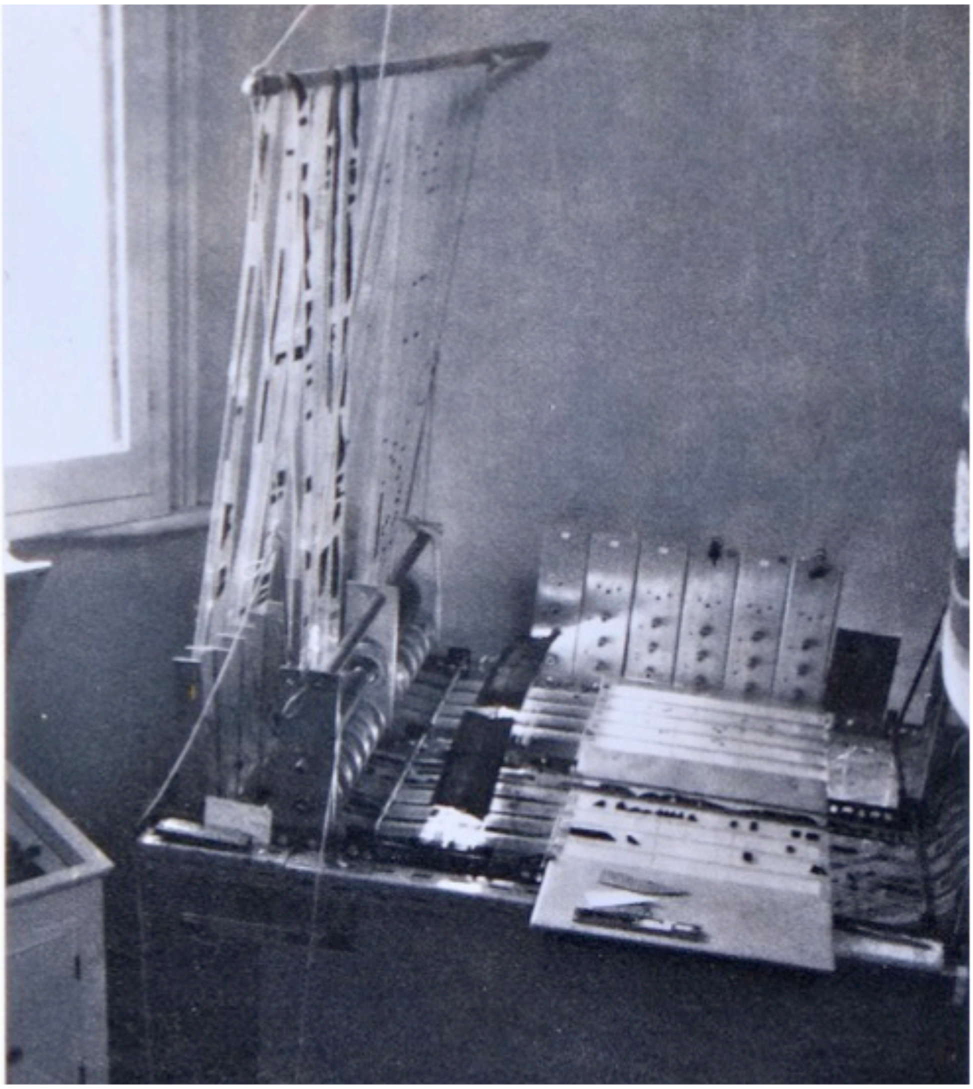

Fig. 19. Oramics in 1976, photo John Emmett. Broom handle and filled in parameter graphs clearly visible. Also note the change to lamps instead of photomultipliers at the play head, when compared to the previous image.

When examining the machine itself, the two redundant wiring looms from the photomultipliers and mini CRTs are clearly still evident. In the place where the mini CRT units would have been are various experimental configurations of LDRs, some using single cells and some using two in series which implies experimentation to achieve the best range from the input.

Oram continued to work with the Oramics Machine until around 1976[182], this last and quite drastic compromise marked the start of a decline in usage, the log books were no longer kept, and Oram spent more time re-thinking her ideas, and working toward Mini Oramics, which will be covered in the next chapter.

[182] Oram 2007 (Audio) DO230. This is the last known recording of Oram using the Oramics Machine, tape dated 1976.

Closer Examination of Oram's Patents

As outlined in the introduction, the history of Oram's patents as told, needs expanding upon.

In 1965, about a year before her prototype machine was operational, Oram wrote to the Calouste Gulbenkian Foundation[183] stating her intent to patent her technologies, and to enquire whether the CGF would seek to retain any intellectual property rights regarding the technology that she was developing with the help of their funding. In this letter she also stated her intention to try and sell these patents to a company or companies who wished to develop these technologies, as she could not envisage an alternate scenario in which she would be able to afford to protect these patents from any potential infringements, or indeed be able to finance and market a potential Oramics product herself.

Having received confirmation that the CGF would not seek to retain any intellectual property rights, Oram engaged the services of London based patent agents Reddie and Grose. Subsequently a Mr John A Bailey from the firm visited Oram's studio to see her work in progress, and on the 23rd November 1965 he wrote to Oram[184], referring to his visit, and confirming (unfortunately mistakenly) that the waveform scanning equipment did indeed appear to be a first, and therefore pursuing a patent for her equipment seemed worthwhile.

Oram then sought UK, US, and Japanese Patents, with the jobs of the US and Japanese applications being sub-contracted to native patent attorneys. Presumably Oram thought the US and Japan to be the most likely countries to be developing similar or competitive technologies. Recent history would largely appear to bear this theory out.

Unfortunately for Oram, any hope Mr Bailey's initial assertion that her wave scanning equipment was a technical first was soon dashed, when her US patent was initially rejected. In Oram's patents and trademarks folder[185], is a series of other patents and a magazine article, which were cited as reasons for this initial rebuttal. Many of these designs use some form of wave-scanning CRT system. Two of particular note are the

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[183] Oram 2007, ORAM01/02/062 letter from Oram to CGF, 18th Nov 1965
[184] Oram 2007, ORAM01/03/018
[185] Oram 2007, ORAM01/03/003 to ORAM01/03/009 are all related patents cited in Oram's initial US patent rejection.

Sunstein magazine article from 1949, already included on page 23 of this thesis, and also a design for a keyboard based musical instrument by Merlin Davis, which shows a plurality of waveforms to be read in a slightly different fashion by a CRT device. Another patent by J.E. Hawkins 1952 describes a system for the analysis of seismographic records which bears much in common with Oram's film based transport system and its graph reading capabilities. It even has a harmonic drive like the Oramics Machine and is in many ways similar to the *pattern playback* device mentioned earlier in regards to the Parametric Artificial Talker. The full list of cited US patents and articles is presented below:

> Paul A Pearson 2989885, 1961, Electronic Musical Instrument and Method
>
> Merlin Davis 2900861, 1959, Electronic Musical Instrument
>
> Merlin Davis 3015979, 1963, Electronic Musical Instrument
>
> R.E. Williams 3140337, 1964, Photoelectric Organ
>
> J.E. Hawkins 2604955, 1952, System for analyzing seismographic records
>
> D. R. Maure et al 2907888, 1959, Function Generator
>
> David E Sunstein, February 1949 *Electronics* magazine, Optical Function Generator.

Fortunately for Oram, she and her patent agents spotted a flaw in the arguments presented: namely that, yes, the wave scanning oscillator had been invented before in the US, but her means of opto-digitally controlling pitch was substantially and conceptually different to anything presented in any of the cited articles. So Oram updated her US patent application without really changing any of the content, she merely reduced the claims to those concerned with the digital control of pitch[186]. She was eventually awarded the US patent number 3478792 *Digitally Controlled Waveform Generators* on the 18th November 1969.[187]

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[186] Oram 2007, ORAM 01/03/029/010 undated letter appealing against the rejection of the US patent.

[187] Oram US Patent

Oram's UK patent, although awarded later, appears to have passed muster and the claims still include all the outlined technologies including the CRT based wave scanning design. Her UK Patent number 1189292 *Improvements in or relating to the Generation of Electric Oscillations* was awarded on the 22nd April 1970.

Oram's Japanese Patent application (number 1967-23891) was also rejected on the basis of several previous and comparable designs, including one of those included in Oram's initial US patent rejection, and another US patent (R.M. Tink) that had perhaps been overlooked by their US counterparts. Those cited were:

> US 2525156, R.M. Tink, 1950, Method and Means for Electrically generating tones.
>
> US 2900861, Merlin Davis, 1959, Electronic Musical Instrument
>
> Japanese Patent No: 115992
>
> And also a Japanese electronics textbook: *Electronic Circuit Handbook* by Maruzen Kabushiki Kaisha, 1963, which included a CRT wave-scanning function generator.

The Japanese patent application process took much longer than the UK and US applications due to bureaucratic and translation delays, and Oram had to wait until the 14th March 1972 before this rejection[188]. There is no further correspondence in the archive regarding to the Japanese patent application, and no Japanese patent for Oramics.

Perhaps as an added intellectual property *insurance policy*, Oram also kept very quiet about the real operational specifics of her device, and a flurry of correspondence and inquiries that Oram received after the publication of *An Individual Note* regarding these matters[189], goes some way to illustrate this. When anyone asked her about these specifics, she simply referred them to her UK Patent, which, as has already been outlined, does not give precise or specific information in this regard.[190]

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[188] ORAM1/3/029/001 and ORAM1/3/029/002 March 14th 1972

[189] Oram 2007, ORAM09/04/051 to 054 are all letters requesting further information about Oramics from students and other interested parties around 1973

[190] Ibid

The significance of Oram's Patents should not be underestimated[191]. Despite the drawn wave scanning technique having been demonstrated previously in several other instances, Oram being the first person to successfully and accurately control pitch with an opto-digital interface is undoubtedly an important and noteworthy achievement within the history of electronics more widely, as well as in the more specific realm of Electronic Music. This alone should be enough to cement Oram's reputation as an outstanding musical and technological innovator, and when this is taken into account within the sophisticated combination of systems she employed in the Oramics Machine, it is all the more remarkable. With the benefit of hindsight, it also appears that the utilisation of the CRT/Photomultiplier feedback system to generate control signals (rather than audio waveforms) for her equipment was also unique, and this specific adaptation does not feature in any of the cited existing technologies in the US and Japanese patent rejections. Whether or not this could have been successfully argued in terms of Oram's patent applications is hard to determine, as it is still so strongly related to the waveform-scanning technology, however its operational means and usage is demonstrably different, and in all likelihood it is also an innovative first for the Oramics Machine.

It is also worth noting that it is common practice to initially make very wide claims when applying for a patent, and then, depending on the feedback from the application, to reduce the claims appropriately. In this instance however, although very difficult to prove one way or the other, it seems likely that Oram was unaware of the existing precedents cited in her applications, and that she would have initially been quite disappointed at the initial rejections of the US and Japanese applications.

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[191] Oram already held another US patent before she attempted to patent Oramics, and this was for a new form of potentiometer (adjustable resistor or voltage divider). It was titled *Variable Electric Resistances* and is US Patent No. 3156890, Granted 10th November 1964. It does not appear to be relevant to Oramics and no evidence has come to light that it was ever commercialised or manufactured, despite there having been some initial commercial interest which is evident in the meeting minutes of Essconic Ltd. The patent describes a wire-wound potentiometer with a spiral (rather than the usual circular) track and suitable wiper, which would allow a greater length of resistance wire to be employed, and thus a greater accuracy of multi-turn adjustment for the user. John Oram also held a number of patents, including one that was for a new type of winding machine suitable for the spiral potentiometer.

Oram's Attempts to Commercialise The Oramics Interface

From examining Oram correspondence with the CGF, it is clear that Oram intended to sell her patents to a developer and commercialise the Oramics concept from as early as 1965[192]. As she developed the Oramics Machine and also started to think about Mini Oramics, there is evidence that she approached three separate potential backers or collaborators.

On the 6th December 1967 Oram wrote to Robert Moog[193] to enquire as to whether he might be interested in collaborating on the Oramics project. There is no reply in the archive, however in a private conversation with the author, Jo Langton[194] stated that she had spoken to Robert Moog during the process of her own research on Daphne Oram. According to Langton, Moog had told her that he had been to see the Oramics Machine, and that he was not overly impressed with it, and therefore decided not to get involved.

On the 15th November 1968, an entry in Oram's logbook concerns a visit by a Jack Boyce of Phillips Recording Company[195]. Oram mentions in her entry that her equipment worked fairly well except for one loudspeaker feed. She states also that 'JB excited by potential'. It has not been possible to find any evidence that this meeting amounted to anything.

On another occasion referred to in a letter dated the 6th October 1972[196], Frank Dawe of the company *Lightomation* wrote to Oram about a recent visit to her studio in which they had been discussing his possible involvement in Oram's venture. It is clear from the technical details mentioned that by now they the discussions are regarding Mini Oramics. Dawe expressed his support, but ventured the opinion that Oram needed a bigger backer. He suggested that EMI, DECCA, or the Nuffield Foundation would be more suited.

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[192] Oram 2007, ORAM/01/02/054, Letter from Oram to the CGF discussing the further development of Oramics, June 1965.
[193] Oram 2007, ORAM/09/04/063, Robert Moog correspondence
[194] Formerly Jo Hutton, see Hutton J. 2003
[195] Oram 2007, ORAM01/04/02 Oramics technical logbook 1968-1970

[196] Oram 2007, ORAM 09/04/061. Letter from Frank Dawe to Daphne Oram. 6th October 1972.

So Oram certainly was trying to commercialise her system, yet the fact that only evidence of three potential backers survives could imply that, either, Oram had problems securing these meetings, or that the technical problems she was having with her prototype interface meant she did not feel ready to further pursue the matter.

CHAPTER 4: ORAM AS PIONEER

Added context for Oram's graphic-sound research.

This chapter is a wider illustration of Oram's shifting position in the world of avant-garde and electronic music. It will add further detail and context to Oram's life and career to be referenced against the specifics of her graphic-sound research in the thesis conclusions. This is not a biography, and in the context of Oram's incredibly prolific and diverse career trajectory, a more complete history must fall to a future research project. Instead, pertinent and illustrative examples will be used to illustrate Oram's attitudes to her contemporaries, her professional standing, and the cultural zeitgeist at key points in her life, and in the context of her graphic-sound research through her mid and late career. Oram's earlier career at the BBC. Has been largely covered before[197] and some more specific technical details have been featured in the *Early Conceptions* chapter.

[197] See Manning, P. 2012, Hutton, J. 2003, Niebur, L. 2010.

Leaving the BBC and Working Independently

As Oram left the BBC to start her independent career in 1959, the speed with which she started to expand her professional circle and win commissions is positively remarkable. Oram's work with advertising and film soundtracks alone, could surely form the basis of another doctoral thesis, and it is testament both to her skill with recording and tape manipulation, and her ability to network and advertise her skills. It is also indicative of her professional standing at the time, as one of the foremost practitioners of electronic sound manipulation and composition in the UK. Some of her advertising commissions included: Horlicks, Lego, Costain, Heinz, Rotolock, Anacin, Tumble Wash, and Nestea[198].

Perhaps her most notable film soundtrack was for Jack Clayton's *The Innocents* in 1961[199], where her sonic treatments added menace and suspense to Clayton's film treatment of *The Turn of the Screw*[200]. Oram also worked on several films with British experimental film maker Geoffrey Jones. Their first collaboration was the award winning *Snow,* (1963) in which Oram's subtle and evocative filter treatments on the drum track[201] invoke the sound of steam trains accelerating, whilst Jones' footage of freezing railway men and speeding snow plough locomotives, keeps pace with the ever quickening tempo.

At what might be described as Oram's mid career heyday in the early 1960s, just as she was making the first practical inroads toward making the Oramics Machine, she also embarked on a series of sonically and visually illustrated lecture/demonstrations throughout the UK, introducing audiences to the 'new' field of electronic music. In these lectures, Oram guided the audience through the physics, history, and the many varied approaches to electronic music. She presented these lectures at the Edinburgh Festival in 1961[202] and the Mermaid Theatre (London) in 1962[203] as well as many other

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198 Excerpts or complete recordings from all of these commissions can be found in the Daphne Oram tape archive. Oram 2007.
199 See for instance Oram 2007, AUDIO, DO180 and DO002 which are recordings from her work on the soundtrack. Also Oram 2007 ORAM/08/02/001 and 002. Oram's ticket to the premiere and her working script for *The Innocents.*
200 Novella by Henry James, 1898
201 The soundtrack was an arrangement of Sandy Nelson's *Teen Beat*, re-recorded by Johnny Hawksworth
202 ORAM/7/5/003 Photograph of Oram's Edinburgh Lecture, Edinburgh Evening News

venues, universities, and professional associations throughout the 1960s. Oram's lecture notes[204] and slides are accessible in the archive and so are her audio tracks for these lectures. Oram's mother kept press cuttings relating to her daughters career[205] and in this folder are many reviews of Oram's talks and demonstrations. Although they are not always positive about the content, they are nearly always very warm about Oram and her presentation style.

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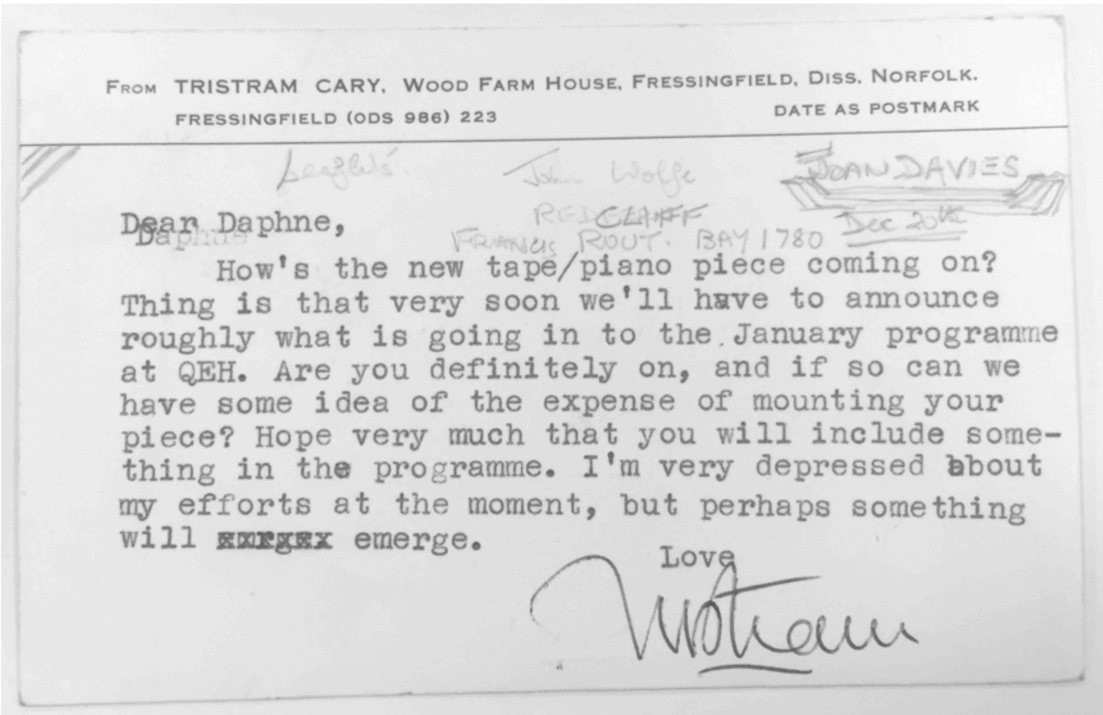
[203] Oram 2007, ORAM06/04/010 Programme notes for Oram's lecture 'the Performer Banished' at the Mermaid Theatre.
[204] Oram's collected lecture notes are at Oram 2007, ORAM/04/04
[205] Oram 2007, ORAM/09/07. Scrapbook of press cutting kept by Oram's mother, Ida Oram

Concert at the Queen Elizabeth Hall

Toward the end of the sixties, as Oram came to the end of her Calouste Gulbenkian Foundation grant period, the British composer Tristram Cary invited her to participate in what was billed as the very first London concert of electronic music by British Composers. It took place in the Queen Elizabeth Hall at the South Bank Centre in London in January 1968.



FROM TRISTRAM CARY, WOOD FARM HOUSE, FRESSINGFIELD, DISS, NORFOLK.
FRESSINGFIELD (ODS 986) 223
DATE AS POSTMARK

Dear Daphne,

How's the new tape/piano piece coming on? Thing is that very soon we'll have to announce roughly what is going in to the January programme at QEH. Are you definitely on, and if so can we have some idea of the expense of mounting your piece? Hope very much that you will include something in the programme. I'm very depressed about my efforts at the moment, but perhaps something will emerge.

Love

Fig. 20. Note from Tristram Cary to Daphne Oram regarding the QEH concert of Electronic Music by British Composers. Oram 2007, ORAM06/04/005

Contrasts Essconic[206] Oram's piece in the concert, was a collaboration with her long time friend and former BBC colleague Ivor Walsworth. It was a piece for prepared tape and live Piano. The piano part was played by Joan Davies, Walsworth's wife.

[206] Oram 2007 (Audio) DO108 Contrasts Essconic Audio


THE REDCLIFFE CONCERTS OF BRITISH MUSIC

QUEEN ELIZABETH HALL

General Manager: John Denison, C.B.E.

FIRST LONDON CONCERT

of

ELECTRONIC MUSIC

by

BRITISH COMPOSERS

MONDAY, 15th JANUARY 1968, at 7.45 p.m.

Tickets 15/-, 10/-, 7/6, 5/- from the Royal Festival Hall Box Office (01 - 928 3191), London, S.E.1 and usual agents

A stamped and addressed envelope should be sent with all postal applications

This concert is given with the support of the Arts Council of Great Britain

C. & C. LTD. S.W.3

Fig. 21. Concert programme cover. Oram 2007 ORAM06/04/017

Also on the bill for the concert was *Partita for Unattended Computer.* This was an aleatoric computer generated work by London composer and technologist Peter Zinovieff,[207]whom Oram had first taught about tape manipulation a few years earlier[208]. The piece was the first in the UK where a computer had been used on stage.

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207 Zinovieff later formed EMS, the company who produced many iconic music technology products including the VCS3 Synthesiser.

208 Zinovieff p. 2010

Cybernetic Serendipity

Later in 1968 a groundbreaking international group exhibition was held at the ICA in London: *Cybernetic Serendipity*[209] curated by Jasia Reichardt. The works explored diverse approaches to computing in art. Within the context of this exhibition, the opposing aesthetic viewpoints of Oram and Zinovieff can be clearly illustrated.

Here is an extract from Zinovieff's contribution to the exhibition catalogue[210]:

> My Studio is now dominated by a computer, and my computer is dominated by other computers. My music tends to be at least partly composed by machines and entirely realised by them.
> This state has gradually arisen over the last few years, because of my deep distrust of the nostalgia and maladroitness of the old techniques of electronic music production, the manipulation by hand of magnetic tape and control knobs, in fact a distrust of recording altogether, and with the idea that there should ever be a finished, once and for all, piece of music. It is preposterous that one should be expected to stick pieces of tape together, and to collage simple recording together by these techniques. The arrogance is extraordinary, and it is only because of this marvellous first flush of arrogance in others that I have acquired an attitude of arrogance to these techniques themselves.

[209] Reichardt, J. Ed. 1968, Cybernetic Serendipity Exhibition Catalogue
[210] Ibid

And here Oram expresses her opinion in a letter to New Zealand composer Douglas Lilburn:

> In the end our school of thought might win this battle too. Meanwhile here in London the I.C.A are mounting a big exhibition called Cybernetic Serendipity costing a mint of money. Everything to be strictly Aleotoric, [sic] so that's ruled me out.[211]

Strangely, as Oram had stated she was ruled out from exhibiting, another reference seems to show that Oram was in fact, invited to take part. In the *Computer Arts Society* folder of the Daphne Oram Archive, a photocopied ICA magazine from September 1968[212] refers to Oram having been invited to participate.

In the Oram's correspondence to Lilburn quoted above, Oram also favourably refers to an article by Tristram Cary on the subject of serialist techniques in electronic music. The article was entitled *Superserialismus - Is There a Cure?*[213] It was published in *Electronic Music Review* issue 4.[214] Cary's article is a critique of some of the techniques being employed by electronic musicians, and expresses a concern that a composer's lack of talent may be easily disguised by taking on the role of a serialist composer. Oram evidently rated it highly, and perhaps interpreted the essay as vindication of her own aesthetic and musical beliefs.

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[211] Oram 2007, ORAM09/04/064. Letter from Oram to Douglas Lilburn, 23rd Jul 68

[212] Oram 2007, ORAM05/04
[213] Cary, T. 1967
[214] Electronic Music Review was published by Robert Moog from his Trumansberg synthesiser factory.

Two extracts from Cary's essay follow:

> We tend to suffer from Superserialismus, or the pursuit of the perfect crossword puzzle. Ever since Schoenberg, the pitfall of serialism has been that it provides a refuge of acceptable academicism for the creatively under-endowed (this does not apply to Schoenberg - needless to say).
>
> […..]
>
> Q: Why did you make that sound?
>
> A: (from serial composer) Because its pitch is number 4 in a thus and thus series which I have calculated; because its loudness is part of a controlled program of dynamics on thus and thus principles; because its length is determined by a thus and thus metric structure. This is the sound, friend - there it is, there could be no other sound in this place.
>
> A: (from non-serial composer) Because it seems musically right at this point; because I have been writing music for X years and am prepared to back my experience and intuition; because I rather like it.

So Oram interpreted Cary's words as in keeping with her own views. However in the view of this researcher, Cary's essay seems to be a rather more balanced critique of what he had witnessed in the field of electronic music. It advocates using the new computer-based, aleatoric and serialist, techniques with caution and consideration, rather than dismissing them out of hand. Perhaps Cary's views sat firmly between the rather more extreme and opposing positions of Oram and Zinovieff.

This background on the aesthetic/technical preferences of Oram and others has been introduced with a view to contextualising another pivotal moment for British electronic music. Shortly after the Cybernetic Serendipity exhibition, something happened which was to have a more material impact on the careers of Oram and her peers.

The 1971 Meeting

A series of documents in the Daphne Oram Archive[215] all pertain to a meeting, which took place in 1971, and the documents reveal the following background and motivations.

As more musicians and researchers were attempting to find their way in the field of electronic music through the 1960s, and in light of Oram's successful funding bid to the Calouste Gulbenkian Foundation, some of these researchers also attempted to get funding through the foundation and also the other natural avenue: The Arts Council of Great Britain.

So, rather than considering the applications piecemeal, the CGF and the Arts council decided to hold a meeting of experts, in to attempt to form ideas for a national strategy for the funding and development of electronic music in the UK.[216] The meeting took place on the 22nd September 1971, at the offices of the CGF in Portland Place, London.

The CGF stated in their introductory letter, that individual grant requests would not be discussed at this meeting and that it was for the purpose of a general overview to help them plan when, and more crucially *if*, they would decide to invest further in this field.

At the meeting Peter Zinovieff, Tristram Cary and Harrison Birtwhistle circulated a pamphlet[217] outlining a proposal that Zinovieff's computer controlled electronic music studio (which by now belonged to EMS, the company Zinovieff et al. had formed to finance it[218]) could be donated to the nation on the grounds that it was housed, and that the operation was financed in some way.

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[215] Oram 2007, ORAM01/2/82 – 85 (Calouste Gulbekian Foundation) letters of invitation, explanation, and meeting minutes.

[216] See also Candlish, N. 2012

[217] Oram 2007, ORAM01/02/057. Proposal from Birtwhistle, Zinovieff and Cary to donate the EMS to the nation. 1971

[218] Ibid

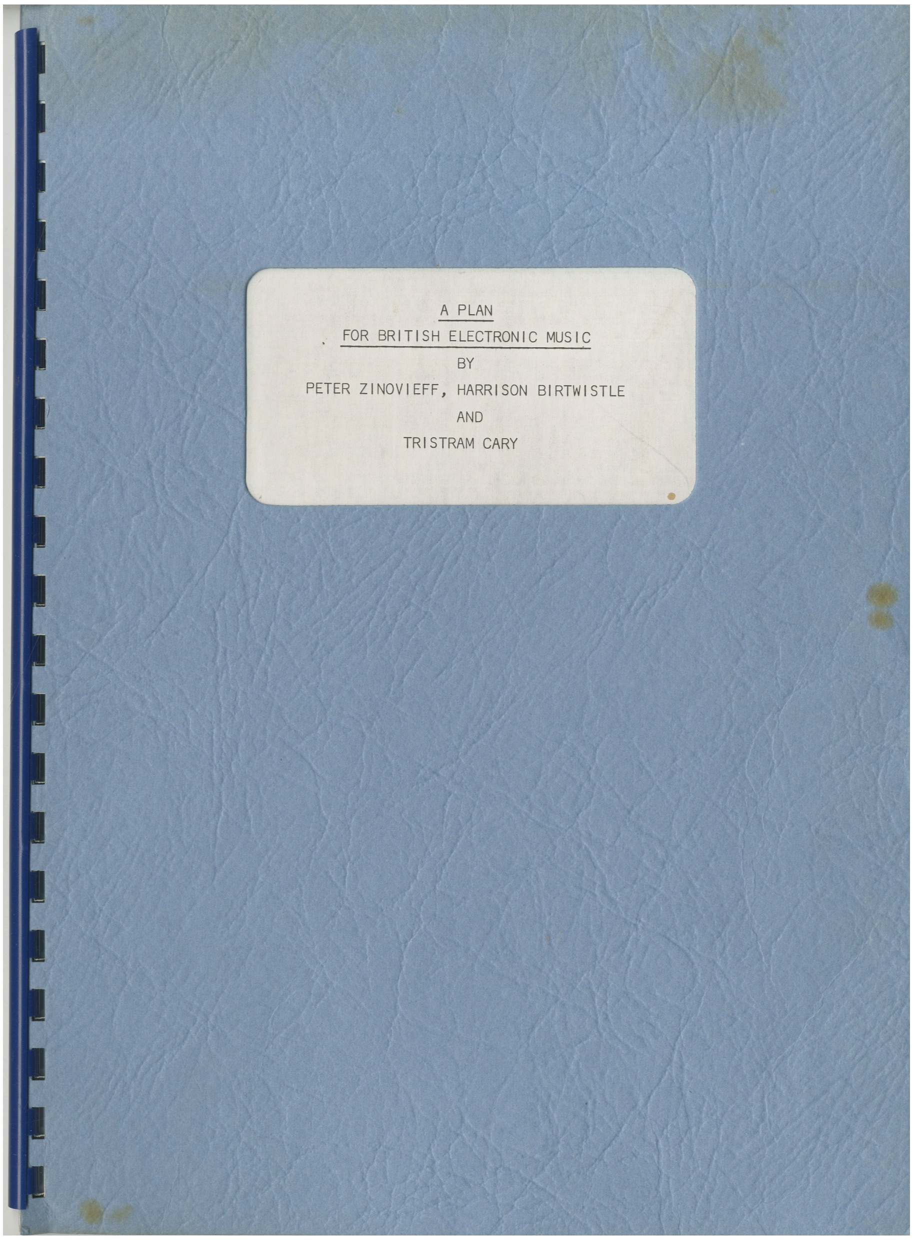

Fig. 22. The pamphlet circulated at the meeting by Zinovieff et al.[219]

In general the attendees of the meeting were supportive of the EMS proposal, although some including Oram, composer Thea Musgrave, and David Lumsdaine of Durham University all agreed that any national studio should not be limited to EMS equipment. Oram also stated that more money should be available for invention of new techniques, and that she would find it very difficult to commercialise Oramics without institutional support.

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219 Ibid

At the end of the meeting however, there was bad news for all of the attendees. The meeting notes detail Arts Council representative John Cruft's closing comments as follows:

> …so far as the prospect of increased help for electronic music from the arts council was concerned, he had to sound a note of caution. The subject was a controversial one; many of its possibilities lay outside the field of the arts altogether and much of it, particularly in universities, was in the field of education. The audience demand for music of this type, moreover, was unproven. It would be very hard to persuade the (Arts) Council to give greater financial support than (it does) at present.[220]

Unfortunately for Zinovieff, the plan to donate the EMS studio to the nation never came to pass, and a series of unsuccessful financial dealings led to the demise of EMS and his studio at the end of the 1970s[221].

In Oram's case she received no further grants from the CGF and she continued to get by as best she could through the 1970s as the Oramics Machine became less and less operable. It would seem that as the seventies progressed, her career slowed down and she received less offers and invitations.

In Oram's correspondence from the late seventies is a draft letter[222] stating that her twenty year old studio was no longer working, and in the same folder is a application form to become an AV technician in a local library, evidently things had become more difficult as the 1970s progressed.

The 1980s and Oram's computer work will be briefly covered in *Further Research.*

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[220] Oram 2007, ORAM01/2/84. Meeting minutes of the CGF / Arts Council meeting, 1971.
[221] Pinch, T. and Trocco, F. 2002
[222] Oram 2007, ORAM09/04/080

CHAPTER 5.1: RE-IMAGINING MINI ORAMICS

Justification for Practice Based Research

It is documented[223] that in the early 1970s, Oram hoped to commercially release a simpler and more portable version of the Oramics Machine, primarily intended for the educational market in the UK. Initially she worked with friend and technical advisor Norman Gaythorpe[224] in conjunction with her old school: Sherborne School for Girls. It was Oram's intention that she and Gaythorpe would design the electronics, and that the engineering workshop at Sherborne would develop the necessary transport mechanism according to Oram's specifications. Subsequently in 1976 Oram met Peter Manning[225] and John Emmett from Durham University, and Emmett went on to assist with the improvement and finalising of the Mini Oramics circuit designs, incorporating digital logic gates, operational amplifiers (op-amps) and analogue switches; bringing the technology up to date, with the hope of improved reliability and compactness. An almost complete electronic design for Mini Oramics[226] is held in the Oram Archive[227] and this version is dated 1976 but also states that the circuits were re-drawn in 1981. The design is credited to Oram and Emmett. This document also includes a basic specification for the mechanical system to be employed, and the media that would be used to draw the composition being read by the machine.

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[223] Oram 2007 ORAM/01/06 (Mini Oramics design). See also Oram 2007, ORAM/01/02/066 (correspondence with the Calouste Gulbenkian Foundation regarding the selling of Oramics patents)
[224] Oram 2007, ORAM01/06, Oram's correspondence with Norman Gaythorpe regarding Mini Oramics. Early 1970s
[225] Manning, P. 2013
[226] The design appears to contain most of the circuitry necessary to start building a prototype, but also suggests additions or modifications in places, indicative of afterthoughts and potential drawbacks.
[227] Oram 2007, ORAM/01/05/001. The design is included in full, in the appendix of this thesis.

It can be argued that Oram's decision to considerably simplify and miniaturise her Oramics Machine before attempting a commercial release was insightful. Pinch and Trocco[228] argue that some of the defining factors that gave comparative success to the contemporaneous *Minimoog* and *VCS3* synthesisers were their small size, relative cost effectiveness, and simplicity of use. This could be seen as somewhat ironic, as the creators of both machines had much more interest in wider ranging, more complex systems: Moog's large modular synthesisers, and Zinovieff's computer-based music studio. In these cases, this *success* can be most simply defined as early adoption by a broad range of musicians and studios. Commercially speaking, the stories behind both devices are rather more complex and do not necessarily warrant the term *success*. As was discussed in the theoretical framework section of this thesis; early adoption is often key to the development of a technical artefact. Mini Oramics never had the chance for early adoption, as it was unfortunately never commercially released. Meanwhile the Mini-Moog and VCS3 (amongst others) went on to define the synthesiser as we know it, despite neither making much money for their creators. [229]

Of course, the Minimoog and VCS3 represent very different interfaces to the one Oram proposed. Both had a keyboard (it was optional on the VCS3), and were performable instruments, rather than score reading machines. However, shortly after the development of the voltage controlled modular synthesiser and its subsequent development into products like the Minimoog, technologists turned their attention to producing sequencers for the new synthesisers. The combination of synthesiser and sequencer is much more analogous to Oram's technology, albeit a system with very different aesthetics, both in terms of sonic output and user interface.

At this juncture, it is tentatively proposed that the domination of voltage controlled synthesiser technology throughout the 1970s can be perceived as somewhat of an anomaly in the evolution of electronic music technology. Broadly speaking, if one were to visualise an evolutionary arc from the imagined machines proposed by Varèse et al in the 1930s, through to Musique Concrète, the RCA and ANS synthesisers, the beginnings of computer music, through the Cubase piano roll, and up to the modern day DAW or digital audio workstation, it could be argued that Oram's technologies would

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[228] Pinch, T. and Trocco, F. 2002.
[229] Ibid

have been more natural fit in this arc, especially when compared with the technologies which were most commonly utilised in the 1970s, before the era of home computing. Mini Oramics seems a more natural fit, as both the beginning *and* end points of this arc (and much else in between) represent linear technologies, where musical events are coded in time using a linear and/or graphical medium, whether it be punched cards, tape splices or graphically represented events on a digital timeline on a computer monitor. Oramics fits this model, and broadly speaking, voltage controlled analogue synthesiser technology does not.[230]

Of course there were other relevant contemporaneous technologies which were perhaps more comparable to Oramics and Mini Oramics. Xennakis' UPIC system and Murzin's ANS Synthesiser being prime examples: both featuring graphical interfaces for the control of musical parameters over time. But if one is situating Mini Oramics within the commercial realm, and within financial reach of smaller studios (perhaps even home studios) then these examples still fall firmly within the ivory tower category and outside of the market Oram was intending for Mini Oramics - even if they had been commercially released in any form.

Mini Oramics then, is most interesting in terms of lost potential: had circumstances been different, if it had been commercialised, might it have succeeded?

This question, as already discussed, is not possible to answer conclusively, yet the technical and aesthetic appraisal of Oramics in any of its guises will surely be more effective when there is some practical experience of both building and using a similar interface. Therefore, to expand upon the knowledge derived from the empirical and archival research, an attempt to re-invent and construct a version of Mini Oramics forms the practice-based element of this PhD research project.

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[230] This statement refers to studio-based non-real time composition techniques, as opposed to the parallel development of live electronic music performance systems - in which voltage controlled synthesisers played a vital part. Throughout this complex history there has always been a large strand of electronic music technology devoted entirely to non-live, pre-sequenced music. The combination of analogue synthesiser and step-sequencer is pertinent to both disciplines. In the absence of many cost-effective alternatives during the 1970s however, this statement is meant in reference only to this non-live discipline.

A Brief Explanation of the Daphne Oram and John Emmett 1976 design for Mini Oramics.

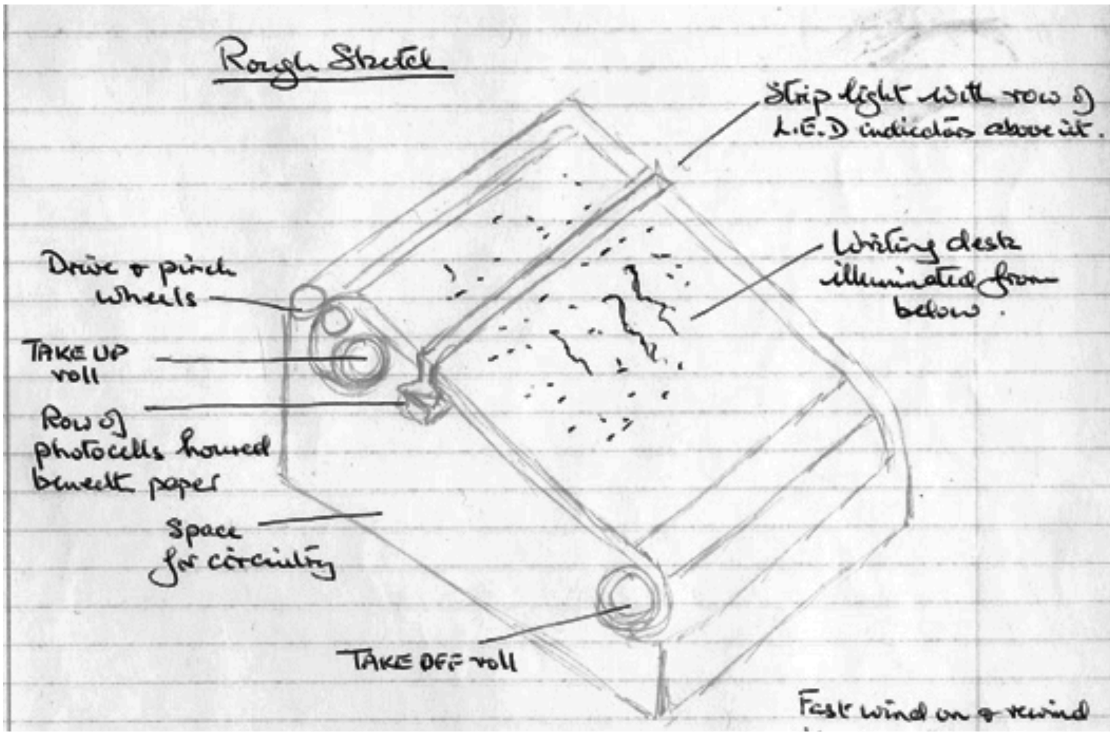

Fig. 23. Oram's sketch of how she envisaged Mini Oramics. Oram 2007, ORAM/01/05/001

The Oram/Emmett design for Mini Oramics is included in the appendix of this thesis. However before going on to evaluate this design and describe the process of building a contemporary version, it is helpful to briefly explain how Oram's design for Mini Oramics would have worked.

The same three-step process as the original Oramics Machine also applies in essence to Mini Oramics, but with some significant changes in the operation of the timbre, pitch, and volume controls.

Firstly in order to define the usable wave patterns (timbres), three horizontal wave patterns were to be drawn in a vertical array on the same glass slide. This slide was to be placed across the CRT screen of an unspecified external oscilloscope. A hood with a light sensor at the rear would then be placed over the slide. Then a simpler op-amp based version of the sawtooth oscillator and y-axis feedback circuit would scan the central wave-pattern in a similar manner to the original Oramics Machine. To select a different wave pattern, the Y- axis could be offset up or down with a fixed DC voltage offset (which was selected by drawing in the appropriate section of the main programming medium). This would have shifted the scanned area to a different drawn wave outline. The system thus offered three timbres, but with the limitation that it would not have been possible to use more than one simultaneously.

The next step was to draw an outline melody on the programming film, which was now to be one wider (30cm) roll of material rather than the multiple 35mm films used in the original. The method for inputting the melody was to be more intuitive, as each note had its own trigger, rather than needing to be entered as coded neumes. Oram planned a separate optical switch for each of the 12 notes in an octave. Then a separate optical switch per octave, to transpose up or down across 7 octaves, and then a further 3 switches to allow 1/3 tones 1/4 tones or 1/8 tones to be added to the base melody, giving Mini Oramics precise microtonal possibilities. Again a vibrato (or pitch bend) control was included, but this time it was to be digitally controlled with eight distinct steps controlled by optical switches. In the case of most of these banks of optical switches, like the original machine's reed relays, they were to switch in and out different adjustable preset type resistors, which in turn would affect the pitch of the time-base oscillator. In the case of the octave control, capacitors were to be switched in and out instead, to similar end.

After drawing the outline melody, the operator could then construct the dynamics of the piece. The volume and reverb controls relied on identical banks of optical switches to the pitch control, and in this case the switches were to simply select between 8 discrete volume levels for the 'envelope' or fine volume. Then a further bank of 8 switches selected the 'coarse' or overall volume. In this way the composer could have constructed the dynamics of the melody line, and then adjusted the whole section in volume relative to other sections of the piece using the overall volume control. The reverberation control[231] was to have three send levels and three return levels as well as a bypass switch. All of these volume switches simply used analogue switches to select different resistors to passively attenuate the signal.

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[231] This was a simple effects send and return function. Oram did not include a reverb design or driver amplifier or receiver preamp, but specified using either an external spring reverb or a reverberation room.

Again, a motorised transport mechanism would then move the score over the bank light sensitive components (the play head), triggering the appropriate switches and playing back the composers work. Oram specified that this mechanism should have five selectable speed settings. Each parameter would then have had a matching bank of LEDs above the play head, to indicate to the user whether the machine was following the score correctly.

Another operational similarity with the original machine was that when a new instruction was received within any given parameter, it would reset all the others so that there were no clashing instructions. A note on the design suggests a possible improvement to the logic circuitry. This was to allow some prioritisation to take place should two triggers be activated simultaneously by any erroneous illegal input from the drawn symbols.

A particularly elegant feature of the Oram/Emmett Mini Oramics design is that the exact same simple optical ‘read-latch’ flip-flop circuit is employed for every single parameter control, and these sixty or so sub-circuits all control the same CMOS 4013 type analogue switches to varying ends. The multiple identical inputs would have made manufacturing and servicing the device cheaper and simpler than some alternative approaches.

However some elements of the design have notable drawbacks, and a critique of the design will follow, before moving on to the description of the process of building a contemporary version of Mini Oramics.

Methodology for Practice Based Research

The first step in this project was to assess the existing design for Mini Oramics and construct a critique of it. During the process of formulating this critique, two experimental circuits were constructed from Oram's schematics, which allowed some additional insight into potential design flaws. These were the oscilloscope-based wave scanning circuit and the read/latch flip-flop circuit. The key points of this preliminary examination are outlined below:

- The existing design was to use an unspecified external oscilloscope and light sensor hood to comprise the waveform-scanning oscillator. A system able to operate without any reliance on external equipment would have been preferable for several reasons. Oram's design would have required individual calibration to any given oscilloscope (depending on the brightness, light wavelength of the display and other factors external to the Mini Oramics design). This would have made the device less user friendly, less portable, and less reliable. The many controls present on the front panel of the oscilloscope would all have had an effect on whether or not the system operated correctly. In the context Oram proposed: music studios in schools and universities, it would have been prone to being fiddled with. Downtime and re-calibration would have been the result.

- Oram proposed using a simple optical-feedback function generator circuit taken from an electronics magazine article[232] to make the wave-scanning oscillator (in combination with the oscilloscope and light sensor hood). The frequency range specified in the article was insufficient to cover a significant part of the audio spectrum: only 500hz. An attempt was made to re-construct the circuit in question and it was very difficult to get it to behave with any stability above this rather low threshold, and the results varied significantly depending on the oscilloscope used.

- The system for the selection of wave shapes was vastly inferior to the original Oramics Machine. The Oram/Emmett design allowed the composer to select one of three wave-patterns drawn on a glass slide, using a DC offset voltage to the Y

[232] Oram 2007, ORAM/01/05/001 Mini Oramics Correspondence

(Vertical) Axis on the oscilloscope, but this did not allow for smooth fades between timbres. One of the most impressive design features of the original machine was that the composer could smoothly fade between timbres within a given musical note. This was a compositional and technical nuance that Oram had earlier prioritised after analysing the audio response of acoustic instruments. It seems a huge compromise to drop this feature on Mini Oramics. It is also evident that Oram still valued this feature as she started work on Mini Oramics in the early 1970s, as she spends some time explaining the importance of this feature in her book *An Individual Note:*

> It is most important to hear, immediately, the aural effect that the volume envelope tracks are having on the timbre shapes, and also to be able to blend and alter the timbre within the duration of a single note.[233]

- Oram's design, like the original Oramics Machine, was a stand-alone system. It offered an interface that allowed for drawn input and audio output, with little or no possibility for expansion or compatibility with other equipment. It would not have been much more difficult to make a design which was operationally very similar, but one that used standard control-voltage and gate (CV/Gate) signals, which could then have made it compatible with other manufacturer's technologies, broadening its appeal and its range of functionality. If CV/Gate had been employed, an external sequencer or keyboard could have controlled the wave-scanning oscillator, or the programmer of Mini Oramics could have sequenced other analogue synthesisers for instance, although many other possibilities also present themselves with a CV/Gate based design.

- With reference to the above point, Mini Oramics could also have easily included some general-purpose gate tracks, designed to trigger external equipment. These could have been interfaced with percussion synthesisers, external tape machines, slide projectors etc.

- One element of the overall Oramics concept, which dogged Oram's progress with

[233] Oram, D. 1972. P132

both mechanical versions of Oramics was that of the opacity of the chosen drawing medium. Oram spent a lot of time evaluating different clear or translucent media with different types of ink and paint etc, trying to find a combination that would allow the optical sensing devices to give an appropriately significant change in voltage to trigger digital logic. In fact this research was absolutely unnecessary for the digital inputs, as a simple comparator circuit on each digital input channel (all input channels in the case of Mini Oramics) would have allowed the electronics to respond appropriately to much smaller deviations in illumination. For instance, marker pen on cellophane, which only gives perhaps a maximum of a 30% drop in illumination,[234] could have been employed without worrying about false-triggers or non-triggers. With Mini Oramics, Oram eventually opted for greaseproof paper and a soft leaded pencil to maximise opacity. This combination might well have caused major problems with messy smudged scores deteriorating over time. Greaseproof paper would also have had a light diffusing effect, possibly increasing the likelihood of optical interference between input channels.

- The Oram/Emmett design for Mini Oramics used sets of opto-digital inputs to represent a range of parameters, for instance each volume (or envelope) control had eight discrete settings. It is unlikely this ‘stepped’ control would have been able to fool the ear into perceiving a smooth gradation in volume[235] and thus the listener would have perceived a discontinuous gradation. Instead, utilising control voltages would allow these steps to be smoothed off by a low frequency low pass filter (or slew limiter) to then provide VCAs with a smoother control signal, significantly improving the quality of the parameterised controls. In the case of pitch, these (adjustable) slew limiters could then function as an optional glissando control.

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[234] A figure derived from my own measurements whilst attempting to build a version of Mini Oramics.

[235] Typical modern digital volume controls utilise over 100 discrete steps to fool the ear into perceiving a smooth adjustment. They also often utilise a technique called *zero crossing detection* to avoid unwanted clicks and audio artefacts.

Although it is not possible to prove conclusively, it appears that the Oram/Emmett Mini Oramics design was a pre-prototype first draft design. It is very likely that had it been constructed, some of the above issues would have become evident and the design would have evolved further. The fact Oram later added the wave-scanning oscillator from the magazine article[236] dated 1980 further supports this theory, and this part of the system appears not to have been fully dealt with in the 1976 Oram/Emmett collaboration, as there is a sawtooth wave oscillator to drive a CRT X-axis, but no feedback amplifier or CRT circuitry to derive a drawn wave-shape. That is, not until Oram adds the feedback circuit from the magazine article dated 1980.

[236] Oram 2007, ORAM/01/05/001, see appendix.

Re-imagining Mini Oramics: Towards a New Design

The next stage in the process was to create a set of rules and assumptions that would guide the development of a new hardware prototype:

- The design should incorporate the criticisms and potential solutions outlined in the critique of the Oram/Emmett design.

- The design should be constructed in such a way that it would have been possible to construct in 1973 (arguably the ideal launch date for such a device, as will be further discussed).

- The design need not be *fully authentic* in the sense that it is made purely from components of that era. It is to be assumed that a design using op-amps, simple logic gates, and analogue switch technology would have been achievable in that era, given that all of these technologies were commercially available as integrated circuits in 1973[237]. It is to be hypothetically assumed for this purpose, that Oram did sell her patents to a developer (as was her intention), and thus a professional mechatronics design team were able to hone and optimise her ideas for the E.M. market, and overcome any technical issues. For the purposes of this project I will become that hypothetical *design team,* and what I lack in professional electronics expertise will be offset with the use of modern materials and CAD/CAM software, as well as access to the many DIY synthesiser resources now available online.

These assumptions and design criteria privilege an optimal commercially oriented version of the Oramics concept, over the concept of authenticity. The approach prioritises having access to a working machine within the timescale of this project, and being able to utilise such an interface for comparative evaluation of potential, rather than trying to build or re-create something which is authentic to component level, yet flawed in its design as outlined in the previous critique. It is arguable that the Oramics

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[237] The history of the development of the various electronics technologies employed in the new Mini Oramics, was sourced from the Texas Instruments website where they offer a timeline of integrated circuit technologies.

concept is better than any of its physical manifestations, and it is hoped that this approach to the practice-based research might assist in confirming or disproving this argument.

The collaborative method for evaluating the device will be detailed after the description of the build process.

Building Mini Oramics

I should state clearly that at the start of this project I was by no means an electronics design engineer, and nor am I now. I have had some limited training in electronics (A-Level, 1996), and have continued to utilise and add to this knowledge in the course of my art and music practices. I had designed and made several electronic musical instruments before undertaking this research, mainly with a rhythmic loop based focus, but none of these instruments were anywhere near as complex as this project would turn out to be.

Considerable research into the techniques of analogue synthesis has been undertaken, and simultaneously I have been learning electronics CAD software (National Instruments *Circuit Design Suite*) to assist with my designs. Over the course of the practice-based project, my knowledge of both analogue synthesis, digital electronics design, and the use of CAD have by necessity, significantly improved.

Drawn Wave-shaping Techniques

The first practical experiment undertaken was to try and build the wave-scanning oscillator specified by Oram[238] in her final Mini Oramics design.

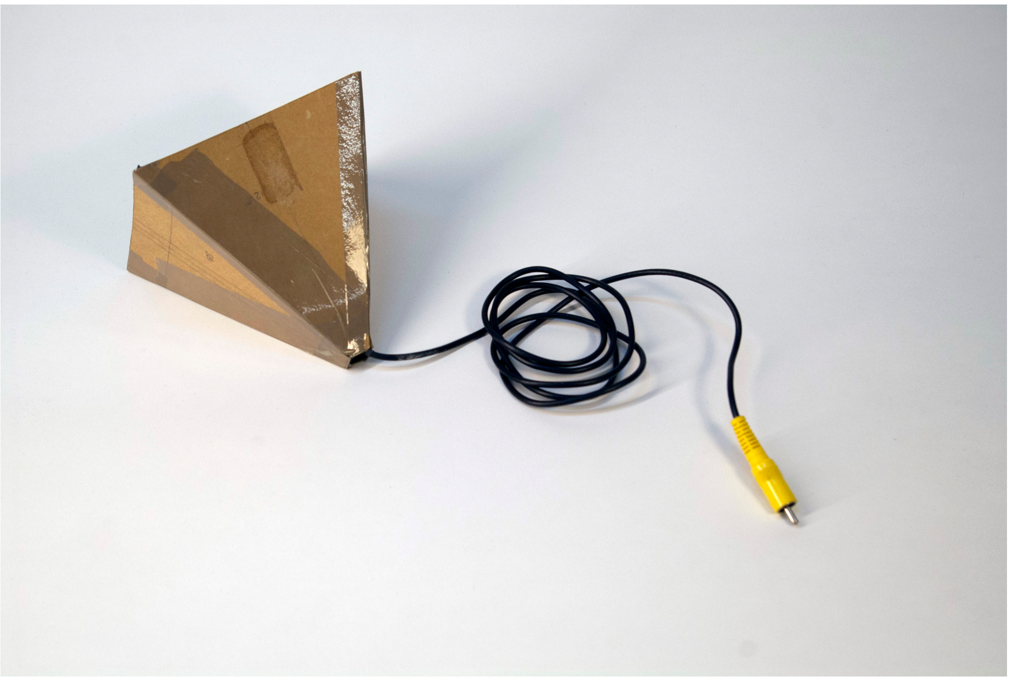

Fig. 24: Oscilloscope hood with integral light sensor, made to test wave-scan circuit.

I am sure that it would be possible to adapt the design to achieve the greater stability and reliability necessary to achieve a stable response across the audio spectrum: not just the very limited 500hz specified for the circuit (most likely limited by the relatively slow response of the specified LDR sensor). However even within the frequency constraints specified, the initial results strongly suggested to me that another route would be preferable. I tried the circuit with two different oscilloscopes and the results were vastly different. One of the oscilloscopes was unable to trace the waveform at all, and on the other, the device would often scan only half the wave before jumping to zero. If one extrapolates these issues to the launch of a commercial venture, it seems very likely that each different customer would get differing results from their own oscilloscope, not to mention the numerous controls on each oscilloscope also being able to accidentally disable the operation of the device. The resounding conclusion of these trials was the decision to scrap the external oscilloscope and find an alternate solution for a drawn waveform generator.

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[238] Oram 2007, ORAM/01/05/001

I decided to simulate the drawn sound technique using an existing technology: the multiplexing of numerous discrete voltages to create a waveform[239]. This approach is analogous to the way Oram sought to control the other parameters with Mini Oramics. The technique is identical to that used in step-sequencers for voltage controlled synthesisers, and when sped up can create audio waveforms. Both Forest Mimms and Peter Manning have described this process[240]. In fact, after starting with this approach I came across a commercially available VCO synthesiser module that also employs this technique[241]. When the discrete voltages are controlled by a row of slide potentiometers like those in a graphic equaliser, it enables the operator to 'draw' the waveform. One then adjusts the multiplexing frequency to adjust the overall pitch. In this case, as I thought it advantageous to be able to integrate the new device with other CV/Gate control systems, I decided to control the multiplexer frequency with a voltage controlled oscillator (VCO) rather than a closed resistor/capacitor network which Oram opted for in both the original Oramics Machine, and in her plans for Mini Oramics.

There is an inherent problem with this multiplexing technique, as the waveforms outputted are stepped (like a very low quality digital audio sample) and this imposes a harsh and unnatural set of overtones to the waveform. However this problem can be largely overcome with the use of a voltage controlled low pass filter (VCF) applied to the output. If the VCO and VCF are calibrated appropriately and applied with the same control voltage, the filter effectively rounds off the steps of the waveform to the same extent whatever the pitch, getting rid of the overtones and keeping the timbre more or less constant over the range of required pitches. Fig. 25 on the following page shows examples of a 'stepped' waveform and the same waveform after filtering. These images were generated with the first prototype (ten step) circuit I built which is shown in Fig. 26.

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[239] I was also keen to avoid CRT components, which are expensive, obsolete, and require very high voltages to operate.
[240] Manning, P. 1985. and Mimms. F. 2000.
[241] Ian Fritz's *Double Deka VCO*

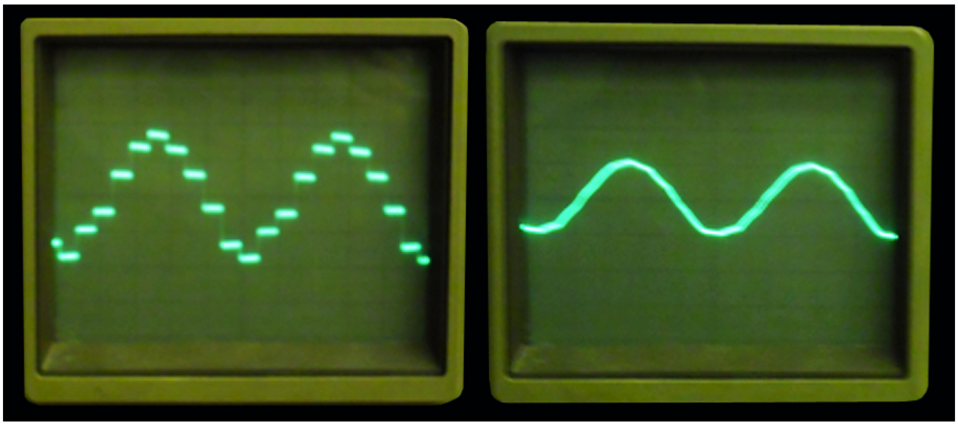

Fig. 25. Stepped waveform derived from multiplexing technique, and the same waveform after appropriate filtering.

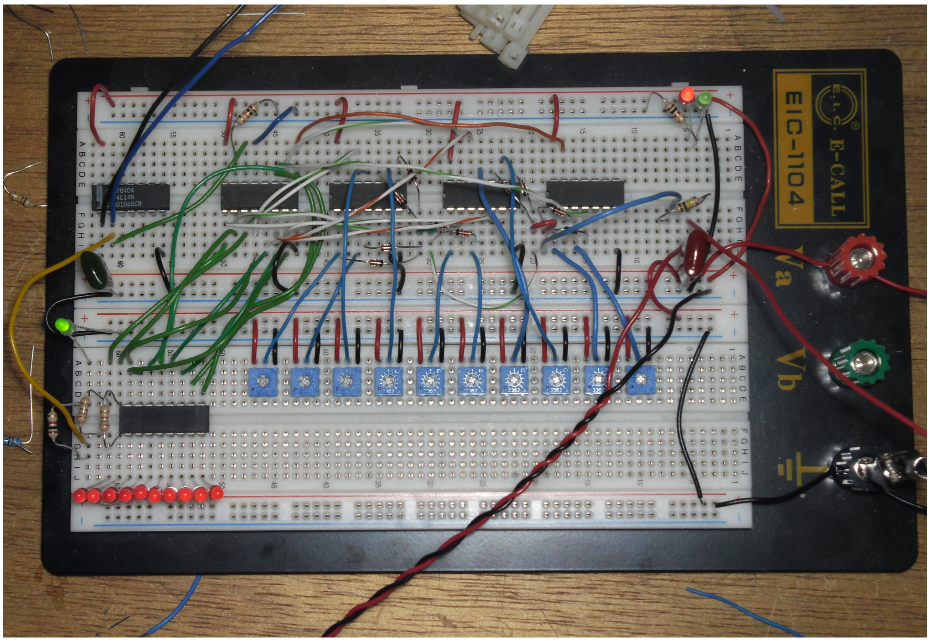

Fig. 26. Initial ten-step multiplexer waveform generator built on breadboard.

This first design[242] was built purely to prove the principles, and did not utilise either a VCO or VCF. The square wave needed to drive the multiplexing circuit was a simple astable circuit controlled with a variable resistor, and the filter was a simple fixed frequency low pass filter tuned to suit one particular frequency.

Having proven the principles, I then built a 16-step version, which incorporated a VCO

[242] Initial video of the 'drawing' of waveforms can be viewed here. INCLUDED MEDIA 003

and VCF. I did not design either circuit, but used circuits published by R A Penfold[243] and combined them with a 16-step analogue multiplexer chip and 16 potentiometers to make a more complete system. This second prototype incorporated the previously described graphic slider arrangement as shown in Fig 27 below.

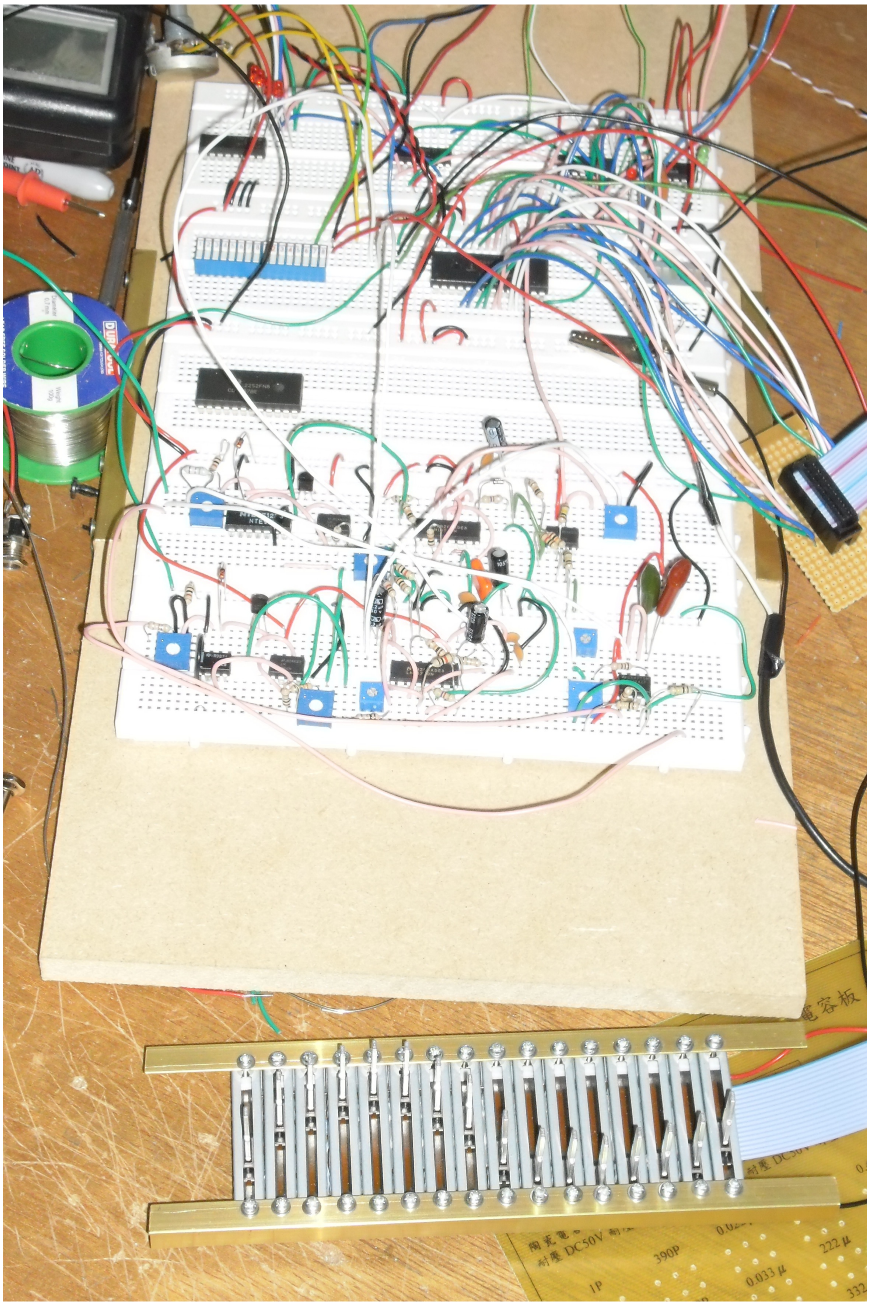

Fig. 27. Second version of wave scan oscillator with 16 steps.

[243] Penfold, R A, 1986

Sequencing

I started experimenting with using the first prototype (slowed to sub audio frequency) to sequence the second one, and some interesting sounds were achieved. This combination was used in a live performance in March 2013. This performance used the breadboard prototypes as shown, and was relatively successful.[244]

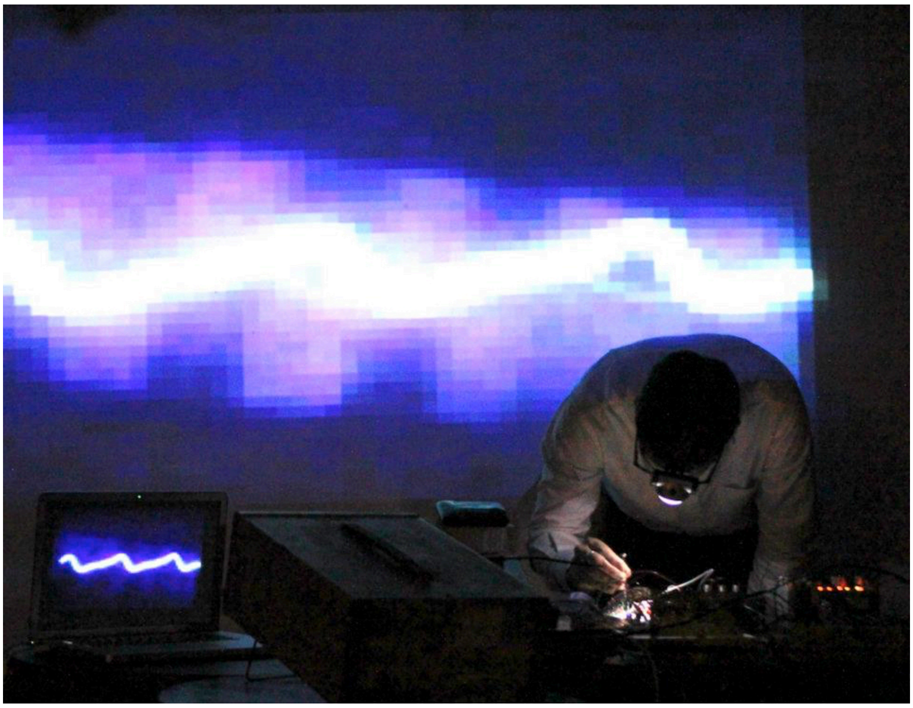

Fig. 28. Performing on the first two breadboard wave-shaper prototypes at the Macbeth venue in Hoxton, March 2013. The ever-changing wave-shapes were projected as part of the performance. Image courtesy of the *Nonclassical* record label.

At this point, somewhat a spin off of the original research plan, I finalised this arrangement of analogue sequencer combined with graphic oscillator and filter and built a more permanent hybrid instrument shown below. This has now been performed numerous times and more details can be found in *Research Outcomes.*

[244] INCLUDED MEDIA 004

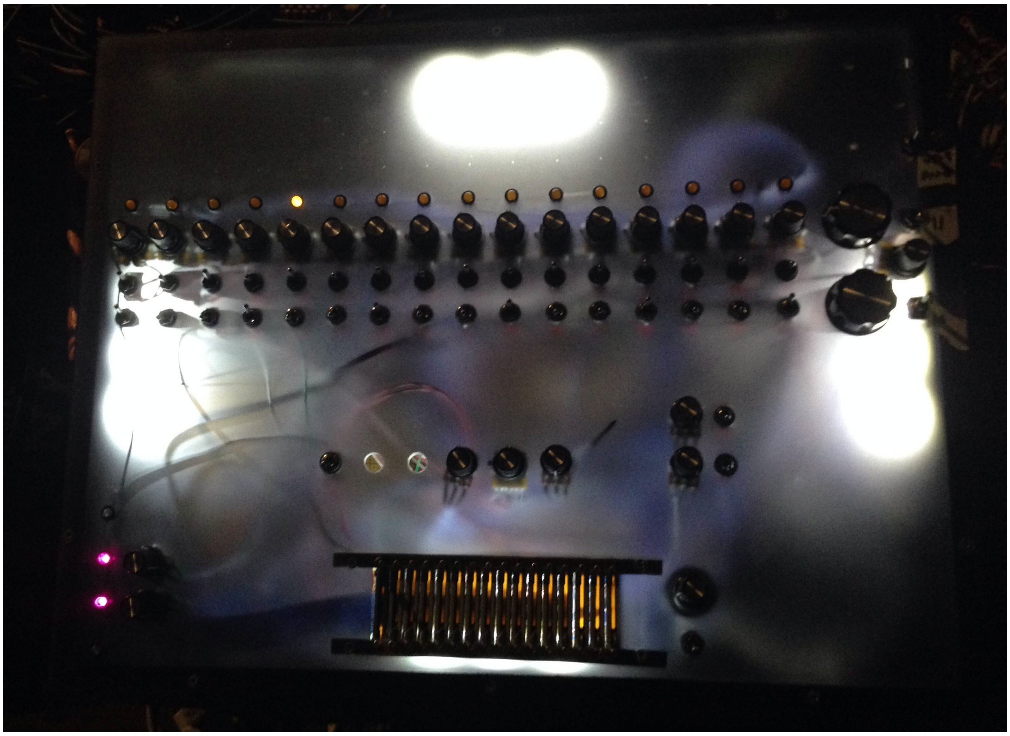

Fig. 29. Hybrid instrument combining graphic oscillator with digital/analogue step sequencer.

There was one other problem inherent within the system I created, although again, it was not insurmountable. The multiplexer clock speed had to be of a higher frequency than the desired fundamental pitch by a factor of the number of voltage steps incorporated into the waveform: in this case by a factor of 16. Most audio VCOs are designed to operate with a standard 1v per octave control voltage to frequency output. They normally respond to the control voltage in a linear fashion within the audible frequency range (up to around 20Khz or less). Many designs no longer function well above this threshold, including the RA Penfold VCO design incorporated into my 2nd prototype, and the hybrid instrument that followed. This means both devices both perform well sub-sonically and up to about 2khz but reaching higher notes is impossible.

It is beyond my skill level to design a VCO more suited to the task, however after some additional research I found some products[245] that considerably extend the upper range achievable. These products were incorporated into a 3rd breadboard prototype, and a far better audio range became possible.

[245] Integrated synthesiser circuits made by Bristol company Hearn Morley, based on the now discontinued Curtis Electro Music chips of the early 1980s.

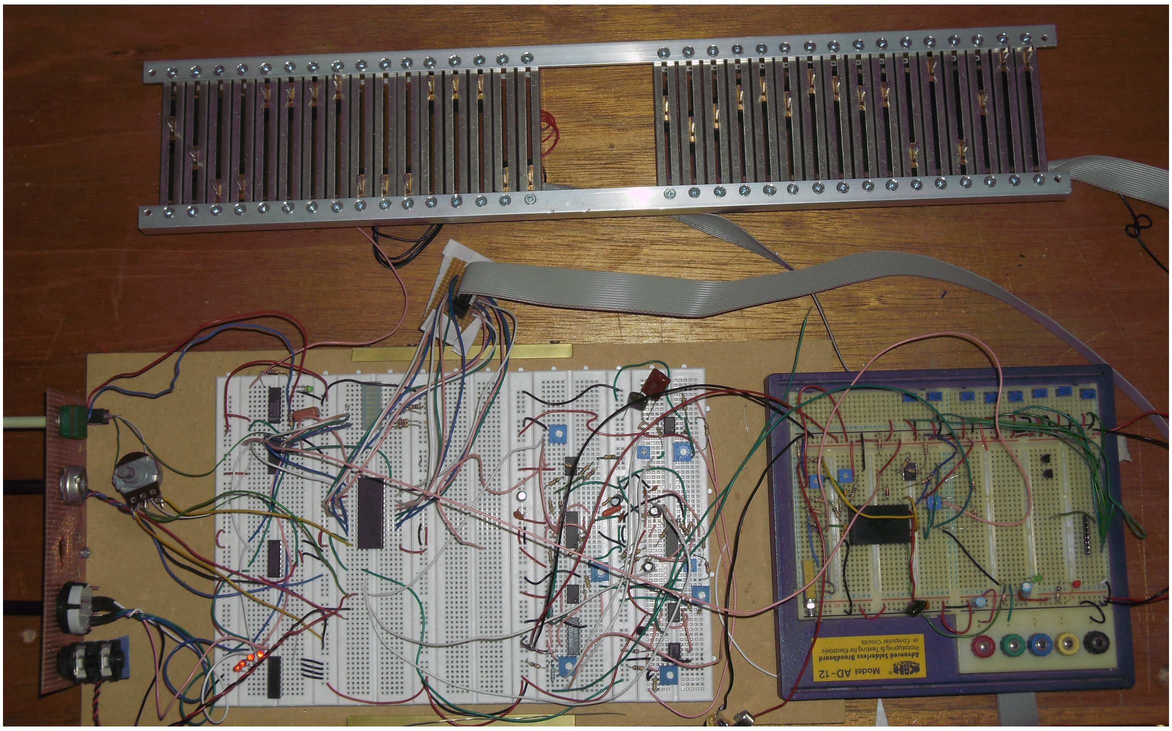

Fig. 30. 3rd Oscillator prototype with larger sliders and improved frequency response.

Transport Mechanism

The next step was to start designing the transport mechanism and optical control interface, which would then replace the step sequencer used in my hybrid version. Of course the opto-digital logic system would be very hard to design or evaluate without some kind of appropriate mechanical transport, so I initially built a small Lego model with four LED /Photo-Diode pairs to detect the changes in illumination made by drawn marks on moving cellophane. I dubbed this interim prototype *Legoramics.*

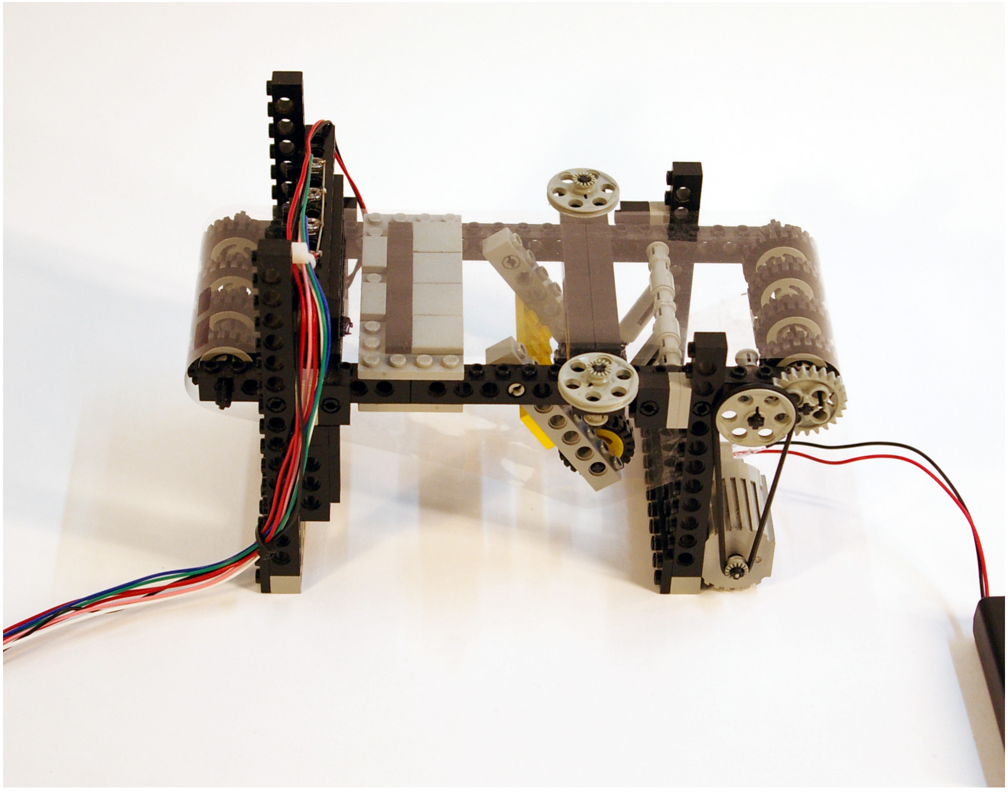

Fig. 31. *Legoramics* interim mechanical prototype with four infrared sensors and LEDS, and a cellophane loop driven by a small motor.

This interim prototype allowed me to start experimenting with some optically triggered parameter-control logic circuits, which are described in the next section. After some initial experiments with these circuits however, it became apparent that any time spent designing them without the use of the final transport mechanism might be a waste of time due to the difficulties presented in transposing the circuits to a new mechanical framework. Before going any further with the electronics I spent the next phase of the process building the transport mechanism. This was early spring 2015.

I decided to make the design in a similar fashion to the classic three motor ¼'' tape-deck design. In this type of system, one motor regulates the speed of the medium using a pinch wheel and capstan. The other motors simply provide back and forward tension to the material to stop it unravelling or becoming loose. The tension motors simply need to go faster than the drive motor (at whatever drive speed is selected), but act via a slipping clutch so that they do not fight the given speed of the main drive. In my design the slipping clutch was realised by means of a rubber washer loosely gripping the edge of the bobbin holding the cellophane drawing medium, and also more tightly fitting the axle connected to the motor. Similar designs with only a single motor are also possible, and are more frequently used in tape and film drive systems. Single motor designs are mechanically more complex however, and simplicity and reliability were my main goals for the transport system as I was hoping not to have to make more than one mechanical prototype.

The other factor in the mechanical design which I thought it important to incorporate, was also similar to ¼" tape technology. This was the possibility of running differing sizes of loops of the drawing medium. In the running of loops, only the capstan/drive roller moves the medium and some means of providing tension must be provided for larger loops. In my design a freely hanging roller pulls the loop down with gravity, to ensure a flat drawing surface and optimal running of different loop lengths within given constraints. The upper and lower loop length constraints are: the minimum distance of one loop around the framework, and the maximum length of loop that can effectively be driven by the drive motor, without the assistance of the tensioning motors.

The width of the unit was defined by my choice to use overhead projector type cellophane rolls, which are as wide as A4 paper is high (292mm) and are similar in size to what Oram had envisaged for Mini Oramics. The control parameters also had to be finalised at this stage, to accommodate the width of the cellophane roll and the size and mounting mechanism for the illumination and light sensing components. These are 3mm LEDs and 3mm phototransistors respectively. They are mounted with 1mm spacings in directly opposing pairs. From these given parameters I worked out the following sets of graphic input controls:

Allocation of Light Sensors

1) Pitch, one octave range, 12 sensors

2) Octave, 8 octaves, 8 sensors

3) Wave-shape A volume, 12 discrete levels, 12 sensors

4) Wave-shape B volume, 12 discrete levels, 12 sensors

5) Reverberation volume, 12 discrete levels, 12 sensors

6) Vibrato/Pitch bend, 9 discrete levels, 9 sensors

7) Triggers/Gates, 6 channels, 6 sensors

Total: 71 input sensors

After designing the transport mechanism on paper, I consulted with artist and designer Christian Nyampeta[246], who produced CAD design drawings for laser cut Perspex to make the framework. The choice of Perspex as a material was made purely because I had some familiarity with it as a medium. With hindsight, other materials may have been preferable due to problems with static electricity making the cellophane stick to the drawing surface (a problem which became apparent on completion of the project).

Nyampeta converted my design into suitable drawings for the laser cutting company, and the framework was ready to fit up with the mechanical and electronic elements by mid March 2015.

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[246] www.christiannymapeta.com

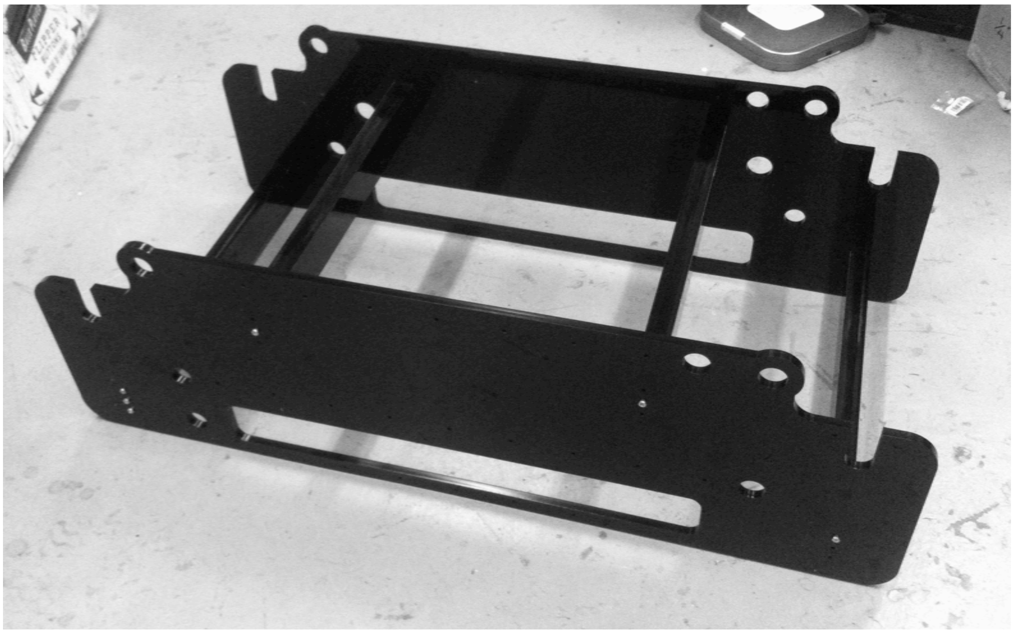

Fig. 32. The initial Mini Oramics mechanical framework. Constructed March 2015

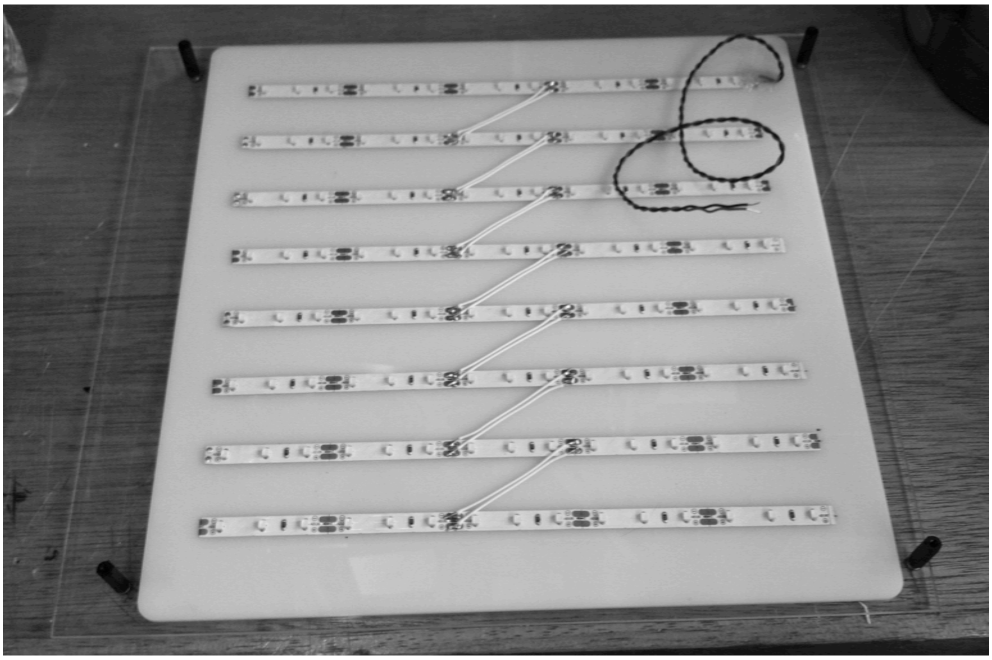

Fig. 33. Mini Oramics LED light-box sub-frame. Constructed April 2015

Motor Control

I then needed to design and build a motor control system so that I could get the transport mechanics working. I chose to use stepper motors for their qualities of high torque at low speeds, precision, and also their relatively quiet operation, which is of course important for a sound-generating machine. I had never used stepper motors before, but managed to build a suitable control circuit relatively easily. I worked directly from designs included with the datasheets of the stepper motor driver chips I had chosen for the project. The only real design work necessary was to combine three drive circuits, so that only one switch and one control knob could appropriately control the speed and direction of all three motors.

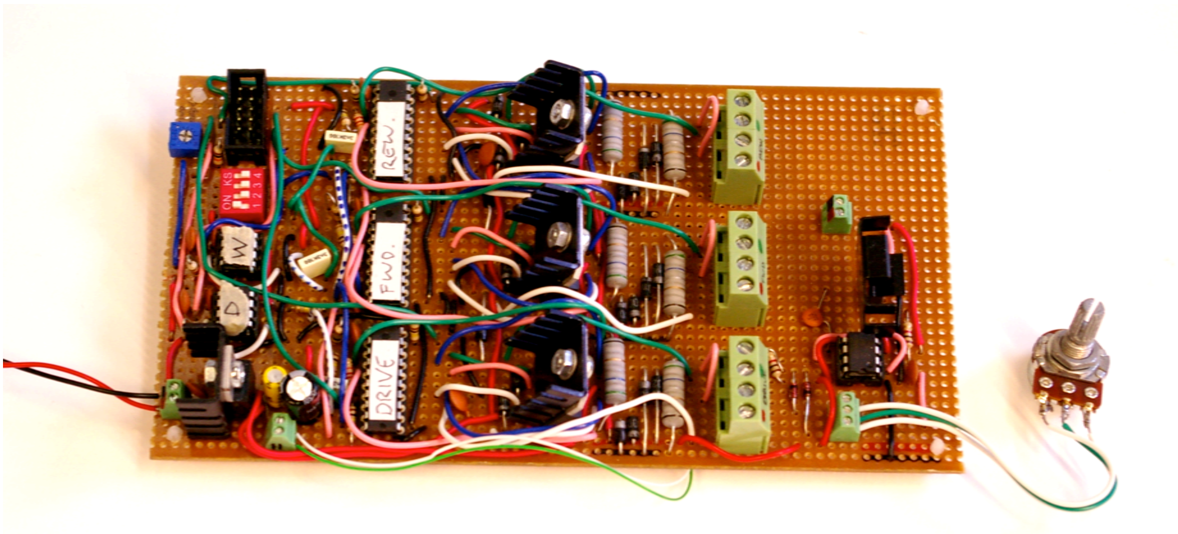

Fig. 34. Three channel stepper motor control/driver circuit combined with a dimmer for the LED lightbox. Constructed June 2015

Initial testing of the transport mechanism in September 2015 was relatively successful considering that it was a first attempt[247]. It certainly worked well enough to get back to designing the graphical-input electronics, which had been on hold during the development and construction of the transport mechanism.

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[247] INCLUDED MEDIA 005

Graphical Input Circuitry

Before being able to further test any graphical input circuitry I needed to connect up a set of light sensors and their respective exciter LEDs. I was then ready to plug new circuit designs into a working transport mechanism for experimentation.

Fig. 35. Wiring the pitch parameter's light sensing components using ribbon cable in order to test the control circuitry.

The Brief for Graphic Inputs

I needed to design an adaptable circuit that could be adjusted to suit all the necessary input parameters. Some parameters would require more sensors than others, as outlined in the scheme above. The brief for such a circuit follows.

- In the first stage of the circuit, a range of 6-12 optical reading devices should be interfaced to a digital logic circuit which would latch onto the last triggered input, and immediately reset all the other latches the moment a new instruction was received. This stage should have the same number of digital outputs as inputs such that only one output (the most recently triggered) is able to be a logical one or high, with all others reset to low.

- Once the prioritised latching circuitry above was working so that only one output was *high* at a time, these outputs would be tied to the same number of CMOS analogue switches such that only one of the switches is activated at a time.

- The analogue switches combine these outputs via a resistor ladder so that each switch will pass a different voltage to the output with all the non-relevant voltage steps being isolated by their assigned analogue switches.

- The output voltages should be buffered and passed through an adjustable slew limiter to enable smoothly changing control voltages to be used where necessary (EG controlling volume or vibrato). Sequences of discrete voltages would also be possible by disabling or lowering the time constant of the slew limiter, to allow stepped control voltages (EG for discrete control of pitch and octave values).

- The circuit should be arranged so that a different number of steps can be employed for different parameters, as some require more than others. For instance there would be less octaves than discrete volume levels.

- The circuit should be able to be adapted so that several channels can be used independently, each generating an output pulse when optically triggered. These output pulses can then be used to trigger external devices.

Designing such a circuit proved quite a challenge, and of any of the sub systems of Mini Oramics this took by far the longest. I had much earlier tried to use or adapt the Oram/Emmett 'read latch' circuit[248]. However, in the design it is unclear which logic gates are specified, it appears as if non-inverting AND gates are specified, yet as a flip-flop circuit, a pair of inverting NAND gates would make more sense. I physically prototyped the circuit with both types of logic gate and neither gave consistent or predictable results based on the optical input.

I had attempted several circuit designs to try and achieve the above brief. I started with very few input channels (2,3 or 4), and then tried to extrapolate them to become the multi-channel circuits I needed. I had some difficulty getting any number above three channels to work correctly and it appeared that the required increase in complexity, in expanding upon the techniques used with low channel numbers would take me beyond my skill level. I therefore decided to enlist the help of electronics engineers Robin Iddon and Roger Dealtry who assisted with a further prototype design.[249]

It was not difficult to get bistable flip-flop circuits to trigger from the drawn dots on the cellophane, this was made relatively easy by the inclusion of simple op-amp comparators on each of the inputs as outlined previously. The most significant problem in designing the circuit, was reliably enabling the output of only one flip-flop at a time to be active, whatever the drawn input, and with the most recently triggered switch always having priority over the others.

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248 Oram 2007, ORAM01/05/001, The Oram/Emmett design for Mini Oramics C1976.
249 Robin Iddon holds a BSc in computing from UMIST and is a prolific electronics hobbyist.

Roger Dealtry B.Eng in Electronics and Communication Engineering from the University of Bath. AMIstP. Member of the British Vintage Wireless Society. Dealtry recently constructed a Pianola roll to MIDI converter using similar optical input technologies to Mini Oramics. Dealtry then used a microcontroller to convert the optically derived information to MIDI.

I constructed further prototypes using a variety of flip-flop types: D-Types, SR, and JK types[250], and a circuit which Roger Dealtry assisted me with, using SR flip flops came very close to operating correctly. When initially implemented with a four channel electronic prototype used with *Legoramics,* it appeared to be working correctly[251]. However when I scaled up the circuit to have 12 input channels, and used it on the newly constructed transport mechanism, it sometimes worked well, but also at times it failed to reset any of the channels as new ones were triggered.[252] In my overall theory of operation, having two or more channels triggered simultaneously would end up giving a nonsensical output: a wrong note in the case of pitch, and other malfunctions with other parameters.

On closer inspection of the SR flip flop used, and the relevant data sheet - it turned out I had missed a crucial aspect of their performance; the possibility of an illegal input state, with an unpredictable output the result. This was obviously what was happening to my circuit when the timings of triggers overlapped (for instance in the event of a steep diagonal line for an envelope shape) so unfortunately I had to start the design again.

I drew out the timing diagrams of my logic requirements and compared them to the results from my circuit. At this point, after several weeks spent working on the input logic circuitry I finally realised how I could make it work. In fact it turned out some earlier attempts using clocked D-type flip-flops had been closer to what was required. During all this prototyping I had been attempting to use combinational logic to achieve the brief. In fact what was needed was relatively simple - but a different approach. All that was required was a move from combinational logic, to clocked pulse-based logic. In this way it was possible to fulfil the brief as follows:

- Firstly the drawn input is registered by the phototransistor and the output from its voltage divider is fed to an op-amp comparator. The threshold of the comparator is set such that a 2-3mm mark on the film triggers it, and provides an

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[250] A bistable flip-flop is a very simple 1-bit form of digital memory. In essence it receives a pulse and its output state changes state from low to high or vice versa, until another pulse is received. SR, JK and D-Type flip flops vary in that they have additional options presented to the circuit designer, for instance additional clock and reset inputs which allow different uses for the different types. Flip-flops are used in counters and shift registers, and are some of the most basic building blocks of many digital circuits.

[251] INCLUDED MEDIA 006

[252] INCLUDED MEDIA 007

output pulse for as long as the sensor is exposed to the drawn part of the film. There are 12 phototransistors in the design for one parameter, so at this stage we get 12 channels of digital signals that are not mutually exclusive (any number can be high at a given time depending on the drawn input).

- These pulses are then shortened to standardised lengths of about 5 milliseconds using simple inverter-based monostable circuits. This means that only the very beginning of each trigger event is now registered. These shortened pulses are still not mutually exclusive.

- Next the 12 lines of digital pulses go two ways. Each one is fed to the data input of a dedicated D-type flip-flop, and also they are all fed into a 12 input OR gate which combines them into one stream of pulses.

- The logic then works like this: the output of the combining OR gate becomes the master clock for all the D-type flip-flops, so each time anything registers on the drawn film *all* the D-types are clocked. When a D-type is clocked it transfers the logic state at the data input to its output and holds it there until a new clock pulse is received. As all the data inputs will be low nearly all the time, as the input pulses have been shortened so much, only the channel associated with the current clock pulse will have a logical high at the same time as the clock pulse, so that one, *and only that one* will turn to a high output. This effectively resets to low any channel which is not responsible for the most recent clock pulse - ensuring only the most recently triggered single output is high, and finally fulfilling the brief I had set out.

I quickly built a new 12-channel prototype circuit with the new logic design, and for the first time the logic responded exactly as required. I added the analogue switches and resistor ladders to the output of the circuit, followed by the buffer/slew limiter section with no real problems, as these are all standard electronics building blocks. Then for the first time I was able to generate meaningful control voltages from a drawn input. The circuit would have to be slightly altered for each different parameter but it was essentially a finished design by the end of November 2015.

As soon as the breadboard prototype worked, I set about designing a PCB for it. I designed the PCB within about a week. I then ordered two evaluation PCBs from a manufacturing company and received the finished circuit boards shortly afterwards. The new boards worked very well apart from some minor component spacing issues, so after some minor adjustments I ordered the final seven PCBs needed to complete the project.

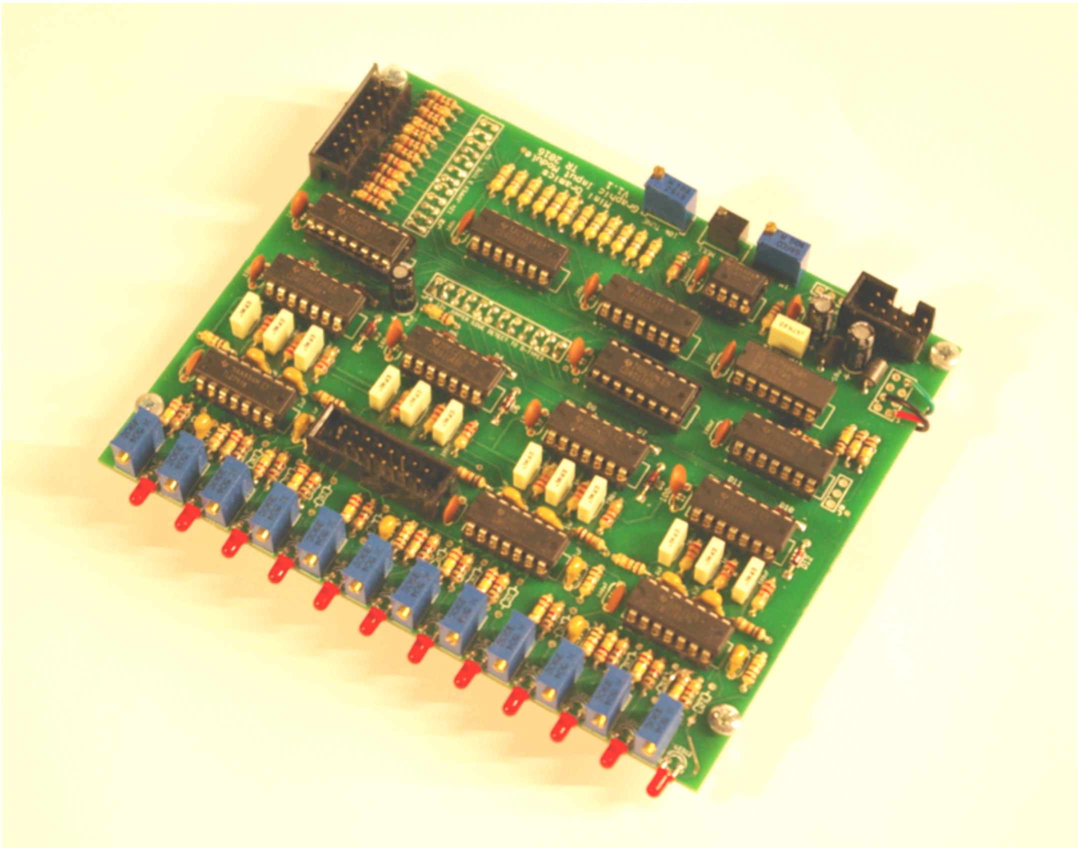

Fig. 36 The first graphic input module completed December 2015.

Finalising the Graphic Oscillators

I then made minor adjustments to the design of the graphic oscillators and produced PCBs for the slide potentiometer and circuitry units. The main improvement to my earlier design was the inclusion of a second sixteen channel multiplexer chip, clocked out of phase to the first. When the outputs of both multiplexers are added together the output gives a *faux* 32-step waveform derived from the 16 input slide potentiometers. The extra 16 steps comprise all the halfway points between adjacent voltage levels. In a sense this gives double the resolution, allowing the user to rely less on the VCF that follows the circuit to smooth the 'drawn' stepped waveforms described earlier.

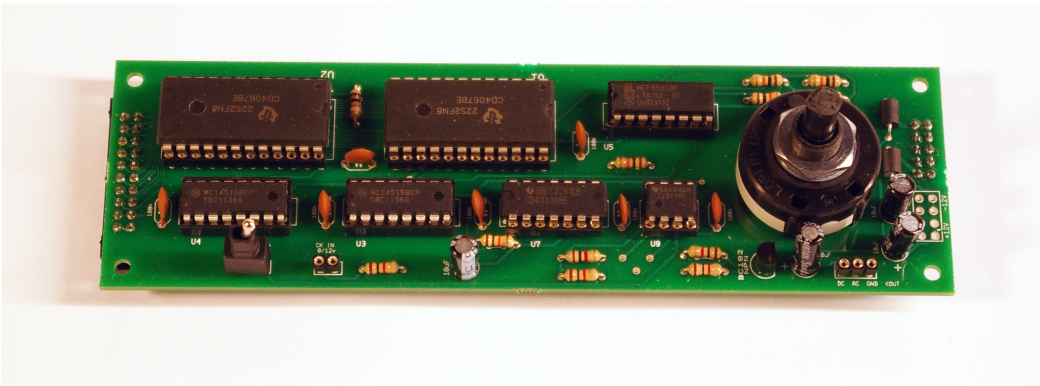

Fig. 37. Multiplexer circuit board for the graphic-oscillator section. February 2016

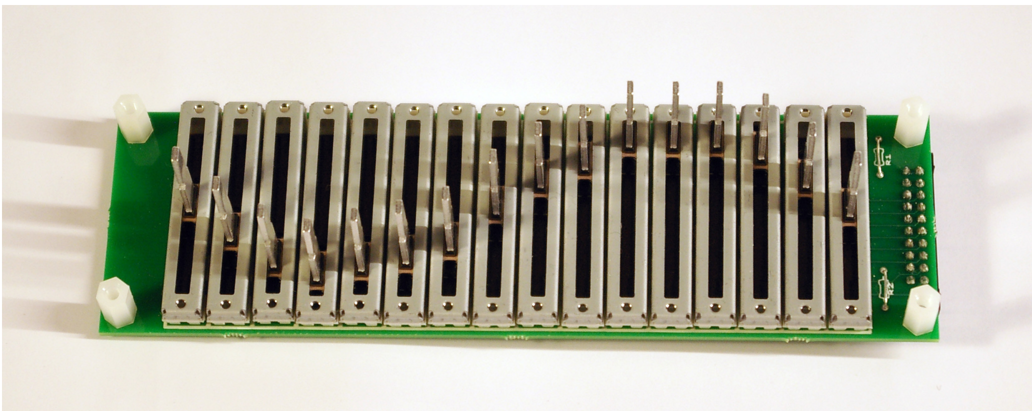

Fig. 38. Slide potentiometer PCB for the graphic-oscillator section. February 2016

Assembling the Final Circuitry

The final circuits needed to complete the system were all very straightforward combinations of standard electronic building blocks. Therefore it does not seem pertinent go into too much detail about their construction. I will briefly summarise what they were and each of their functions.

1) DC Mixer for Pitch Control.

A simple DC voltage mixer, to combine the three control voltages provided by the pitch, octave and vibrato sections, so that one coherent voltage is fed to the master VCO. The only slightly exacting requirement of this circuit was the need for accuracy, as any error inherent in its output would have the potential to affect the tuning of the device.

2) VCAs /Audio Mixer

This unit adjusts the relative audio volumes of the two graphic oscillators and the amount of reverberation inherent in the mix. It takes the control voltages given by the three relevant graphic input modules and applies them to three voltage-controlled amplifiers. These amplifiers are fed the audio signals from the two graphic oscillators as well as a mix of both sent via a spring reverb unit. All three output levels can then be controlled by drawing graphs on the programming medium. After this process a simple audio mixer combines the three signals and provides the master audio output. I returned once again to the RA Penfold book[253] for a suitable VCA design.

3) Reverb

I utilised a simple commercially available spring reverb[254], and integrated it with the VCAs as outlined above.

4) Power supplies.

I built the split + / - 12V DC power supply needed for the audio and digital electronics. This was a standard linear design using a centre tapped transformer and two voltage-regulator ICs. Hoping to avoid any possible audio interference, I used a separate

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[253] Penfold, R, A. 1986
[254] Doepfer A-199, Eurorack format spring reverb unit.

commercially available 12V switch mode power supply for the motors and LED light box.

5) The Master Oscillator and Voltage Controlled Filters

These were still breadboard prototypes until very near the completion of the project. I simply needed to finalise them into a more permanent soldered prototype circuit boards.

Final Construction

I realised (to my disappointment) soon after building the mechanical framework, that it was unlikely I would be able to fit all the circuit boards inside it. Therefore a second electronics casing would be necessary to complete the system. The logical split seemed to be along the sequencer / synthesiser divide and so I decided to house all audio generating, processing and mixing components in a separate unit. I happened to have a standard 3u rack-mountable instrument case in my studio, so I decided to house all the audio circuitry in that. I designed a front panel for the audio unit, and then had it manufactured and sent to me. Some minor reworking of the mechanical framework also had to be undertaken to accommodate the electronics control panel on the programmer.

I was then ready to assemble all the sub-systems and complete the prototype. The following series of photographs illustrate the process of the final construction:

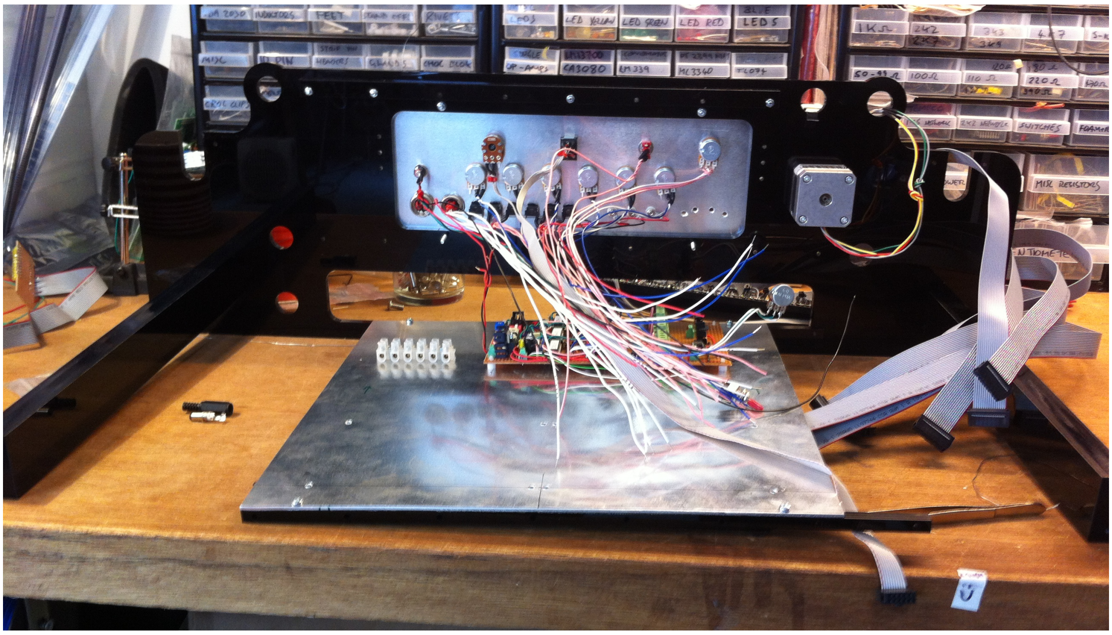

Fig. 39. Starting to re-assemble the transport mechanism with the electronics inside. March 2016

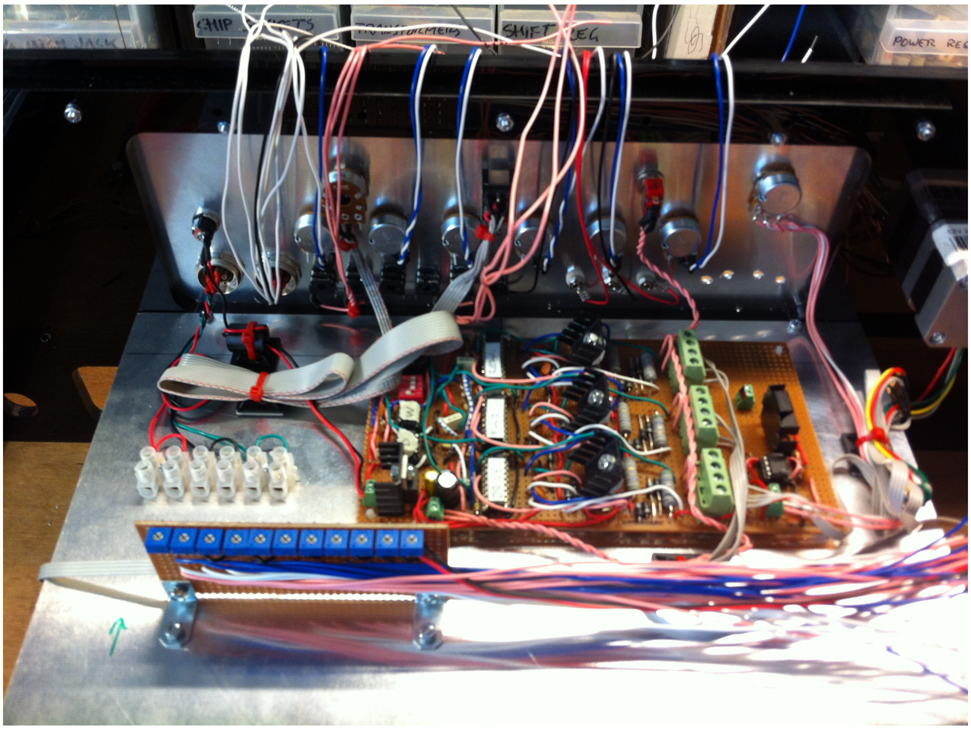

Fig. 40. Continuing re-assembly. From top to bottom: the rear of the transport front panel, the motor controller, and then a row of preset potentiometers. These potentiometers output the 12 discrete voltage levels utilised by all of the VCAs to adjust the relative volumes. March 2016.

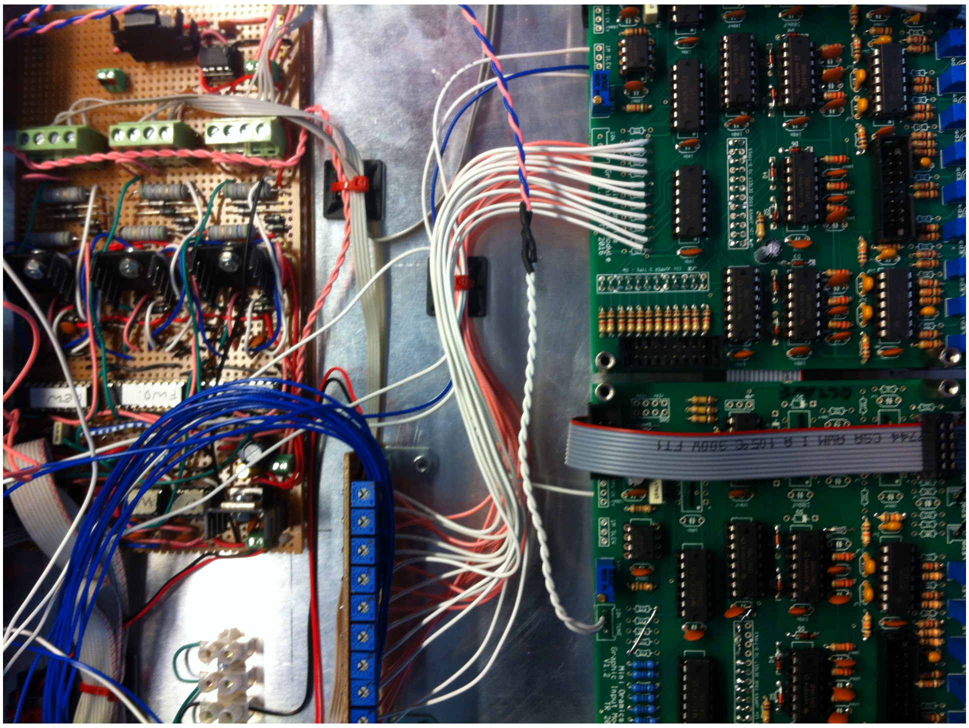

Fig. 41. Wiring the VCA control voltage potentiometers to the relevant graphic input modules. March 2016.

Fig. 42. The front panel of the transport control/programmer unit. March 2016

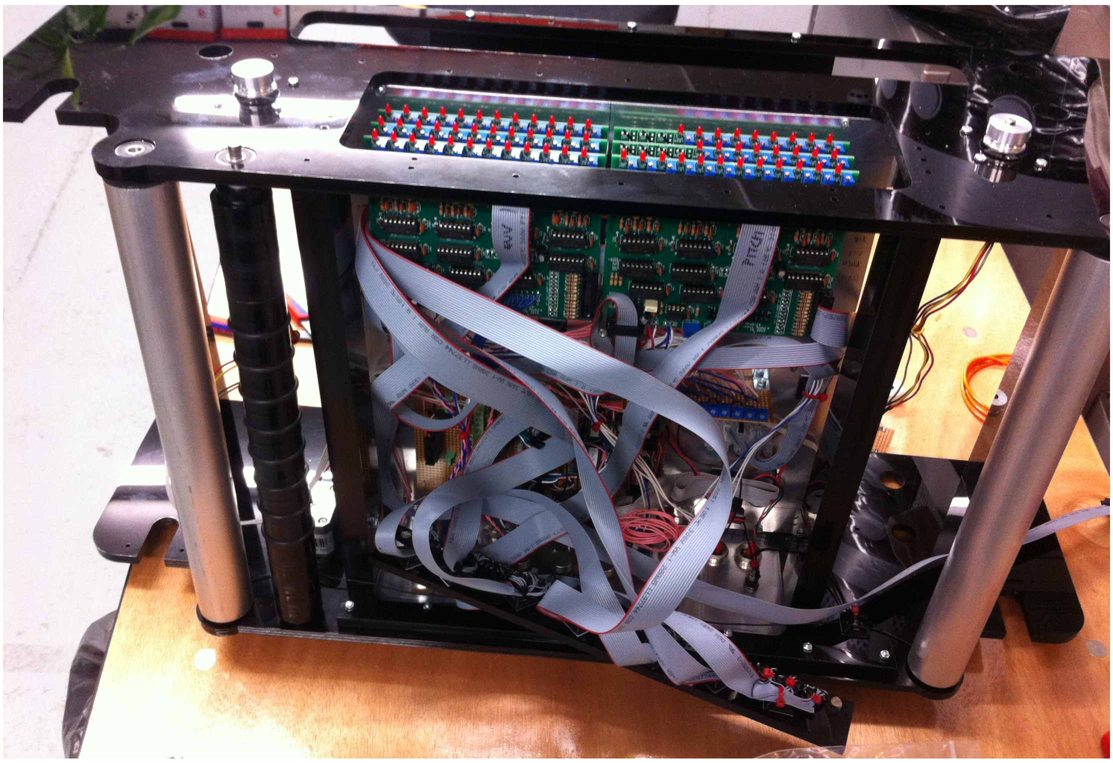

Fig. 43. Attaching the numerous ribbon cables from the light sensors or ‘play head’ to the graphic input modules. March 2016

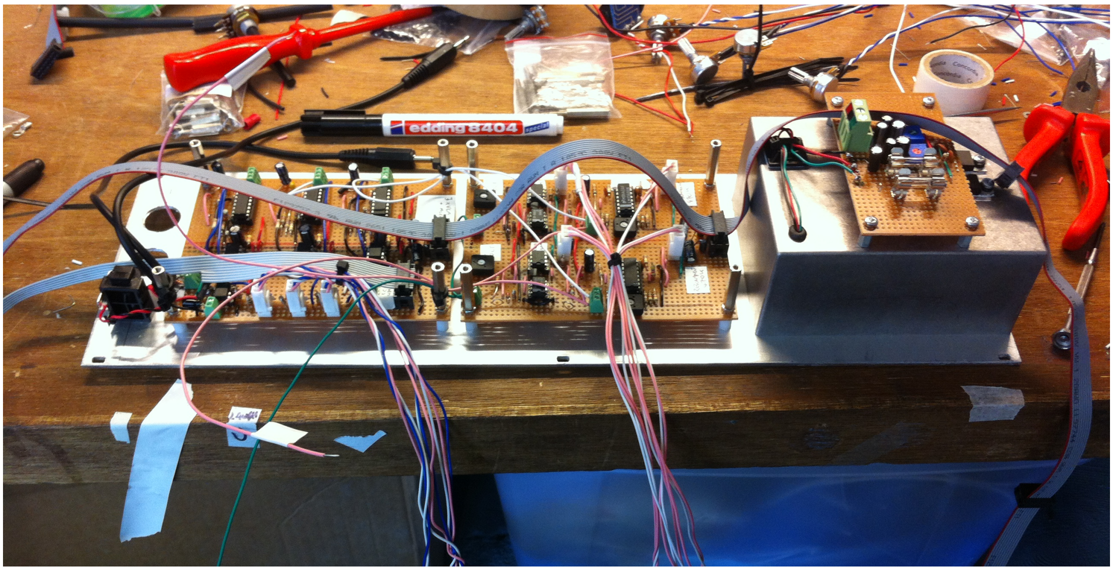

Fig 44. Construction of the rear panel of the audio unit. From left to right: the VCA board, the dual filter board and the dual linear power supply. March 2016.

Fig 45. The front panel of the audio unit. March 2016.

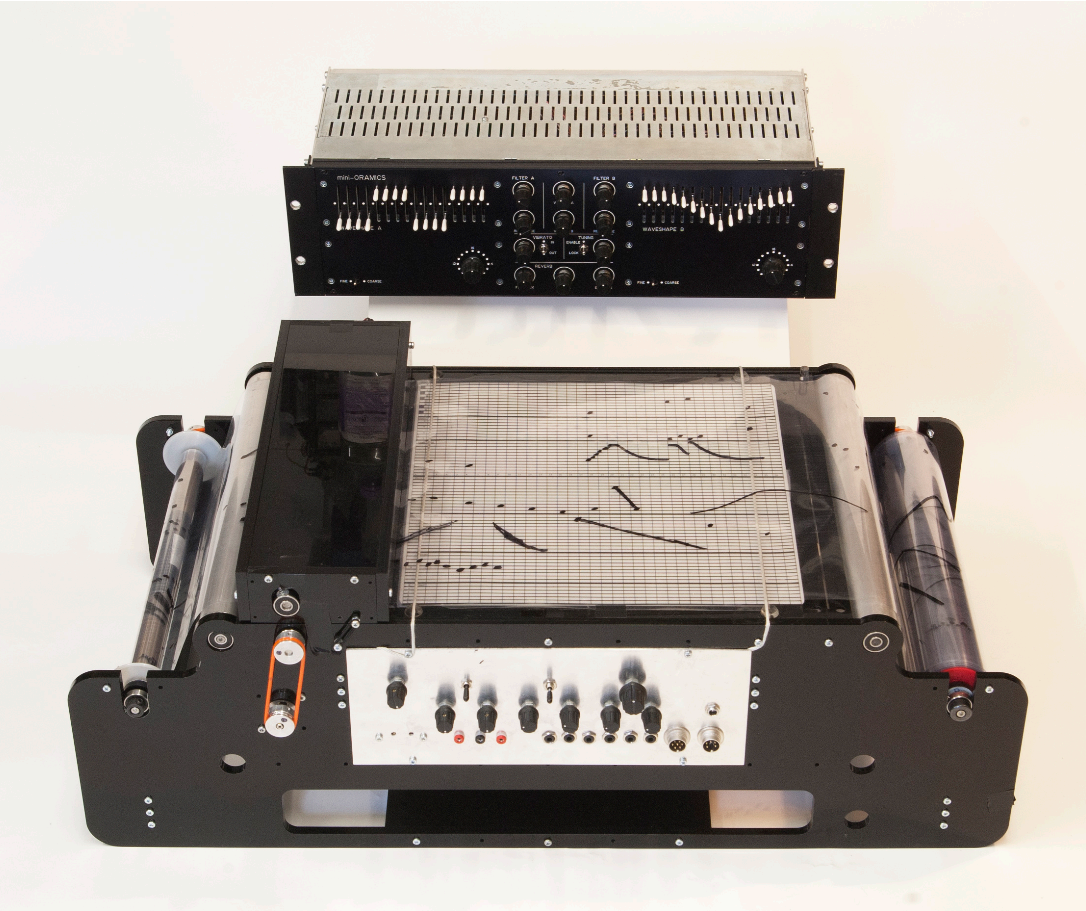

Fig 46. The finished Mini Oramics machine. Photograph the author, June 2016.

Switching on Mini Oramics for the First Time

Despite having thoroughly tested all the sub circuits before the final assembly, it would never have been possible to just switch on the machine and start composing. There were many elements that needed calibration or adjustment before it could become a functional and integrated system. Simply getting all the input parameters calibrated, the VCA volumes smoothly incrementing, and the oscillator correctly tuned, took the best part of a day. At this point, to my great relief, on the 7th April 2016, Mini Oramics was complete.[255]

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[255] INCLUDED MEDIA 006 and 007

CHAPTER 5.2 EVALUATING THE NEW MINI ORAMICS

After having re-imagined and built Mini Oramics, and having been wholly consumed for some time in the more practical discipline of electronics design, it was necessary to evaluate this practice-based research. It was time to re-visit the research questions and establish the significance (if any) of having made the prototype, and assess the potential ramifications. These ramifications could fall within a number of criteria:

- Further appraisal of Oram's artistic and technical research avenues.
- The wider understanding of historical 'drawn sound' and music technologies.
- Contemporary research into HCI / interfaces.
- The significance of 're-construction as research', the *what if?* methodology.

Evaluation Methodology

It was important to open the project out to other musicians and technologists to start to better understand the value and meaning of Oram's interface. I invited a range of six electronic musicians to each spend two days working with Mini Oramics and then give me their feedback, both verbally, and more formally on a questionnaire that I had devised. Four of them eventually took part.

The questionnaire was designed in such a way that the respondents would have flexibility in making quite open-ended observations about the interface and the sound. In order to try and get the information that was required, in addition, the separate functional categories of the machine were listed as possible topics to respond to. These feature categories were: Waveform Generators, Volume Envelopes, Pitch Control, Vibrato (pitch bend), Speed Control, and Slew (glissando) Controls. The completed questionnaires are in the appendix of this thesis.

With each of the musicians I spent some time explaining the basic operation of the device, before leaving them to experiment and explore the potential. We then discussed their findings and listened to the sounds they had ‘drawn’.

During this process it became clear that there were some minor technical problems with the new device. However these drawbacks did not seem technically insurmountable. Also none of them pertained to the overall conceptual premise (or promise) of Mini Oramics. For this reason I decided to categorise and evaluate the musician’s responses in two categories, the technical and the conceptual: the comments pertaining to the specifics of my design and build (technical), and those pertaining to the wider concept and potential of the Mini Oramics interface (conceptual).

The Participants.

Before examining the responses, it would be prudent to outline the profile of the participants who took part in this exercise. All are electronic music practitioners. Two are studying for a PhD in a relevant discipline. Two already have a relevant doctorate. Both of those with a doctorate also teach at university level. Two are female and two are male. All had some prior knowledge of Daphne Oram and her work, and two were already very knowledgeable about Daphne Oram. More information about their varied skills and specialisms can be found in their full responses in the appendix.

RESULTS PART 1: Feedback on Technical Aspects

I will first summarise the findings of the technical category and add some notes of my own. Some of these notes pertain to later improvements I made, and some pertain to the constraints of my design; of which some would also have been relevant to Oram's design.

All the participants found that there were problems with static electricity building up as the clear cellophane rubbed over the Perspex body of the programmer. This led to the material getting stuck quite often and the transport mechanism failing. Soon after the workshops I managed to significantly improve the problem with some earthed anti-static dissipative cord, which I stretched in two lines across the programming surface between the body of the machine and the clear programming film. Also after the evaluation I upgraded the stepper motors to increase the available torque.

Participant B and myself both noticed that some noise from the light-box dimmer circuitry bleeds through to the audio output unless the light is at the maximum or minimum setting. I intend to replace the PWM (digitally clocked) dimmer circuitry with a selector switch, giving different brightness selections for the backlight, and this will solve the problem.

Participant B and myself noticed the need for an overall volume control. When one stops the machine in the middle of a phrase, the sound continues at whatever volume it is set to, until you change it on the programmer, or until you turn down the three separate volume controls. This continuous tone can be very distracting when trying to think and write. I intend to add a volume control pedal or mute switch.

Participants B and D both mentioned the need for a place on the media outside the parameterised area where the composer could write notes to themselves, to indicate changes to settings on the device, or which wave-shapes are to be used at a particular part of the composition. At the time of writing this is possible, as I have yet to instigate usage of the six trigger tracks, so that space on the film is available for notes. However the parameterised 'real estate' of the media is at a premium due to the limited width of the material, so this potential feature may not really be practicable. One feasible solution is that red or pink pen might be used with no effect on the sensors as they use infra red light, therefore with careful calibration these colours might not set off the sensors.

Participants C and D found the slew controls confusing or perhaps un-intuitive. This factor was mentioned in particular regard to the volume controls, as if one draws a value of ten, depending on the speed of the piece and the slew rate, it may only reach a value of five for example, before the next instruction is received. This is a difficult problem to solve, as otherwise you would hear the steps between volume levels as explained earlier in the critique of the Oram/Emmett design. Certainly the analogue CRT/photomultiplier readers of the original Oramics Machine would be (conceptually) superior and negate the need for the slew limiters, however this would not be in keeping with Oram's *solid state* Mini Oramics, and would be bulky and problematic for a number of other reasons which have already been discussed. Participant C stated a desire to have the slew speeds controlled by separate drawn parameters, yet this would require a significant overhaul and re-design. It would use a lot of precious film width, and might still be fairly un-intuitive as it is quite an abstract value to assign as part of a compositional device or sequencer. Another potential solution would be to have an additional 'look ahead' sensing head, to time the changes in values before they hit the main playback head, and adjust the slew rates accordingly. Again this would require a significant re-design, but it would have the advantage of freeing the composer from thinking about this abstract and non-musical parameter. It would also have the disadvantage of significantly altering the sound when played backwards. The system of slew limiters is certainly a compromise, and for now we will have to cope with it.

Participant B mentioned an issue with the media having some sideways travel, and therefore not always lining up with the sensors correctly, thus adversely affecting the playback. There are two reasons this happens. Firstly I have had trouble getting consistency from the supplier of the cellophane film rolls. Often they are above the specified width by 2-3mm, with the consequence that they curl up at the edges as they go through the machine. Another reason is the fairly primitive system I have used to place the spools on the axles and guide them through the play head, an issue that will be simple enough to remedy in time.

Participants B & D commented that the vibrato/pitch-bend range was not wide enough. I was immediately able to remedy this by changing a resistor value. Participant D also mentioned the accuracy of this feature, and asked whether it would be possible to assign precise microtonal values to the steps. This would be possible relatively easily, and I will endeavour to do so.

In a conversation with participant D, we re-appraised the parameter layout and use of light sensors. We agreed that a future design should encompass changes to the octave, pitch and reverb parameters. With the octaves, I was unable to get the oscillator to track accurately across the rather optimistic eight for which I assigned inputs. This could be reduced to six. In terms of reverb it has become clear that, due to the diffusive nature of the sound, the ear cannot differentiate twelve discrete volume levels. So Oram's idea to have three send and three return levels would give greater use of the effect, the user would also be able to instantly cut off the reverb tail; a feature which is not possible at present. These savings in sensor inputs would also allow more pitch inputs, allowing for some precise microtonal intervals in the pitch parameter as Oram had also intended with her design. Participant D also wondered about the possibility of having two separate pitch tracks, allowing for two separate yet synchronised melody lines. Certainly in principle this is possible for a future design - it is just a case of prioritising the parameters that are valued the most, within the constraints of the available width of film.

Another issue that I have noticed, is that any slight change in the positioning of the exciter LEDs, has the potential to quite drastically alter the response of the input comparators and therefore the accuracy of score reading. These LEDs are fitted opposite the sensors in dedicated housing above the main programmer. This needs to be remedied by having a more precise positioning system for this small sub unit.

To conclude the technical appraisal: the machine is not perfect. It is however, absolutely workable enough to get a sense of what Mini Oramics could have been like to work with. Also the process of re-thinking Oram's design and building a version of it has illuminated some of the technical and artistic challenges that Oram faced.

RESULTS PART 2: Feedback on the Conceptual Aspects

In terms of responding to the interface concept and working methods, the response was overwhelmingly positive.

Participants B, C and D all made favourable remarks on the quality of the sound. They used phrases such as: 'I loved the sound' 'ethereal' 'expressive and humanistic', and 'delicate colouration'. Several of the participants also agreed with me (verbally), that it is possible to generate sounds similar to those of the original Oramics Machine, which goes some way to proving that a smaller and more portable version of Oramics such as this, might have stayed in keeping with Oram's vision. Participant C also stated that it was possible to generate sounds that would be very difficult or impossible to produce using contemporary software - a striking statement considering that the original design is now 40 years old.

> Participant C
> I loved the sound. I was able to get some really ethereal, complex sounds, which I'd never be able to achieve using programming in ChucK or Max.

Two of the participants: A and C discussed alternative approaches to working with the device. Both realised that one could approach a potential composition 'freehand' with an open and experimental outlook, trying things out and listening to the result. Or, one could approach more deliberately, with an analytical mindset, attempting to score a pre-planned musical idea. Participants C and B also discussed the potential for mixing these approaches - switching between the two modes:

> Participant B:
> This is a wonderful compositional machine. It sits between composition and performance as a device, and allows the composer to compose 'in time'.
>
> Participant C:
> I could play it analytically (as I tried to very carefully "program" sounds according to a musical idea I had in my head) or holistically/creatively (as I drew new shapes just to see what they would do). I liked that I could easily get surprising sounds out. But even when I drew something whose sound surprised me, I liked that I could analytically reconnect that to the shapes I drew. This allowed me to develop a visual "vocabulary" for the instrument…

An unplanned but interesting nuance of the machine, a 'happy accident' perhaps, is that when composing, the operator often needs to run the composition forwards and backwards through the machine. This means hearing everything forwards and backwards too, although, due to the nature of the input readers, it is not reversed exactly, unlike reversing an audiotape for instance. The rhythmic and dynamic structure changes significantly more than just being a mirror image of the forward version[256]. This led to at two of the participants (C and D) attempting experiments to make compositions that were to be played both forwards and backwards. One can envisage this becoming a feature of a Mini Oramics score. It is worth noting, that as in many other instances of instrument designs, users of Mini Oramics almost immediately started to experiment with *expanded technique.*

> Participant C:
>
> … I really love the fact that you can play your scores backwards and forwards, and that you don't get an exact reversal between the two! This is mind-bending and super cool. If I had a long time to spend with the instrument I would enjoy trying to manipulate this to make pieces that could be played in both directions.

---

[256] This *asymmetry* of playback is due to the fact that the reading head of Mini Oramics only responds to the momentary change when a new trigger is detected. Notes are drawn as short dots rather than durational lines, and last until a new note is triggered. Therefore when played backwards, what was previously a long note will last only until another note is triggered and therefore could be very much shorter or longer. The same applies to the dynamics of the piece: a previously loud note might be quiet or even silent when played in reverse, or vice versa. The user could change this (with the pitch/octaves at least) by drawing a trigger dot at the beginning and end of every note, which would make no difference to the normal forward playback. However some of the participants found the asymmetrical playback an interesting feature to utilise.

There was another response that seems particularly pertinent in the contemporary context of the resurgence of hardware based EM interfaces and current research into alternative (non-Mouse/keyboard/VDU based) interfaces for electronic music software. Participants A and B both stated how much they enjoyed the physicality of using a pen to interface with the machine: statements which both add credence to Oram's drawn-sound concept.

> Participant A
>
> I loved having the ability to interact with it via a marker pen, and to be able to control the various parameters by drawing on the acetate.
>
> Participant B
>
> The biggest relief for me is being able to compose without recourse to a computer screen.

Participant B also commented on the freehand nature of composing on the machine when compared to the default gridded settings present on most software sequencers. With Mini Oramics there is no copy and paste, no quantise function, you get only what you physically draw. As Oram had hoped in her *Written Sound Waves* design brief[257], participant B agreed that this led to a greater expressivity and a more acoustic sounding result.

> Participant B
> As a monophonic instrument it is more expressive and humanistic than anything I've yet used outside of acoustic instruments.

After closely examining Oram's painstaking progress with the first Oramics Machine, one question I had hoped my reconstruction might help to answer, was regarding the timescale of composition. In other words, I was worried that it might be very painstaking to draw each of the six or seven parameters required, and that it would be frustratingly slow for the user to make any real progress. After watching the participants working with the machine, each for the very first time, it became clear that this was not the case. All of them started to generate musical sounds very quickly (within an hour at

[257] Oram 2007, ORAM1/1/18. Oram's notebook containing the *Written Sound Waves* design brief.

most). In particular, those who were classically trained, soon managed to make quite accurate renditions of familiar melodies. Participant B soon managed to write ‘Little Brown Jug’ a favourite of Oram’s. Participant D quickly managed a phrase from ‘We Are the Robots’ by Kraftwerk.

This practice as research project can therefore help us start to conclude (in conjunction with the other evidence presented), that Oram’s slow progress and limited musical output with the original machine was largely down to the technical issues she faced, and perhaps, some of the more abstract input methods - for instance the coded neumes for pitch control. Her simplified and more reliable Mini Oramics interface design, now finally realised, seems to have overcome these issues to a large extent. In fact all of the participants of the initial testing phase expressed their enjoyment working with the machine, and felt it to be an exciting interface, both in the contemporary sense, and the contemporaneous.

ANALYSIS: What if Mini Oramics had been released in 1973?

Returning once again to the central question of this practice based research, I asked the participants to imagine the impact Mini Oramics might have had, if it had been commercially released in 1973. Unfortunately (but quite understandably) only two of the four participants wanted to attempt to answer this *unanswerable* question:

> Participant B
>
> Conceptually, I have nothing negative to say, I think if this had happened at the time Oram had proposed it, this would have caused a change in the way people think about the electronic composition of music.
>
> […] I think the graphic aspect of it in particular would have had a huge impact. This idea of laying down a composition 'out of time' and off grid as it were would have had a big impact […]

> Participant D
>
> I think the Mini Oramics machine would have been very warmly received by composers and musicians [in 1973], because it offers a unique way of putting together potentially quite ornate and repeatable audio and CV sequences, yet it recalls techniques and technologies that were already available to studio musicians, i.e. tape machines and analogue synthesis. The interface design also preempts the kind of detailed parametric layering that MIDI sequencers would eventually make possible. Had the Mini Oramics machine been available to musicians in 1973 I can imagine it having a considerable impact on the direction taken by both electronic music and electronic instrument design.

So the prevailing consensus amongst the two participants who responded was, yes, Mini Oramics could have been very well received. Obviously this reaction, from a tiny sample of contemporary electronic musicians, is by no means enough to definitively conclude that this would have been the case if (hypothetically) Oram had received further investment. However this specific reaction, within the context of the very positive overall reaction to the device, does certainly contribute to the information we previously had about the viability and merit of the Oramics interface concept, especially when so few people ever got to use the original machine (and so few of those are still alive to discuss it). The overall results of the survey point toward a vindication of Oram's ideas, and help to argue that the Oramics interface more generally, was overlooked prematurely by those with the power and money to help take it forward.

There was one other potentially relevant outcome arising from the, slightly unorthodox *what if* research methodology. The participants all, without exception, examined the machine as a contemporary instrument first, and then, often only when prompted by the questionnaire, did they begin to discuss the historical relevance of Mini Oramics. All knew beforehand of the context they were working in, and this response seemed to offer up a further question (especially when participant C had stated that sounds were produced which would not have been possible using computer software). Whether Mini Oramics, had it been produced, might have remained in use far beyond being superseded as a music technology, just as the Minimoog, VCS3, Ondes Martenot, and the Theremin all have.

This reconstruction has attempted to formulate an alternate genealogy for music technology, to illustrate what might have come to pass, a lost potential. It is hoped that the reader can now imagine a hypothetical alternative history, where Mini Oramics was rolled out, and many musicians could have learned and experimented using Oram's interface.

CHAPTER 6: CONCLUSIONS

How then, can we attempt to assign value or meaning to a failed technology? The title of this thesis[258] *Oramics: Precedents, Technology and Influence,* presents a framework, within which this question might possibly be answered. Precedents, technology and influence are categories used to evaluate the Oramics Machine and its further incarnations. Yet attempting to separate Oramics technology from Oram herself is problematic, as her philosophy of sound and music[259] is bound up in the physical and technical aspects of the Oramics Machine, as well as the ethereal and evocative sounds of its output. Oram herself used the term *Oramics* interchangeably, using it to refer both to the composition system she had created, and her wider philosophy, which often used acoustic and electronic metaphors to represent and discuss elements of the human condition[260].

Oram's drawn-sound research spanned more than three decades, and was in one sense her life's work. Yet she was prolific in many other fields that go beyond the remit of this thesis[261]. One doctoral research project is certainly not sufficient to adequately touch on all the aspects of Oram's life and work. This is a largely techno-historical and meritocratic account of Oram's journey with drawn-sound interfaces. For this thesis at least, the term *Oramics* has mainly been limited to the realm of music technology, although when approaching the *influence* of the thesis title, it will become necessary to broaden this definition.

As has been discussed in the theoretical framework of this thesis, the *failure* of the Oramics Machine does not mean it did not function, or was not a good concept. Rather, within the *social construction of technology* or SCOT model, the Oramics Machine and its later incarnations, were not adopted by composers and musicians, leading to the Oramics interface becoming an evolutionary dead end in the history of music technology. A dead end, despite a seemingly natural fit within the evolutionary arc of studio-based music composition/production as was outlined at the beginning of chapter

[258] This title was originally assigned by Tim Boon, my supervisor, as part of the process of developing the Oramics research project, after the acquisition of the Oramics Machine by the Science Museum.
[259] See Oram, D. 1972
[260] Ibid
[261] See *Further Research* at the end of this thesis.

5. The Oramics Machine also had an uncanny similarity[262] to what would become the standard technology for electronic music production: the software based DAW or digital audio workstation.

As no commercial version of the Oramics interface was ever commercially released, this lack of adoption by musicians and composers is a given: a constant in the subsequent analysis. We therefore first need to address the question of why it was never released, despite Oram's intention, before we are able to understand how it came to be (for forty years at least) an evolutionary dead end, despite its promise - a promise, which to many, is easy to recognise from a contemporary perspective.

It is important to re-assert that the Oramics Machine meant something very different at the time of its design and construction, than it does today. Once at the absolute forefront of post-concrète music technology, it was then forgotten, sidelined as other technologies came to dominate. It is now being revisited in the context of renewed interest in hardware approaches to electronic music, renewed interest in previously underrated female composers, and also in the context of numerous re-imaginings of musical interfaces (after the mouse and keyboard), where sonic experiments of the past are often researched, re-worked and integrated into contemporary music practices. It is perhaps, also remembered with a kind of nostalgic *vintage-ism* in certain circles. The Oramics Machine has re-surfaced in a world where a very large proportion of music contains at least some electronic sound or treatment, and indeed some genres are overwhelmingly electronic, whereas the opposite was true at the time of its conception, with public attitudes to match.

So to summarise and extrapolate on the findings of the research, the conclusions are divided between contemporaneous and contemporary perspectives. Firstly those conclusions concerned with what actually happened and why (the techno-historical), and secondly those which deal with what might have happened, and why Oramics is still of interest today (the conceptual – viewed in the context of more recent/contemporary interfacing in music technology). Before that, the sonic aesthetics of Oramics will be briefly re-examined.

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[262] Boon/Grierson 2012

The Oramics Sound

Before delving further in to the commercial, social and techno-historical analysis of Oram's interface and its development toward Mini Oramics, it would be prudent to re-examine and further discuss the sonic output of the original Oramics Machine. It was a privilege to have access to Oram's ¼" tape archive, and it was frequently astonishing to hear early and unpublished audio examples of the Oramics Machine, especially given the time they were produced.

As has been argued, Oram's vision for her music creation machine can be situated within the Varèsian notion of a *universal musical tool*, allowing the composer to be free of the constraints of conventional acoustic instruments, free from the interpretation of musicians, and allowing the composer absolute control of every aspect of a musical work, within a comparatively intuitive interface. This paradigm also sets Oram in opposition to the alternate philosophies of Aleatoric and Serialist composition, which were often (but not exclusively) associated with the early use of computers in music.

From a contemporary perspective the search for this universal musical tool might appear a little naïve, as practitioners are now aware that electronic circuits are every bit as unique and characterful as the acoustic elements of conventional instruments. Certain circuit topologies and component types are frequently sought after for their distinctive sound, and musicians, engineers, and producers will pay a disproportionate premium for electronic instruments and sound processors which are subjectively deemed to *sound better* than their equivalents, especially in the realm of analogue technologies.

David Tudor and his group *Composers Inside Electronics* (CIE) were early proponents of using the inherent qualities of different types of electronic circuit as musical material. They were amongst the first to articulate that the design, construction, alteration, and combination of electronic circuits can be a fundamental part of the compositional process. Nicolas Collins describes this approach as 'like Michelangelo finding the figure in the marble'[263]… and that with this approach one should 'pause to listen to the composer inside the electronics'[264]. Collins has of course taken the CIE aesthetic and philosophy very much to heart, and he remains a key figure in the development of circuit-bending and DIY electronics, both as practitioner and pedagogue.

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[263] Collins, N. 2004
[264] Ibid

Perhaps it is an oversimplification then, to try and slot Oram's interface(s) into the Varèsian paradigm, despite her echoing it in her own writings and design brief. In fact she advocates a hand drawn technique 'to obtain sounds which are more musical than those so far achieved by electronic devices, and which have a far greater range of timbre'.[265] So despite wanting the unmediated control and direct interface of a Varèsian machine, Oram was also looking for a specific (rather than universal) sonic aesthetic, one which sounded less 'cold, calculating, lifeless'[266] than the electronic music of some her contemporaries.

This she most certainly achieved; the Oramics Machine has a unique sonic signature. Nothing else sounds quite like it, despite its versatility. Arguably it does sound less mechanical and lifeless than many of its contemporary technologies. Therefore it is worth considering what makes its sound so instantly recognisable.

In the opinion of this researcher, after having worked with the new Mini Oramics, having listened to most of the existing recordings of the original machine, and also having worked with computer music and analogue modular synthesisers, the key to the Oramics sound is the dynamic control of timbre and reverberation. When listening to her 1972 radio interview[267] we can hear a rare glimpse of the development of an Oramics work, first the sequence of tones at constant volume, which Oram describes as 'very dull' despite the sound having hand drawn wave-shapes. Afterwards we hear the re-phrased work with dynamics and reverb added, and certainly it is this second stage of the process that brings the piece to life and makes it sound like Oramics. Just as Schaeffer realised the importance of dynamics to identifying the character of a sound[268], the unique ability to hand-draw these dynamics (including the reverb mix) is the essence of what makes the Oramics sound. Yes, the ability to draw the timbres is a powerful tool, but on the original machine these were fixed for any given piece[269]. It was the infinitely variable and unrepeatable dynamic and rhythmic contours that made them into such distinctive sounding music.

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[265] Oram 2007, ORAM01/01/018 (Oram's personal notebook 1961)
[266] Oram 2007, ORAM01/02/039 (CGF Correspondence 1965)
[267] Oram 2007 (AUDIO) DO236 (INCLUDED MEDIA 011)
[268] Schaeffer, P. 2012
[269] One of the best additional features of the new Mini Oramics is that these can be hand 'drawn' and altered during playback/recording.

Failure to launch: why was an Oramics interface never brought to market?

Ambition Versus Budget

The difficulty of the task Oram had set herself should not be underestimated, especially when taken in the context of the technologies available at the time, and the budget the Calouste Gulbenkian Foundation had allowed her. As the examination of the CGF section of the archive[270] has clearly shown, Oram set out to build her machine with around half the funds that she had initially planned for. Her rather optimistic reaction to this reduced budget appears to have been fateful. Rather than scaling down any part of her plans, Oram tried to keep every single feature of the machine that she had envisaged in her 1961 'design brief'[271], with the ill fated hope of further potential funding foremost in her mind[272]. In designing and constructing the Oramics Machine, she attempted not one, but four, new yet interdependent technologies (in addition to the transport mechanism which would tie the whole system together). These were the opto-digital control of pitch, the wave-scanning oscillators, the graphical volume and vibrato controls, and the multi-track synchronised tape recorder.

It is unfortunately ironic that having only partially succeeded in building the *ivory tower* version of her concept with the original Oramics Machine, she went on to attempt a considerably simpler version immediately afterwards with Mini Oramics, but she struggled to do so without a real budget for the project, having to rely instead on the goodwill of her friends and contacts[273]. It is quite possible to imagine an alternative and more successful sequence of events, where the simpler version came first, and having been more demonstrably successful, was able to attract investment for the further development of the project.

So one factor that certainly contributed to the *failure to launch* of the Oramics interface, was Oram's initial unwillingness to compromise, her decision to remain absolutely true to the brief, without the budget to match.

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[270] Oram 2007, ORAM01/02
[271] Oram 2007, ORAM01/01/018 (Oram's personal notebook 1961)
[272] Oram 2007, ORAM01/02/050. Oram's Report to the CGF. April 1965.
[273] Oram 2007, ORAM01/06 Mini Oramics correspondence with Norman Gaythorpe and Sherborne School

The Team

In the mid 1960s, Oram was quite legitimately able to compare her research to advanced electronic/sonic research projects at US Universities and corporations, as well as some closer to home[274]. Many representatives of these institutions, corresponded with and visited Oram, and also hosted her, and demonstrated their own facilities[275]. This gives a good indication of Oram's high national and international standing in her field at this time.

The fact she achieved as much as she did with the first Oramics Machine, without institutional affiliation is testament to her vision and determination. And despite its notable shortcomings, the fact that the Oramics Machine functioned as well as it did, is also testament to the skill and hard work contributed by her first team of technical collaborators, most notably John Oram, Fred Wood, and Graham Wrench.

As was discussed in the *Oramics Post BBC* chapter, Oram's personal and professional disassociation with both Graham Wrench and her brother John Oram in 1966, could not have been helpful to the progress of her project[276]. The timing was bad. The parting of company with two of the most crucial engineers of Oramics, came at the very end of the CGF funding period. At this point she had an operational prototype of sorts, but the machine was not finished to a standard that Oram was satisfied with, or that she felt confident demonstrating to her peers. Nor did she have funding to continue her ambitions. It was left to Oram and Wood to turn this prototype into a machine that would satisfy Oram's design brief, a process that would continue over several years.

The various achievements and setbacks of this period (1966-1973), are detailed in Oram's technical log-books[277] where it becomes evident that despite some wonderful sounds being generated, the overall process of trying to write music with Oramics was frustrating at best, due to the numerous technical problems Oram regularly encountered. If anything, it appears that it this process became more difficult as time went on and as the equipment was relocated within Tower Folly. The fact that no long-form

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[274] Oram 2007, ORAM01/02/050. Oram's Report to the CGF. April 1965.
[275] P.A.T. Edinburgh, Columbia Princeton EMC, amongst many others.
[276] Graham Wrench has also stated that the sudden end of his involvement in the project went on to adversely affect his confidence and career. See Wrench 2012.
[277] Oram 2007, ORAM01/04. Oram's technical log books 1966 -1973

compositions[278] appear to have been composed entirely with Oramics, as she intended[279], adds further weight to the assertion that, the technical problems Oram faced were to eventually prove insurmountable.

The fact that half the development team for the Oramics Machine left the project at such a crucial stage, undoubtedly contributed to the eventuality that the Oramics Machine was never truly finished.

Attempts to Commercialise

Again referring to Oram's CGF correspondence[280] it becomes clear that (in 1965 at least) she did not intend her prototype to be the final version of the interface she was designing. She stated her intention that the machine should be finished 'in a polished style to international standards' and describes her actual prototype as 'the more utility "Heath Robinson" working model'.

As has been demonstrated in *Oramics Post BBC,* the Oramics Machine was never to become the 'polished' version Oram had hoped for. In reality it was ungainly, unreliable and not at all portable, thus harder to promote. As was asserted in the *Justification for Practice Based Research* the Oramics concept was better than its eventual realisation.

Oram was explicit in her desire to patent and commercialise the Oramics concept[281], however there is no evidence to suggest that she ever approached more than three potential investors (Moog, Philips, and Lightomation) despite her continued attempts to produce a more workable interface, first with Mini Oramics and the later Computer Oramics. Of course it is possible that Oram approached many more potential investors,

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[278] Bird of Parallax (1972) is perhaps the closest to a long form Oramics composition, but this piece was almost certainly made using more traditional tape editing techniques with short recordings of the Oramics Machine.
INCLUDED MEDIA 010
[279] Oram 2007, ORAM01/01/018. Notebook containing Oram's brief for the Oramics Machine. 1961
[280] Oram 2007, ORAM/01/02/054, Letter from Oram to the CGF discussing the further development of Oramics, June 1965.

[281] Oram 2007, ORAM/01/02/066. Letter from Oram to CGF detailing plans the Oramics system.

but given that no other commercially oriented demonstrations are mentioned in her detailed Oramics log books or her correspondence, it appears somewhat unlikely.

Why then, did Oram not cast the net wider? The evidence from her logbooks suggests that frequent faults and downtime made scheduling Oramics demonstrations a risky proposition. Obviously she would not have wanted people to come all the way to Kent, from London, or further afield, only for the machine not to work as intended. Instead, Oram promoted the Oramics system by recording demonstration tapes[282] from the better days of the machine's operation. By Oram's own admission, the machine was Heath Robinson-esque in its construction, and this would have been a further, more aesthetic, but nevertheless pertinent consideration when inviting potential backers to her remote studio.

[282] Oram 2007 (Audio) DO227. Oramics demonstration tape.

Toward Mini Oramics: The Timing

One could argue that working within the fields of electronics or computation has always come with the risk of technology moving on before a project is ready to be launched. It would follow therefore that it is necessary for these practitioners to work quickly, to avoid being superseded before a potential product is ready for market.

In Oram's case more specifically, her unhurried approach, exemplified in a letter to New Zealand composer Douglas Lilburn, is somewhat at odds with the *need for speed* paradigm outlined above.

> I must choose just the right moment to launch it [the Oramics Machine]. But how difficult it shall be to assess that moment - and anyhow I shall always be thinking of ways to improve the techniques and never want to call it finished.[283]

Of course writing in 1968 Oram was all too aware that the Oramics Machine was not ready to launch, even if she chose to. But also as we have heard in *Oram as Pioneer*, she also concerned herself with the fashions of time, particularly with regard to computer generated and aleatoric music, both fields that she was opposed to. Oram seems to have been convinced that these fashions should also be considered with regard to any potential launch date for Oramics:

> The computer can then produce 'music by the yard' and get away with any rubbish. It is depressing for me, having spent some years devising 'computer like equipment' as an 'extension to the composer's arm', responding only to the minute instruction of the composer. But it does mean that I can have longer to perfect my invention - and it really needs years of work for the potentials are enormous.[284]

In Oram's case, despite not having appeared to worry too much about it, being superseded should perhaps have been more of a concern. As the SCOT model has shown, early adoption can be the key to the success of a technological system, whatever the relative merits of competing technologies. Arguably the late 1960s and early 1970s were a key point for the adoption of non-tape based electronic music composition systems, and specifically those which went on to dominate the electronic

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[283] Oram 2007, ORAM09/04/064, Letter to Douglas Lilburn, 23rd July 1968.
[284] Ibid

studio market through the 1970s: the voltage controlled synthesisers and sequencers of Moog et al (before MIDI). Whatever the comparative merits of Oramics/Mini Oramics against these technologies, the fact is commercial products were coming to market when Oramics was still only a prototype. Yes, Oram's decision to simplify and miniaturise her system and create Mini Oramics was incisive, but time was limited for this system to have a chance at making an impact.

So the timing was crucial, and the period 1970-1973 would arguably have been perfect for the new solid-state Mini Oramics to launch. Perhaps she might have started work on it earlier, had it not been for writing her book *An Individual Note*, to be ready for publication in 1972, and also the death of her mother, which occurred in 1972[285]. Oram did get to work on Mini Oramics in 1972[286], but obviously to work more quickly, she would have needed investment or funding which, as outlined in *Oram as Pioneer* in regards to the 1971 CGF / Arts Council meeting, was not forthcoming in the cultural sector. And as outlined above, Oram's efforts in the commercial sector were limited and perhaps compromised.

An additional timing factor, which was perhaps inconvenient for Oram, although not as crucial, was the fact that toward the end of the sixties, transistorised electronic devices were becoming more dominant than valve designs. This perhaps sped up the process of the Oramics Machine beginning to appear old fashioned, when compared to the new synthesisers which (in the commercial sector) had been transistorised from the outset.

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[285] Oram's family history was provided by her niece, Carolyn Scales, in an email to the author. 6th March 2013

[286] Oram 2007, ORAM01/06 Mini Oramics correspondence with Norman Gaythorpe and Sherborne School

Investment and Funding in EM technology

In a broad sense, nearly all of the problems synopsised above, could have been overcome with sufficient money (save those which pertain to Oram's attitudes to her competition/peers). Additional funding or commercial investment could have provided replacement engineers, better facilities and professional marketing. But perhaps most importantly, additional money could have afforded Oram speed with bringing Oramics, in whichever form, to market.

Unfortunately for Oram, a variety of factors kept this investment from coming. Perhaps the most crucial of these factors was that, despite electronic music not being *new* per se, the markets for this music, or the machines that made it, were 'as yet unproven'[287], at least in the sense of mass markets and mass appeal: who were the relevant social groups for these developments? Were there established markets for these technologies? Therefore the problems that Oram faced with getting investment, she certainly did not face alone. In the early 1970s (in the UK at least) getting any funding or investment for electronic music based projects was extremely difficult.[288] As Pinch and Trocco[289] have stated, even those who did manage to bring products to market in the early days of commercial electronic instruments, also often struggled to survive financially.

As the EM markets did grow and evolve toward the late 1970s, and electronic sounds were more frequently employed in popular music, large corporations moved into the field. They built upon the proven technologies of the pioneers, and to be more precise, they built upon the technologies which had been subject to *early adoption*. In doing so, they sealed the fate of the Oramics interface.

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[287] Again referring to John Cruft of the Arts Council in the fateful 1971 CGF meeting. See Oram 2007, ORAM01/02/084 for the meeting minutes.
[288] See Candlish N. 2012
[289] Pinch, T. and Trocco, F. 2002

Oramics Now – Contemporary Perspectives

The contemporary construction of Mini Oramics has allowed a more authoritative appraisal of the potential of Oramics as an interface concept, as well as providing greater insight into the challenge of building such a device. In the context of appraising a non-functioning fifty year-old artefact which very few people ever used (the Oramics Machine), the contemporary version of what Mini Oramics *might have been* has proven illuminating.

An Alternative?

Conceived at a time when all was still to play for in music technology, could Mini Oramics have offered an alternative interface to other commercial offerings?

The influential works of Kraftwerk, Giorgio Moroder and others, characterise the driving, repetitive, and quantised aesthetic of sequencers and analogue synthesisers in the mid to late 1970s[290]. Yet to some, including Oram[291], this *gridlocked* system of composition held little or no interest.

> A freehand drawing method might produce very much more artistic results because of the inaccuracies inherent within it.[292]

[290] It is recognised that the possibilities of early sequencers were not firmly 'locked to a grid' but rather, depending on how they were clocked, able to offer more sophisticated rhythmic structures. That said, the process of achieving such structures was by no means as transparent as just 'drawing what you wanted'. The quintessential aesthetic of early sequencers was certainly regular and repetitive.
[291] See Oram's notes on minimalist music: Oram, D. 1972 PP76-77, also her musings on pop music in comparison to Bach: Oram, D. 1972 PP55.
[292] Oram 2007, ORAM01/01/018. Oram's 1961 notebook containing the *Written Sound Waves* passage used as the Oramics design brief for the purposes of this thesis.

Musicians and composers are diverse in taste and technique, and they utilise what they have access to. So it follows that had Mini Oramics been commercially launched (and it is hoped that the reconstruction has proved this was possible), some musicians would in all likelihood have preferred its qualities to the commercially available competition[293]. It is also likely that its alternative interface would have appealed to musicians who were perhaps put off by other electronic means of composition: composers who eventually settled on using acoustic instruments. The construction of Mini Oramics, and the subsequent user study, has demonstrated that Mini Oramics somewhat paradoxically allows both a level of detailed nuance in the control of sound, and at the same time, a 'humanistic'[294] and inherent inaccuracy, exactly as Oram had hoped. It is a very different interface to the synthesiser/sequencer combination described above, and one where attempting to compose a repetitive piece of music would be a real challenge.

It is futile to argue the superiority of one system or other. It is enough to conclude that Mini Oramics could have provided a unique and genuinely alternative approach to the electronic musician, at a time when all the options were expensive, and all somewhat limited in scope. It is also worth re-stating that, had Mini Oramics been built on the CV/Gate standards of other technologies, composers would have been freely able to combine these two strands of music technology in hybrid configurations.

So, has Oram's passionate advocation of a drawn sound interface been vindicated? Perhaps this question has been partially answered, but to further assess the significance of the Oramics interface, it would be prudent to briefly examine some later and contemporary electronic music interfaces, especially those that use graphical input methods.

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[293] When discussing the potential commercialisation of Mini Oramics, comparisons are drawn with commercially available technologies. The ANS, UPIC etc, although more analogous to Oramics as interfaces, were not commercialised at the time (now there are software emulations), and will not be referred to in this argument. The Fairlight system perhaps is more relevant as it was commercially available, and had graphical input possibilities, but it was also very expensive and came later than the hypothetical *launch* of Mini Oramics.

[294] Quoted from Participant B in the user study.

MIDI (Musical Instrument Digital Interface)

During the Mini Oramics evaluation process, Participant D made the astute observation that the Mini Oramics interface pre-empted 'the kind of detailed parametric layering that MIDI sequencers would eventually make possible'.

It would be simple to argue that, had Mini Oramics been launched in the early 1970s, the advent of MIDI in 1983 would have spelled the end for the Oram's interface. However, assuming that Mini Oramics had gained some market share, and returning to the SCOT model, there is no reason to suppose it would have remained a static entity. If it had been adopted by composers and musicians, Mini Oramics could have evolved and certainly could have integrated with MIDI to an extent.

It is also problematic to assert that MIDI would have entirely superseded Mini Oramics. In fact they have different advantages and disadvantages. In particular MIDI is an excellent tool for recording performance parameters, especially when using velocity sensitive keyboard or drum pads. Yet in terms of scoring or programming music in other ways, in *graphic* ways, entering notes and velocities using a mouse and keyboard leaves much to be desired. On the other hand Mini Oramics has no copy and paste function[295], no polyphony and other disadvantages when compared to MIDI.

In some aspects they are similar technologies. The ability to see a graphic and parameterised representation of the composition as it plays, recalls the barrel organ or the player piano, and is a highly logical and intuitive approach to composition. Yet this is a feature that was notably absent from many early electronic sequencers.

Referring again to the Mini Oramics user study, there were positive remarks about the feeling of using a pen to compose, and also positive comments in regard to not having to use a computer screen. This user feedback, in addition to the *non-static technology* theory outlined above, all add weight to a possible scenario where Mini Oramics might have survived the arrival of MIDI in some form. It is certainly possible to argue that Mini Oramics could have retained enough unique sonic and interfacing characteristics, to remain a viable alternative or accompaniment to MIDI within some musical

[295] It may also be argued, that the lack of a copy and paste function can be advantageous for musical creativity.

practices, much as the Theremin and Ondes Martenot have survived later competition and still gain new devotees amongst young musicians.

Contemporary Drawn Sound Practices

Within the realm of creative technology and Human Computer Interaction (HCI), researchers and musicians are still considering approaches to drawn sound interfaces. Papers and presentations on the subject are still regularly included in prestigious conferences and symposia such as New Interfaces for Musical Expression (NIME) and the ACM Conference on Human Factors in Computing Systems (CHI).

The emergence of touch screen technologies has also contributed to the burgeoning interest in drawn/gestural parameter control.

Software interfaces reminiscent of earlier drawn sound technologies are still very much in use, for instance *Metasynth*[296] which appears to owe a lot to the ANS Synthesiser in its microtonal and spectrographic drawn interface.

Hardware examples of drawn-sound approaches are also still appearing, for example Ian Fritz' Double Deka VCO, similar to the eventual Mini Oramics wave-shaper solution, and also Seth Kranzler's 'drawn' wavetable synthesiser, which again forms a wave shape using a series of physical slide controllers, this time using embedded software to integrate with Ableton Live.

In parallel with many other approaches to electronic music composition, drawn sound interfaces are still being conceived and explored many years after Oram conceived Oramics. This goes some way further in affirming the validity of her concepts, and helps to illustrate just how forward thinking her ideas were, especially given the fact that the eventually dominant visual/parameterised technologies of electronic music software have so much in common with Oramics.

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[296] Uisoftware.com. (2016). *MetaSynth 5 for Mac OS*. [online] Available at: http://www.uisoftware.com/MetaSynth/index.php [Accessed 31 Oct. 2016].

> I wonder how long it will be before people become bored by 'chance art' and the pendulum swings the other way. At present here, one only has to mention the word computer for everyone to swoon away in wonderment...[297]

Perhaps now the pendulum has *swung the other way*. Whilst there are still composers exploring aleatoric techniques, many more are exploring linear composition, and many are also utilising drawn sound, in one way or another.

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[297] Oram 2007, ORAM09/04/064 Oram's letter to Douglas Lilburn 23rd Jul 1968.

Precedents Technology and Influence

Finally, to briefly return to the title of this thesis, what has been discovered about the Oramics Machine and Oram's wider interface concept within the above terms?

In terms of precedents, it is clear that Oram researched her field exhaustively and many factors were borne in mind as she developed her ideas for the Oramics Machine. Oram took advice and consultation from as many experts as she could muster in the years before she left the BBC and after. In terms of a direct genealogy to the Oramics Machine, it appears that Edinburgh University's early speech synthesiser: the Parametric Artificial Talker can be seen as a eureka moment for Oram as she first watched its graphical control films generate recognisable speech in the 1958 BBC documentary.[298] Myron Schaeffer's Hamograph also had a considerable influence, and was possibly what helped Oram to choose 35mm film as her first programming medium. That said, Oram was able to extrapolate and expand upon the limited brief of the Hamograph to eventually build a much more powerful interface, a complete system of composition, rather than the simpler audio processing module that the Hamograph was designed to be.

When discussing Oram's technologies, it is important to remember that many aspects of the Oramics Machine were *unprecedented* and were the unique inventions of Oram and her engineers. Both her patents and her machine are testament to this. The patents alone are not enough to fully assess Oram's work, as the machine has given up secrets that are difficult or impossible to locate within the patent documents. Being the first to opto-digitally control an oscillator in this way is a major technological achievement, amongst many others. But by far the most impressive thing about Oram's technological prowess was her analytical capability to conceptualise larger systems from smaller sub-systems, to take an idea and run with it. The Oramics Machine and its overall conceptual premise, is so much greater than the sum of its parts.

Direct evolutional influences stemming from the Oramics Machine are difficult to discern. None have been found in the course of this research project. It does appear that

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[298] *Rees, A. Prod. 1958. Eye On Research: The Six Parameters of PAT, 31 mins.* BBC, UK [internet video] <vimeo.com/26005634>.

even beyond the SCOT model, in the literal sense, Oramics was an evolutionary dead end in the course of the history of music technologies. This is where we need to broaden the scope of *Oramics* to include Oram's influence and her broader philosophy. Untold numbers first learned about electronic music through Oram's lectures and seminars, her teaching, her work at the BBC and beyond, as well as her book, which has now been republished. Oram taught many of the great and good of UK electronic music how to splice tape, how to process and combine sounds, and her influence in terms of the passing on of knowledge cannot be underestimated. That said, the Oramics Machine itself continues to influence if one examines it outside of the aforementioned evolutionary context. The 2011 *Oramics to Electronica* exhibition at the Science Museum allowed the machine to baffle and inspire people in equal measure. And of course, the very positive reaction[299] to the new Mini Oramics further illustrates that Oram and Oramics continue to influence and inspire.

[299] In addition to the positive feedback from the user study, Mini Oramics has caught the imagination of many, thanks to the Goldsmiths press team, social media and the press. The machine has now been demonstrated at several conferences, festivals and workshops, and invitations are still forthcoming. See *Research Outcomes.*

SUGGESTED FURTHER RESEARCH

Oram's Commercial Work

Having set up one of the earliest private studios for electronic sound production in the UK, Oram quickly gathered an impressive client list. Her creative and often humorous soundtracks in the fields of advertising and film deserve revisiting. In the Oram audio archive at Goldsmiths there are numerous tapes that Oram had kept from this work. Some are interim demonstrations with Oram personally talking her clients through different sonic options, others are finished works. Sadly, the archive lacks any of the corresponding moving images for these recordings. Tracking these films down would be of great value to the archive and Oram's wider legacy.

Oram's Pedagogy

Oram taught in various contexts across the span of her career, from primary age children, to university students, and old age pensioners. She developed an experimental syllabus for electronic music to be taught in schools, and in fact, she intended Mini Oramics to be used in this way. Much of the evidence of her efforts survives and is kept in the Daphne Oram Archive.

A Feminist Reading of Oram's Work

As was outlined in the introduction of this thesis, a specifically feminist account of Oram's life and work would be of utmost value. Oram wrote her own take on these issues in her 1994 essay *Looking Back to See Ahead*[300]. Goldsmiths scholar Laurie Waller has made a start here by writing about Oram in the context of Donna Haraway's *Cyborg Manifesto*[301].

Oram's More Esoteric Interests

Dan Wilson, in his 2011 article *the Woman from the New Atlantis*[302], published in Wire magazine, looked at Oram's interests in esoteric and new age subjects, including sonic healing and the supernatural.

Holly Pester[303] has researched Oram's *The Sound of the Past*[304] – an essay which explores theories for the design and usage of sub-sonic resonances in megalithic structures.

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[300] Oram, D. 1994
[301] Waller, L. 2014. PP148
[302] Wilson, D. 2011
[303] Pester, H. 2013
[304] Oram 2007, ORAM06/01 Oram's notes pertaining to *The Sound of the Past* mid 1970s

Oram's Computer Work

After her career slowed down in the late 1970s, Oram regained momentum in the 1980s. During this time she learnt to program a series of home computers. She was designing an Oramics style graphic-sound software application. This fascinating and under-researched part of the Oram Archive contains one of her computers, her floppy discs and a significant quantity of written material.

Some initial research into her computer work was made as this thesis was undertaken which revealed that Oram had designed/commissioned her own custom sound interface with the help of a local engineer, and that she had received Arts Council funding in order to pursue this research. It emerged that she had recorded her sonic efforts onto cassette tapes - which are now regrettably missing.

It is entirely possible that a researcher with the right skills could bring her software back to life, and we might be able hear these sounds for the first time.

Fig 47. Oram with her Apple II computer, early 1980s. Her custom designed audio interface is clearly visible directly below the computer.

APPENDIX

Contents

APPENDIX - Section 1 – Mini Oramics User Study – Participant Questionnaires

Mini Oramics 2016 Evaluation Questionnaire (Participant A)

Please describe briefly your musical and music technology training.

Have played both the saxophone and piano in the past. Took classes in both, but never got to the point where I was able to sight-read notation.

Music technology training has encompassed Logic, Pro Tools and Ableton. The level of expertise in these DAWs is enough to generate work, and the learning curve is developed on-the-job, so to speak.

To what extent do you feel you have a good command of electronic musical interfaces?

I haven't had much experience of electronic musical interfaces, so therefore feel that my command of them might be considered poor. However, I'm quite good at digging in, having followed instructions, and am always keen to play around and investigate devices.

Please briefly describe your musical practice and the tools you might normally use.

My compositional practice is predominantly an electroacoustic one. Within this I source material from the environments, which are then turned into sonic pieces to be used within compositions. Currently Ableton is the DAW of choice. Within this software, I make extensive use of samplers and processes.

Hardware includes: MacBook Pro, Komplete Audio 6 audio interface, Alesis studio monitors, AKAI APC40, Roland PC300 midi keyboard, Tascam DR100 MK2 digital recorder, Naiant omnidirectional condenser microphones, Sennheiser HD25 II headphones.

Please describe your experience of using Mini-Oramics including positive and negative aspects of the device and your overall impression. If possible please refer to the following aspects in your reply:

waveform generators, envelopes, pitch control, vibrato (pitch bend), speed, slew (glissando) controls.

It's difficult to remember how I used the Mini O as I didn't spend very long with it. However, I loved having the ability to interact with it via a marker pen, and to be able to control the various parameters by drawing on the acetate. . In all honesty, the way *in which I drew onto the acetate was random and haphazard, but this is ok, as my compositional practice is one of discovering elements that lie within sonic materials before and after being processed.*

I was especially interested in the accompanying control box (name?), where other parameters could be controlled. This somehow resonated more with me in terms of generating the sound. It was certainly easier to visualise the sound being made and, of course, was somewhat closer to technologies that I've experienced in the past.

Please imagine it is 1973. How do you think composers and musicians might have received Mini-Oramics? (Please bear in mind the kind of contemporaneous technologies one might have had access to: monophonic subtractive synthesisers e.g. mini-moog, modular synth, step-sequencers, tape recorders etc).

APPENDIX - Section 1

Mini Oramics 2016 Evaluation Questionnaire (Participant B)

Please describe briefly your musical and music technology training.

> *Originally 'classically trained' – piano / violin / woodwind, grew up playing and writing music using notation. At 18 began studying music production at Goldsmiths as a BMus, then a Masters in studio composition, now doing a PhD between fine art and music.*

To what extent do you feel you have a good command of electronic musical interfaces?

> *I'd say I have a pretty consummate command of most electronic musical interfaces – I've worked in studios, doing live engineering, using complex technologies for composition (both hardware and software), also I've used a lot of homemade electronics and systems for music composition in my practice as an artist*

Please briefly describe your musical practice and the tools you might normally use.

> *Varies hugely. I'll often work from notated score or graphic scores, I'll then do a lot of studio based studio recording sessions, and then work with software programmes (max, pro tools, able ton live, custom software in C or Python), I often use PCBs, field recording etc – I also often work with non-linear compositional systems and large multi-channel speaker arrays in varying environments (galleries, public museums, outdoor remote locations). The aim of most of my work is to explore new forms in musical composition and the ways in which they can heighten our understanding of the world around us. I very rarely work with static 'linear' music as such. I also very rarely create a finished recording in any real sense (other than documentation of an event).*

Please describe your experience of using Mini-Oramics including positive and negative aspects of the device and your overall impression. If possible please refer to the following aspects in your reply:

waveform generators, envelopes, pitch control, vibrato (pitch bend), speed, slew (glissando) controls.

> *This is a wonderful compositional machine. It sits between composition and performance as a device, and allows the composer to compose 'in time'. It's by far the best synthesiser (for me particularly and the way I work) that I've ever used – at once a sequencer and an instrument – unlike anything I've come across. It's incredibly intuitive and exciting to work with, as it has both a high level of granularity but it is also incredibly easy to work with. As a monophonic instrument it is more expressive and humanistic than anything I've yet used*

outside of acoustic instruments. Conceptually, I have nothing negative to say, I think if this had happened at the time Oram had proposed it, this would have caused a change in the way people think about the electronic composition of music. The biggest relief for me is being able to compose without recourse to a computer screen.

Some detailed thoughts about technical aspects (some of which you may have already solved!);

*1. **Static issues** - over time, particularly when writing and erasing notes a lot of static is created, which makes for variable speed and the acetate unspooling etc - this plagued me, but I learnt to cope mostly.*

*2. **The back light on the machine** - this creates a variable tone dependent on brightness which is quite distracting when using the machine. This ideally would have no effect on the sound.*

*3. **Resonance pots on the filters** – these, when I was using it were upside down, but consistently so between the two.*

*4. **Reverb** - this has quite a bit of noise on it in the high end, but this is probably unavoidable given that it's spring. Be great if this could be cleaned up*

*5. **Vibrato** - you could increase the depth quite a bit on this, to me it is nearly imperceptible*

*6. **Pitch track on the perspex** - it'd be useful to have the pitches on the right hand side (as well as the left), to make it easier to keep track of where you are, I find myself today doing a lot of counting and using a ruler a lot to make sure I'm at the right pitch.*

*7. **Speed of the roll** - this isn't particularly smooth when you increase from very slow to fast, there seems to be quite a big jump somewhere in the middle. It would also be useful to either have a click dial, or some way of setting a constant speed, or to have some markings that make logical sense (so that I can note down the speed of a given piece).*
This speed thing is interesting as another thing is that I found myself slowing it right down so I could align things back on the grid on the perspex (to work out note lengths etc), but, because it's really difficult to stop it in the right place, everything is always slightly off (which is kind of great, but makes rhythmic accuracy quite difficult)

*8. **Potential notes/writing lane** - I'd find it really useful to have the drum track as a lane for notes (i.e. what speed a thing is at, what settings should be applied etc*

*9. **Pause switch** - I didn't use this at all (as I just use the stop, mid-way point instead of scroll left and right, which achieves the same thing I think)*

***10. Volume pedal / control** - I think this is a definite need, it would be incredibly useful - perhaps it shouldn't be a pedal though, and a dial would do the job fine...*

*11. **Tracking/alignment of roll** - over time it does go slightly off, making pitches and other things misalign etc, be great to have a way of keeping it dead straight and consistent.*

*12. **Mirror for the LEDs** - this would be great - I'd love to watch what is going on, while I'm doing things, it would definitely help people understand what is going on very quickly, although arguably from a design aesthetic side, white LEDs might be better and more in keeping.. the mirror should be retractable as there is a real elegance to not seeing them also.*

*13. **Octave jumps** - with everything clean and no gliss etc, I am really struggling to get clean jumps between octaves, even with very careful enveloping etc, I've tried every way round I can think of - see the 'little brown jug' example I've written and you'll hear two instances of it and see what I mean. Maybe I'm just doing something wrong with it though, I can't figure it out!*

*14. **Drawn Volume steps** - feels like when drawing the volume curves for the A&B that there is a bit step up between grid height 3 and 4 or thereabouts, its very hard to get a smooth curve between them (i.e. from quite quiet to medium volume or thereabouts)*

Please imagine it is 1973. How do you think composers and musicians might have received Mini-Oramics? (Please bear in mind the kind of contemporaneous technologies one might have had access to: monophonic subtractive synthesisers e.g. mini-moog, modular synth, step-sequencers, tape recorders etc).

I think the graphic aspect of it in particular would have had a huge impact. This idea of laying down a composition 'out of time' and off grid as it were would have had a big impact (almost all computer sequencers default to a grid setting which has reflected heavily in dance music since their advent).

I also think the notion of 'drawing' sound is a very progressive and humanistic way of working. The current use of a mouse in the making of electronic music is actually very frustrating and restrictive and is not conducive to direct human expression. The gestural aspect of drawing is a wonderful thing to integrate within electronic music composition – the machine acts as a bridge between two forms of composition (the classical notated technique, and the programmed electronic music technique).

APPENDIX - Section 1

Mini Oramics 2016 Evaluation Questionnaire (Participant C)

Please describe briefly your musical and music technology training.

30+ years of playing & performing acoustic instruments; Bachelors degree in flute & orchestral flute experience; MA in music technology, PhD in computer science with music technology focus; I currently do research & teach music technology subjects at university level.

To what extent do you feel you have a good command of electronic musical interfaces?

Excellent. I haven't done much with analogue synthesisers, but I teach & do research on custom musical interfaces.

Please briefly describe your musical practice and the tools you might normally use.

My current musical practice mainly involves software (written by me in ChucK, Max/MSP, and/or Java) and controllers (e.g., M-Audio trigger finger, MIDI keyboard, game controllers, custom sensor-based systems.)

Please describe your experience of using Mini-Oramics including positive and negative aspects of the device and your overall impression. If possible please refer to the following aspects in your reply:

waveform generators, envelopes, pitch control, vibrato (pitch bend), speed, slew (glissando) controls.

Most positive aspects:

- I loved the sound. I was able to get some really ethereal, complex sounds, which I'd never be able to achieve using programming in ChucK or Max.
- I liked being able to approach it in so many different mindsets. I could play it analytically (as I tried to very carefully "program" sounds according to a musical idea I had in my head) or holistically/creatively (as I drew new shapes just to see what they would do). I liked that I could easily get surprising sounds out. But even when I drew something whose sound surprised me, I liked that I could analytically reconnect that to the shapes I drew. This allowed me to develop a visual "vocabulary" for the instrument, and I could use physical variations of my gestures to vary sound in intuitive and delicate ways.

APPENDIX - Section 1

Waveform generators:

I liked the tactility of the inputs. They didn't give me as much interesting control as I'd expected, though, so my strategy ended up being to set the two waveform generators to different shapes so I had 2 distinguishable timbres. I did like having the option of changing the size of the wavetable, though, since this was such an easy way to create "riffs" on the content I'd "programmed" by drawing, by changing the pitch.

Envelopes:

I don't think I used these.

Pitch control & vibrato:

I wasn't very interested in playing melodies, and I didn't usually like "locking" to discrete pitches. It was fun to draw pitch shapes and see what happened, and I was amused by the "noodly" fast notes I could get when my line varied quickly between pitches. But musically, I was more drawn to the vibrato/pitch bend. It sounded nicer within the style I was using, which was more about texture than melody.

Speed:

I didn't use this very expressively. I forgot about it, then realised after working with the system for a long time that I could speed everything up and make it sound funny.

By the way, I really love the fact that you can play your scores backwards and forwards, and that you don't get an exact reversal between the two! This is mind-bending and super cool. If I had a long time to spend with the instrument I would enjoy trying to manipulate this to make pieces that could be played in both directions.

Slew: I found myself wanting to programmatically control this with its own track.

I used this a little bit for fine-tuning, usually when I wanted a more abrupt or sensitive response to my drawing but wasn't getting it.

Other thoughts:

I would have liked another "track" on the bottom where I could write text notes to myself about how to control the non-programmable parameters (e.g., when to change waveform or slew or speed). Like a track to program myself.

Please imagine it is 1973. How do you think composers and musicians might have received Mini-Oramics? (Please bear in mind the kind of contemporaneous technologies one might have had access to: monophonic subtractive synthesisers e.g. mini-moog, modular synth, step-sequencers, tape recorders etc).

While I would enjoy hearing what other people have said in response to this question, I really hate speculating myself.

APPENDIX - Section 1

Mini Oramics 2016 Evaluation Questionnaire (Participant D)

Please describe briefly your musical and music technology training.

I studied music and music technology at school and university to Doctorate level. I have been active in the international experimental music scene for 20 years, and I currently conduct research in electronic music and verbal notation. I have been an avid follower of developments in music technology since being given my first Electromusic Research BBC MIDI interface, and I have taught composition, sonic arts and music technology at university level since 2004.

To what extent do you feel you have a good command of electronic musical interfaces?

I am very comfortable using both analogue and digital interfaces, and I employ both in my daily practice for music creation and analysis. These tools augment my exploration of music and are essential to my ongoing experience of sound.

Please briefly describe your musical practice and the tools you might normally use.

As a composer I make work for acoustic instruments, occasionally with electronic components (noise, tape etc.). In my daily practice I work with a range of tools including pencil and paper, piano, laptop, headphones, digital sequencers, analogue sequencers, mathematics software, calculator, ear etc.

As a performer I realise the work of other composers such as Alvin Lucier, Christian Wolff and Chiyoko Szlavnics, and I also make improvised music with musicians such as John Tilbury, Michael Duch and Angharad Davies. I currently generally use modules and other analogue equipment, alongside Max, Supercollider, resonant objects, percussion, ear etc.

Please describe your experience of using Mini-Oramics including positive and negative aspects of the device and your overall impression. If possible please refer to the following aspects in your reply:

waveform generators, envelopes, pitch control, vibrato (pitch bend), speed, slew (glissando) controls.

Overall my experience has been very positive and inspiring.

APPENDIX - Section 1

The waveform generators are subtle and allow for delicate colouration of tone which feels very much in keeping with the overall character of the machine. The interface for the waveform generators is really quick and intuitive to use. The oscilloscope was also very useful for understanding how the waveforms could be manipulated.

The envelope controls are also fairly intuitive, though I felt slightly confused by the layering of written input in addition to the scaling provided by the envelope knob, which means that a written volume of 10 does not necessarily immediately produce a volume of 10.

The pitch control works well, and I was able to quickly understand and use this component. The interface assumes octave equivalency, which can be a positive or negative thing depending on the musical context. It would be exciting if different acetate templates were available that allowed the user to access other tunings and metric underlays.

While the pitch bend is effective, it's not possible to create very accurate tunings (to the level of, say, Just Intonation), so for me the pitch bend remains more of an effect than a controllable parameter. In combination with the slew control it is possible to make the oscillators sound more 'organic', which can be a welcome addition in some circumstances.

The transport is generally consistent and easy to use, but has occasionally slowed or stopped (probably due to build up of static). I found that it was possible to create unpredictable quasi-symmetrical patterns by running the same material back and forth across the head using the direction knob. This means that on/off markers are not always read, which produces unpredictable results (potentially useful for playing the instrument in a live context).

It is the machine's idiosyncrasies that for me give the instrument character and make me want to spend more time getting to know its temperament.

Please imagine it is 1973. How do you think composers and musicians might have received Mini-Oramics? (Please bear in mind the kind of contemporaneous technologies one might have had access to: monophonic subtractive synthesisers e.g. mini-moog, modular synth, step-sequencers, tape recorders etc).

I think the Mini-Oramics machine would have been very warmly received by composers and musicians, because it offers a unique way of putting together potentially quite ornate and repeatable audio and CV sequences, yet it recalls techniques and technologies that were already available to studio musicians, i.e. tape machines and analogue synthesis. The interface design also preempts the kind of detailed parametric layering that MIDI sequencers would eventually make possible. Had the Mini-Oramics machine been available to musicians in 1973 I can imagine it having a considerable impact on the direction taken by both electronic music and electronic instrument design.

APPENDIX Section 2 – The Oram/Emmett Design For Mini Oramics

MINI - ORAMICS

TOWER FOLLY, FAIRSEAT. WROTHAM.
KENT TN15 7JR.
0732-822398.

page (A)
MAY 1981.

MINI ORAMICS — Notes with circuits.

Oramics is a system of generating sound by graphic means. The following parameters are covered.

Analogue –

Timbre – waveshape mask before oscilloscope CRT.
3 waveshapes at a time before one CRT.
(Pulse code selection of 1 of 3 shapes?) (3 switches) digital
Disc of masks – revolve disc to select 3 (adjacent) masks.
While scanning 3, others can be manually replaced.

Digital –

Pitch – frequency of oscilloscope timebase varied by –
12 chromatic positions
7 octave positions
1/8 tone, 1/4 tone, 1/3 tone } transpose positions.
8 vibrato steps (width)

Volume – modulation of output to amplifier
8 envelope steps (fine volume)
8 loud/soft steps (course volume)

Reverberation – three switched levels to reverberation unit & cancel.
(or perhaps 6, comprising 3 in & 3 out)

Speed – 5 steps of drive motor speed.

AUXILIARY
2 switches for remote control of tape recorder.

Thus the programming disk requires 60 read & latch circuits. (at least!)

page (B)
May '81

Mini Oramics

Mini-Oramics is a method of composing sounds, by defining separately in digital (or "analogue") form the necessary parameters.

The programming desk consists of ordinary greaseproof paper (bought in a roll from Boots or W.H. Smith) which is transported from a feed roller across a illuminated panel (lit from beneath), under a filament strip lamp, through a pitchwheel/roller drive system and onto a take up roll. The composer marks dots & curving lines on the paper using a soft pencil (3B) which will make dense opaque marks. As the paper passes beneath the strip light photocells are appropriately deprived of light & switch in latching circuits.

The following parameters are controlled —

pitch (within one octave) in semitone steps
choice of octave
sharpening by 1/8, 1/4 or 1/3rd of a tone.
frequency vibrato
course volume control
fine volume control (ie envelope shape)
reverberation (output to & from spring echo or reverberation chamber)
choice from 3 wavepatterns
control of speed of paper transport.

An existing oscilloscope (or specially built C.R.T + photocell arrangement) is used to scan the upper edge of an opaque outline inked on a plastic slide. Two other wave outlines are drawn on the same slide (one above the other). The biasing of the Y signal downwards can be momentarily cancelled (or amplified) in order to make the C.R.T spot jump vertically to the chosen wave outline.

Greaseproof paper is preferable to clear plastic film for a number of reasons.

page (C)
May '81

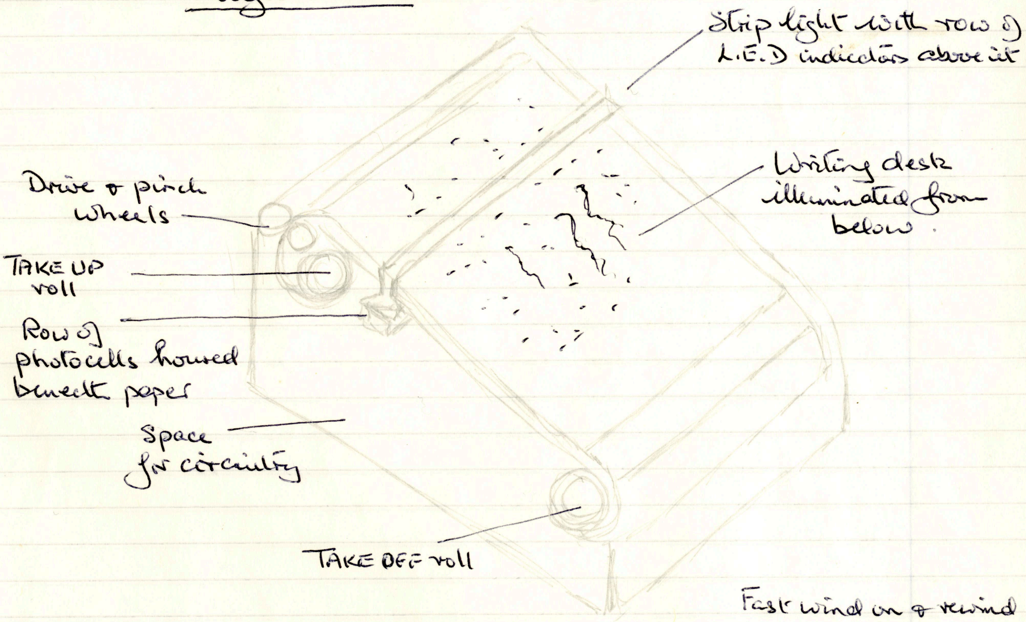
MINI ORAMICS

The photocells need to be rather sensitive in order to see the light through the greaseproof paper. (On the other hand they must not sense the variations in transparency of greaseproof paper itself). They need to be of small diameter. (2 mm approx)
TEXAS TI cell, about ·082" diameter, will probably do well, but is expensive. Motorola = 1·5 mm wide

It was hoped, at one time, that decapitated transistors might work — BC108s for instance. Advice requested on this, please. (Motorola)

.... shows distance apart of cells. 1/10"

Rough Sketch



Fast wind on & rewind
Hand wind on & back
Take up roll perhaps located outside rear for ease of threading.

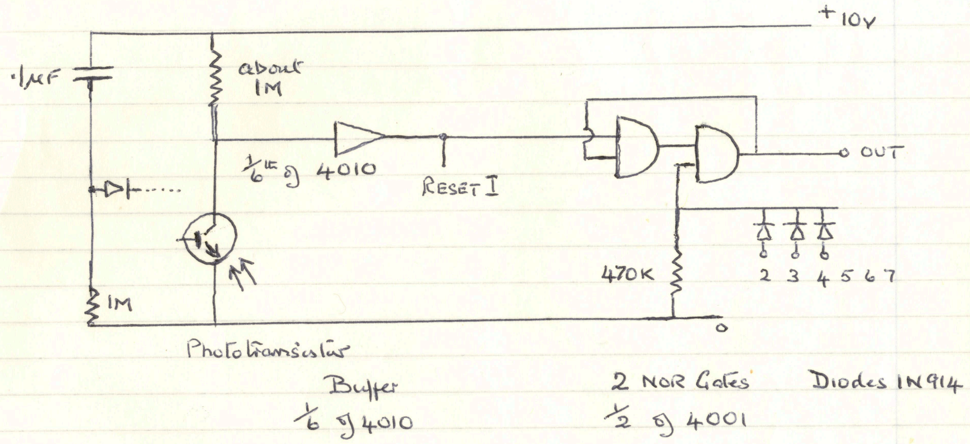
Greaseproof paper 15" wide
75 ft of writing on 80 ft roll
say 4" per sec = 3 mins 45 secs
In 12" width 112 cells could be accommodated, giving 2 "voices"
Boots roll 80 ft long x 15" wide cost 43p in 1979.
Half width (7½") machine might be preferable. (1 voice)

APPENDIX Section 2

Page 1.

MINI-ORAMICS CIRCUITS redrawn MAY 1981.

Optical reader & latch circuit.
(called Read/Latch, shortened to "R/L" circuit)



One of 7 circuits to set 'OCTAVE' (other functions similar)
Suggested alteration — put 'reset out' before buffer. Put AND gate in one circuit, to operate that latch if TWO dots are written at once — timebase then still operates.

Starter circuit fitted to the stage which is required to be ON when one switches on.

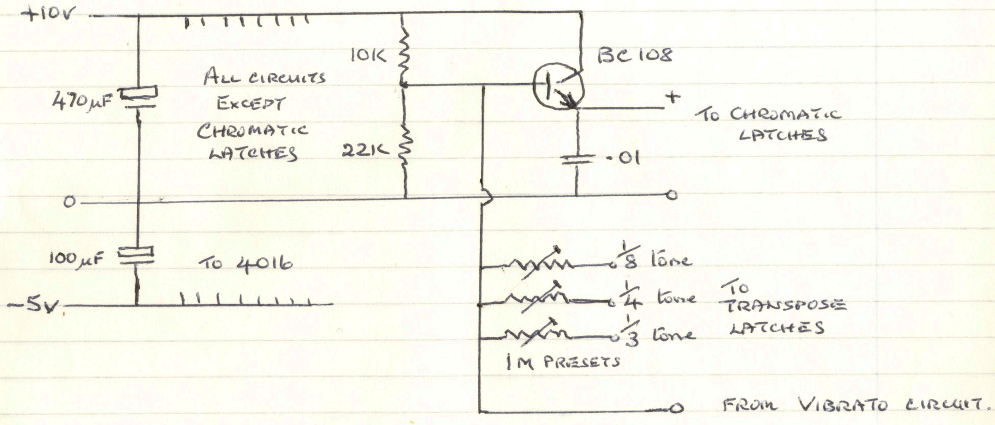
(Consider the saving in cost of 6 octaves instead of 7)

APPENDIX Section 2

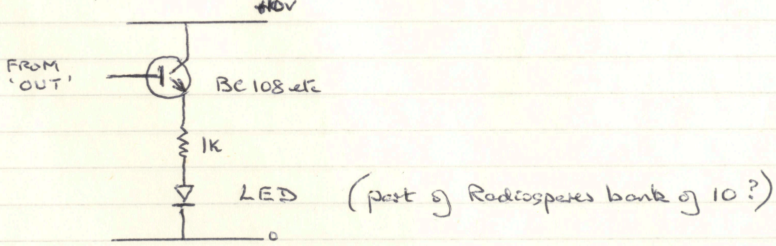
Page 2

Mini Oramics

Circuits Redrawn May '81



Output Indicator.



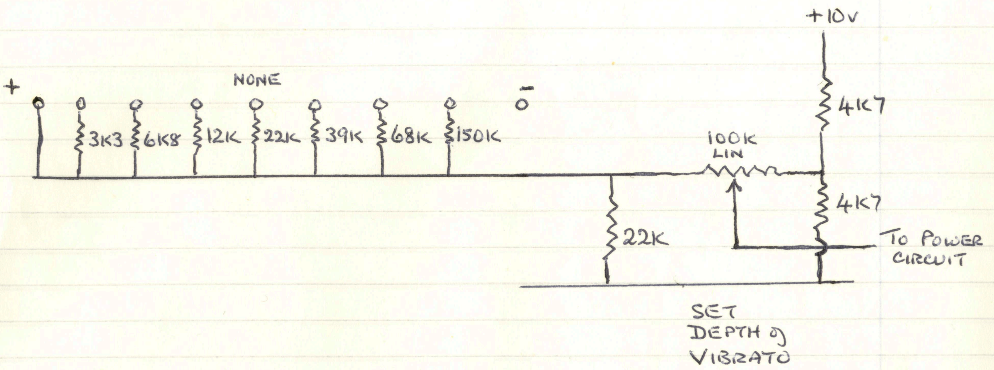
APPENDIX Section 2

PAGE 3

MINI ORAMICS

CIRCUIT REDRAWN MAY 1981

VIBRATO LATCHES.



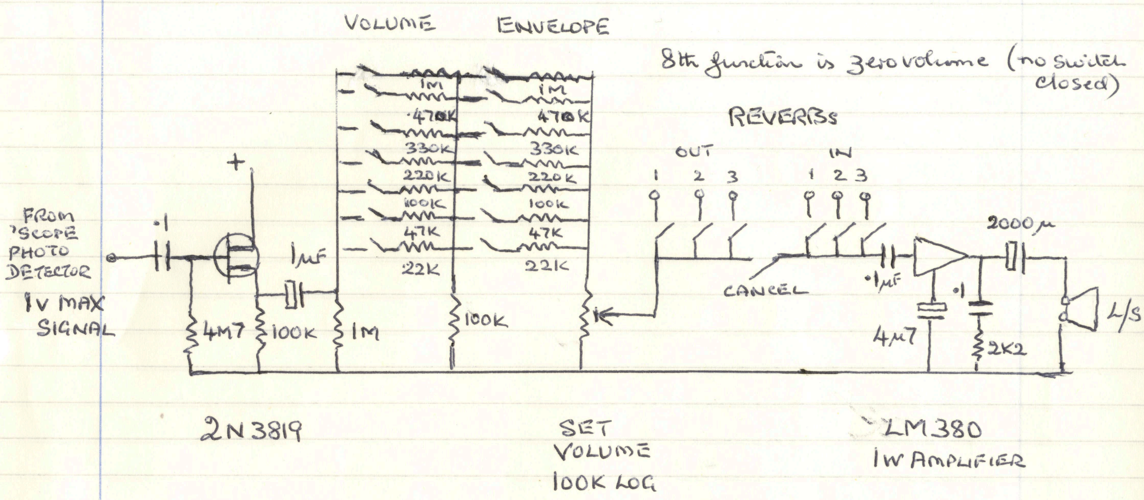
APPENDIX Section 2

PAGE 4.

MINI ORAMICS

CIRCUIT REDRAWN MAY 1981.

8th function is zero volume (no switch closed)



ALL SWITCHES
¼ of 4016

Is this
-||- 1μF ?

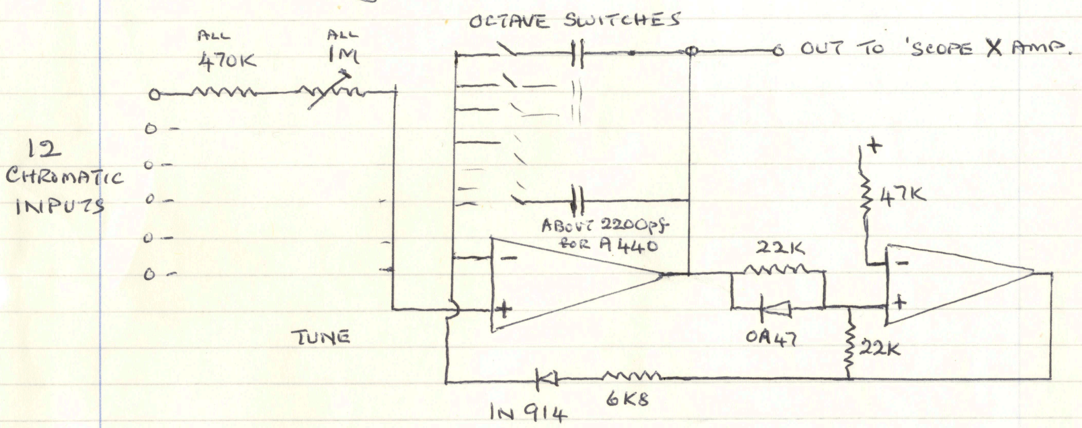
APPENDIX Section 2

PAGE 5

MINI ORAMICS

CIRCUIT REDRAWN MAY 1981

TIMEBASE for SCANNER ('scope)



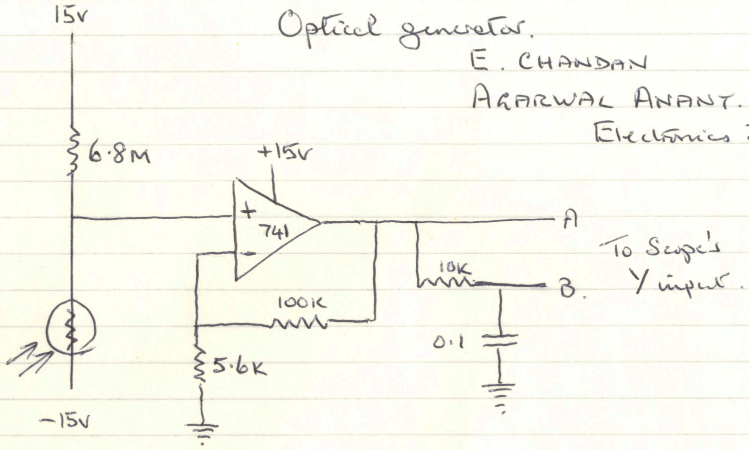
Op Amps 1/4 of LM 3900N or equiv.
SWITCHES 1/4 of 4016

APPENDIX Section 2

PAGE 6

For Mini Oramics?

Optical generator.
E. Chandan
Agarwal Anant.
Electronics July 3 1980.



Use B (after low pass filter) output if scanning beam oscillates.

APPENDIX Section 3 – Waveform Scanner Design Oram Intended To Use For Mini Oramics, (from *Electronics* Magazine July 1980)

Optical generator traces scope-mounted masks

by E. Chandan and Agarwal Anant, *Department of Electrical Engineering, Indian Institute of Technology, Madras, India*

Using a photoresistor encased in the aluminum hood of an oscilloscope for adjusting the position of the scope beam in the vertical axis, this function generator reproduces almost any waveform by electrically tracing out the pattern of the waveshape's defining cut-out mask that is mounted on the scope's face. It eliminates the need for expensive digital systems of the kind often employed for arbitrary waveform generation in biomedical and other applications below 500 hertz.

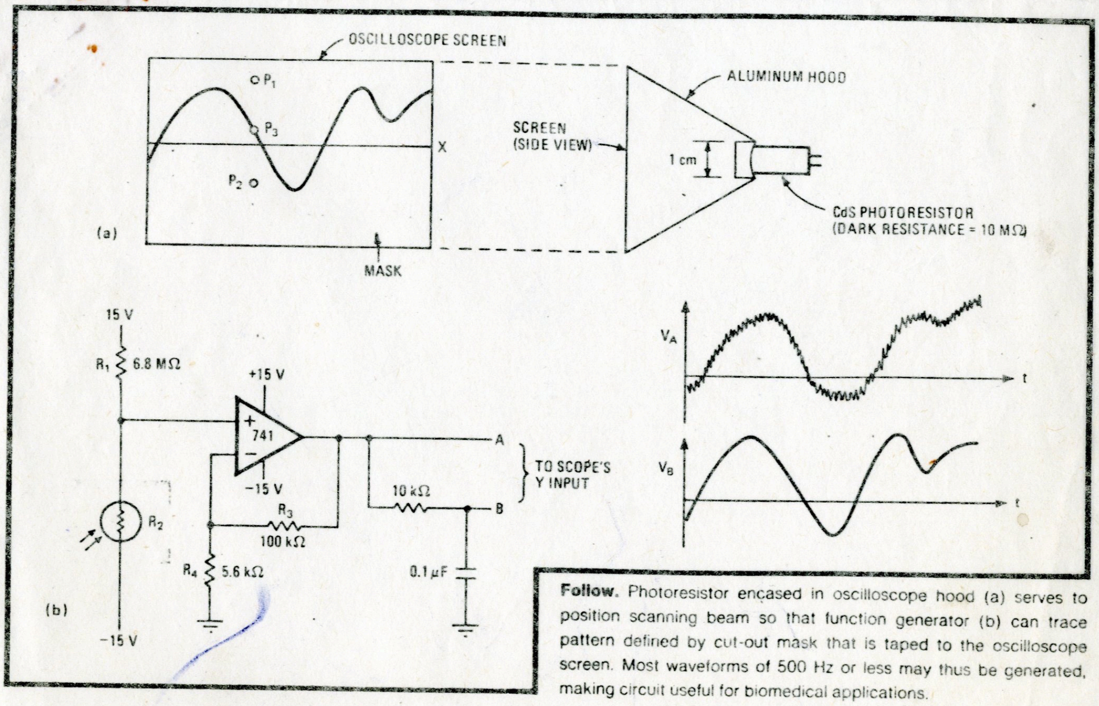
The photoresistor should be placed snugly in the scope's hood in such a way that light from all parts of the scope screen is directly incident upon it, as shown in (a). The black paper cut-out of the required waveshape is then taped on the screen.

The sensing circuit (b) monitors the screen illumination and adjusts the scanning beam to fall at the upper boundaries of the mask. Suppose the instantaneous location of the beam is at point P_1. The photoresistor will be intensely illuminated and assume a low resistance of perhaps only a few hundred ohms. Therefore, the noninverting input of the 741 operational amplifier will go negative, and its output will also of course move to a corresponding negative voltage.

The output of the 741, which represents the generator output, drives the Y input of the scope, so that the beam will be forced to move to a low point on the vertical axis. The beam will tend to fall below the upper boundaries of the mask in most instances, at point P_2. Consequently, the photoresistance will rise to several megohms, causing the voltage at the noninverting junction of the 741 to move positive and to force the beam upward.

Because of the aforementioned feedback, the beam attempts to rest at P_3, where $R_1 = R_2$. Of course, the beam traverses the X axis from left to right at the same time, and so the circuit will try to position the beam along the mask's boundaries, thereby generating an output voltage conforming to the cutout.

Occasionally, the gain of the 741 stage $(1 + R_3/R_4)$ needed for the vertical displacements desired for a given scope may cause the scanning beam to oscillate to an unacceptable degree. If the output of the 741 is taken after a low-pass filter (port B), the problem will be eliminated entirely. □

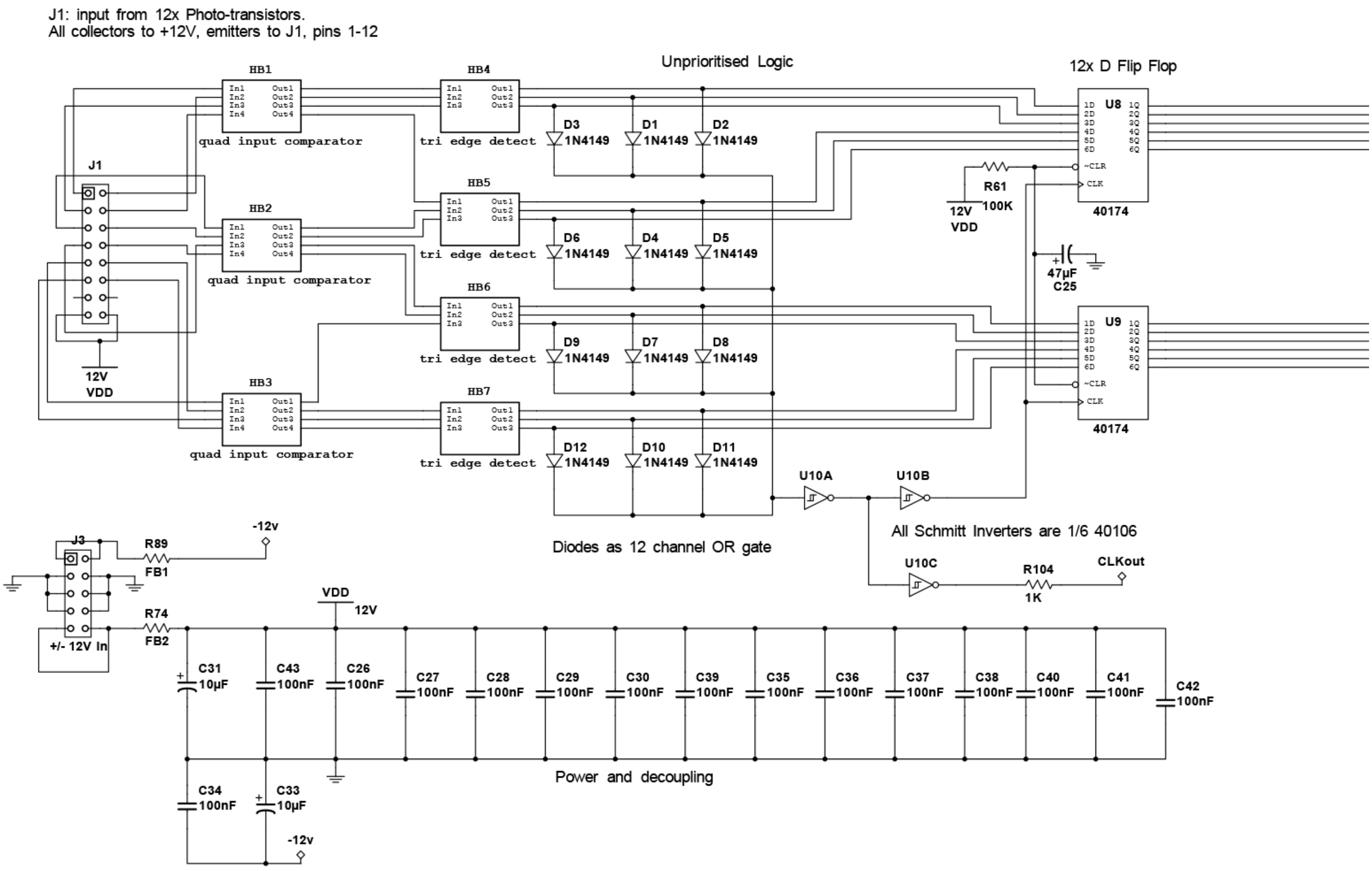


Follow. Photoresistor encased in oscilloscope hood (a) serves to position scanning beam so that function generator (b) can trace pattern defined by cut-out mask that is taped to the oscilloscope screen. Most waveforms of 500 Hz or less may thus be generated, making circuit useful for biomedical applications.

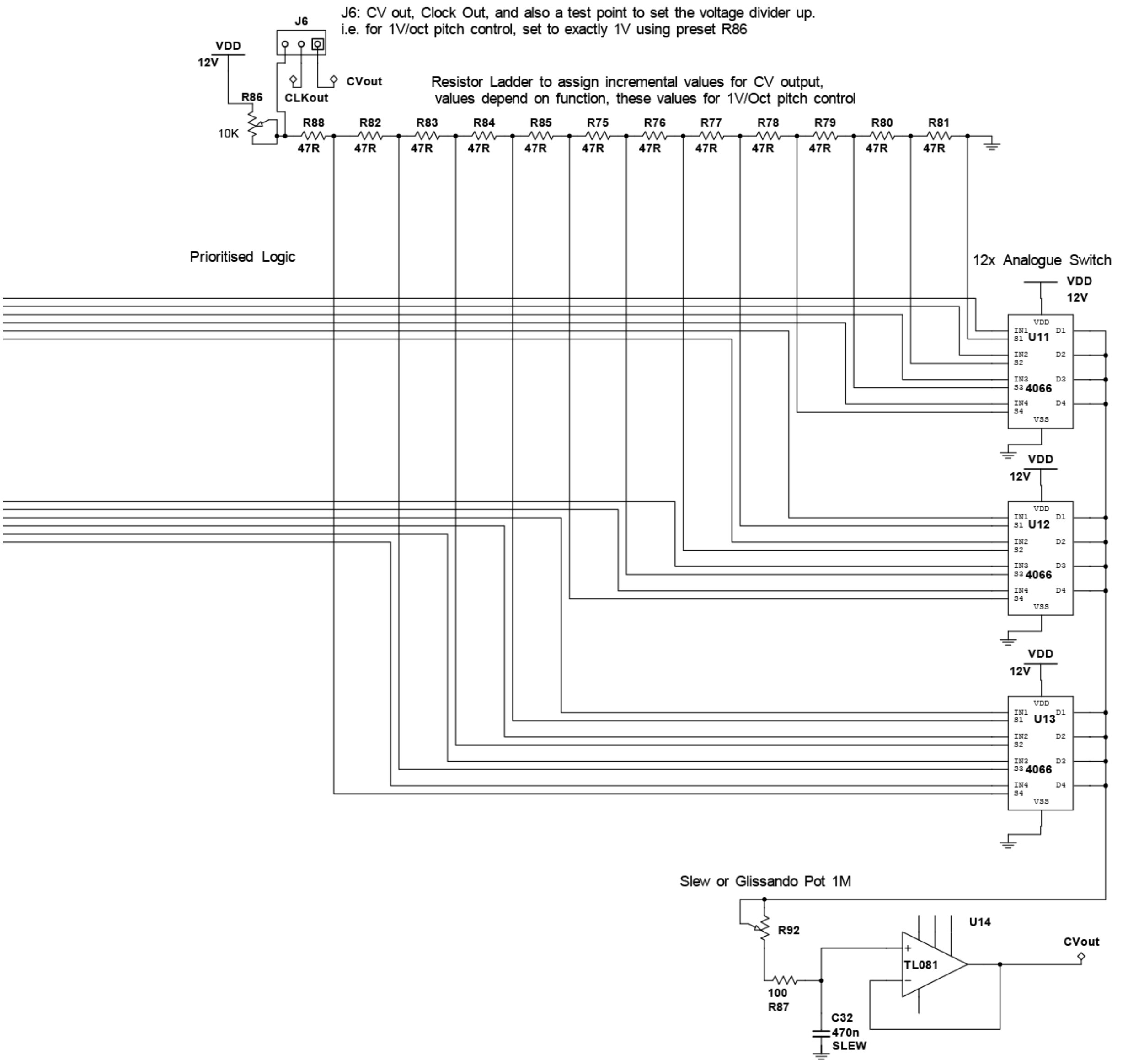
APPENDIX Section 4

Circuit designs for re-imagined Mini Oramics 2016

Graphic Input to Control Voltage Circuit

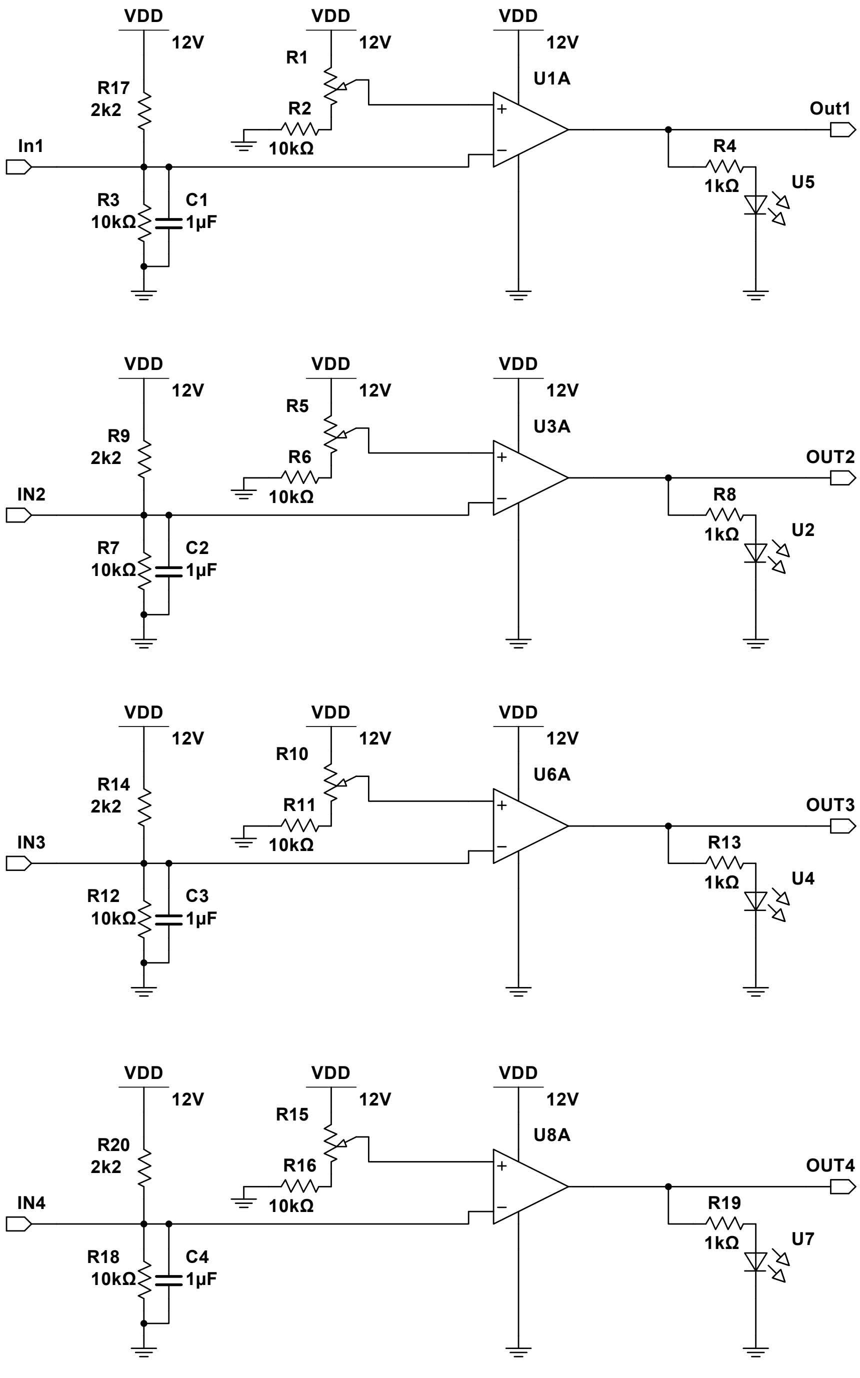


APPENDIX Section 4



APPENDIX Section 4

Graphic Input to Control Voltage, Sub-circuit 1, Quad Input Comparator

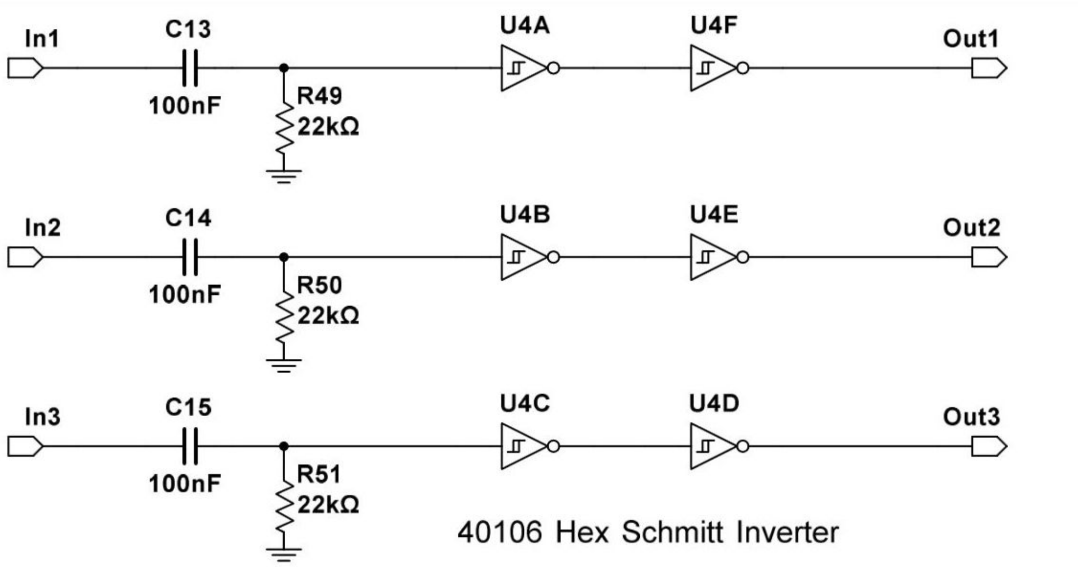


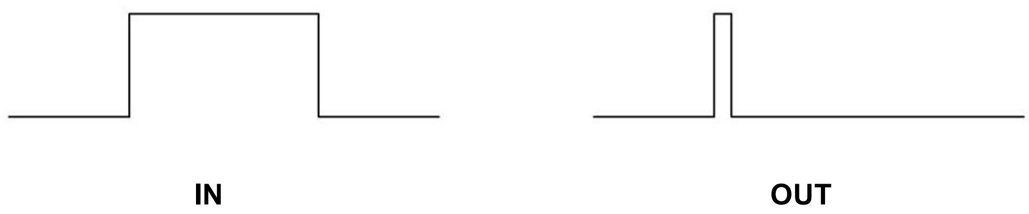
All Op-Amps 1/4 LM324
All preset (threshold) pots 500K Linear

The 2k2 pullup resistors should be left out for normal operation.
They are only for when a channel is not needed, to stop it affecting the outcome of other channels. They effectively blank each channel that they are included in.

APPENDIX Section 4

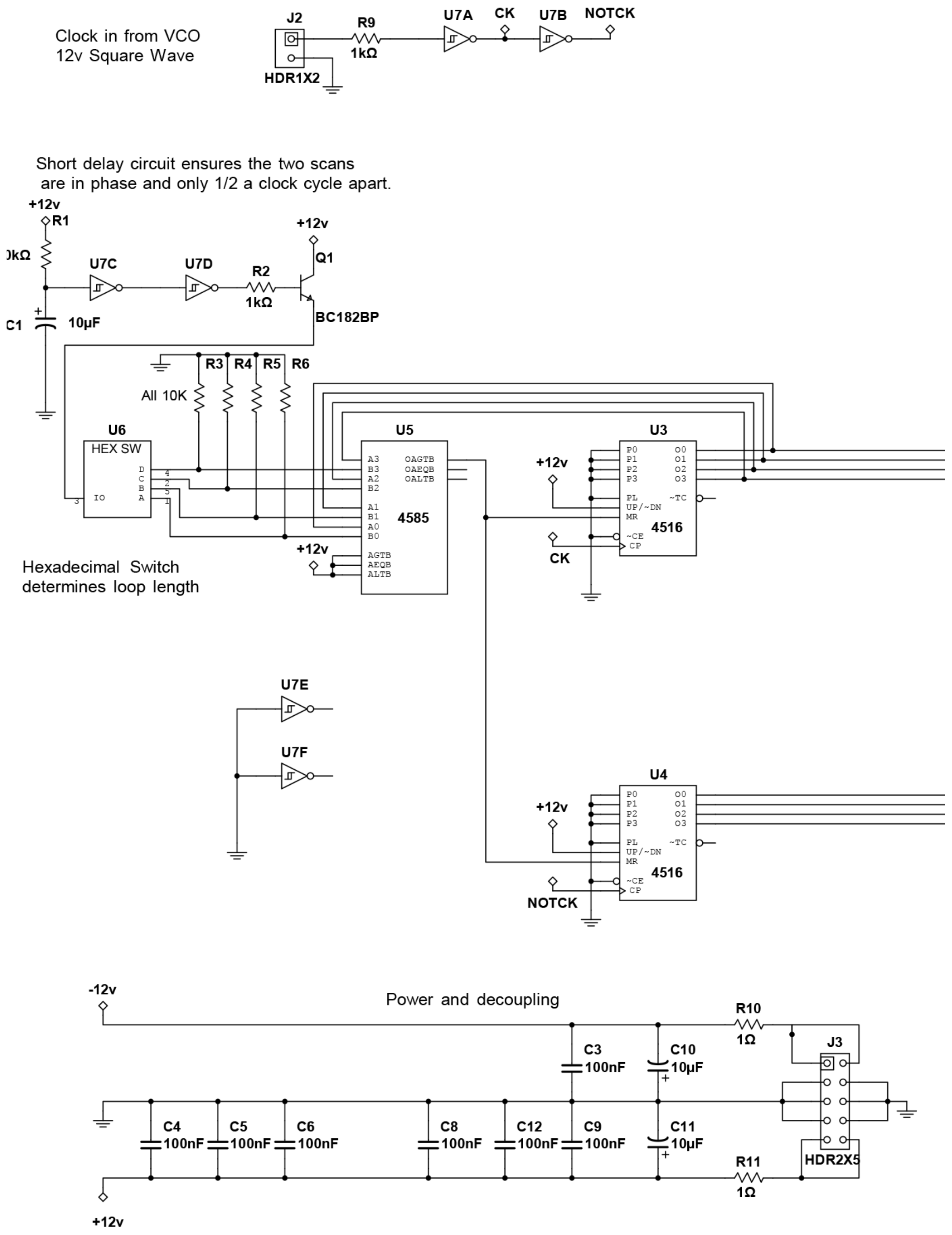
Graphic Input to Control Voltage, Sub-circuit 2, Triple Rising-Edge Detector

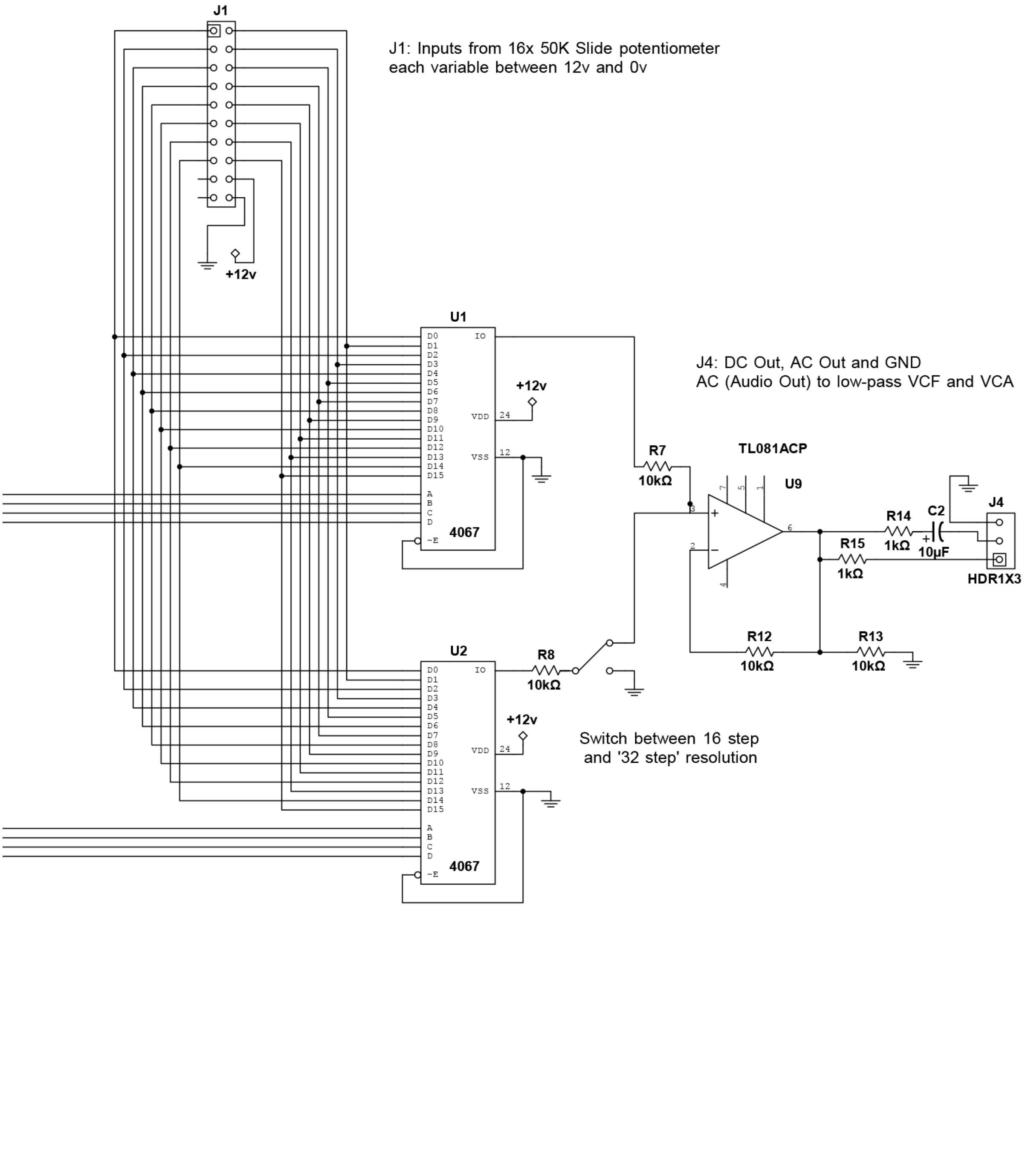




APPENDIX Section 4

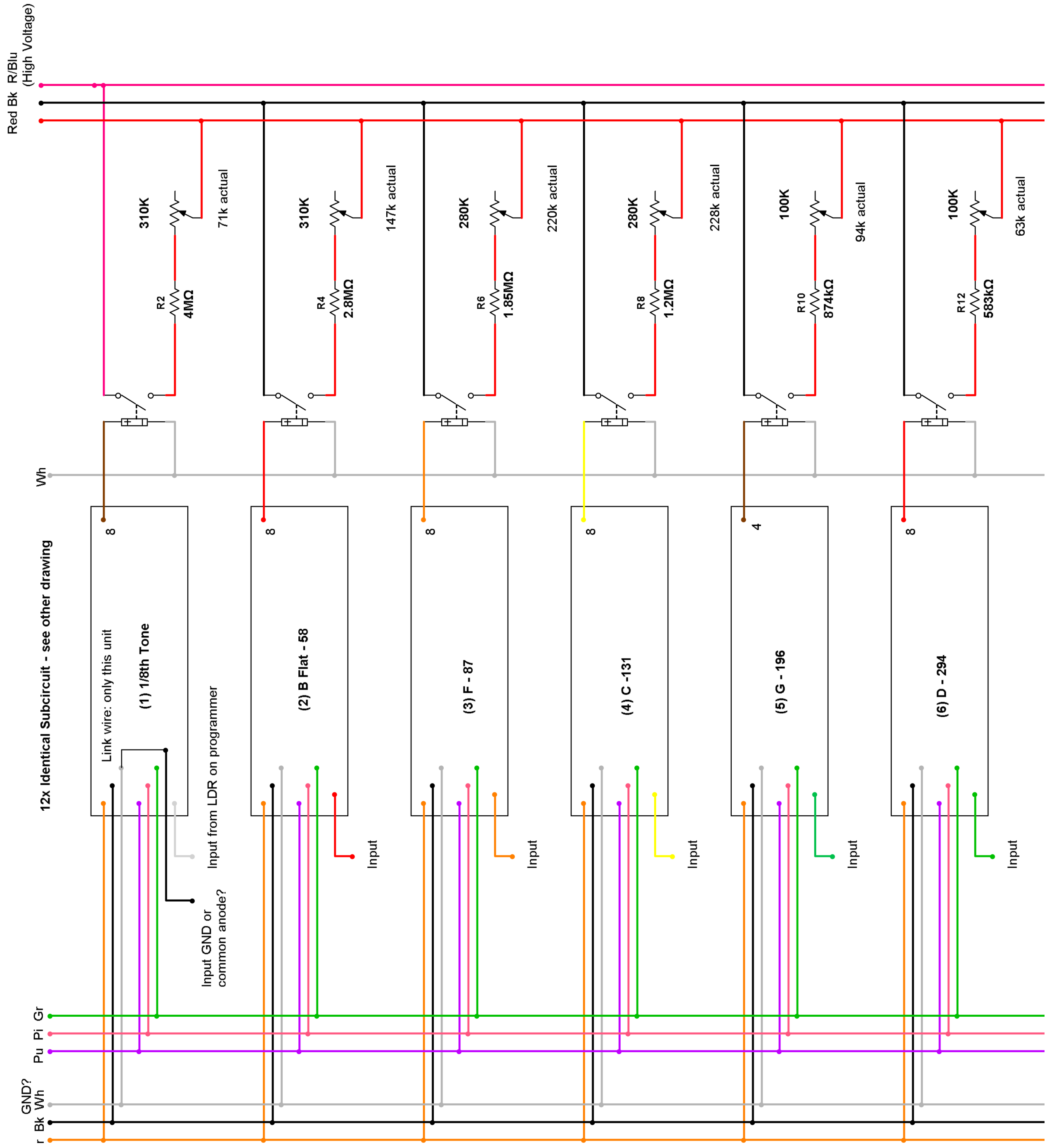
Wave Shaper Circuit

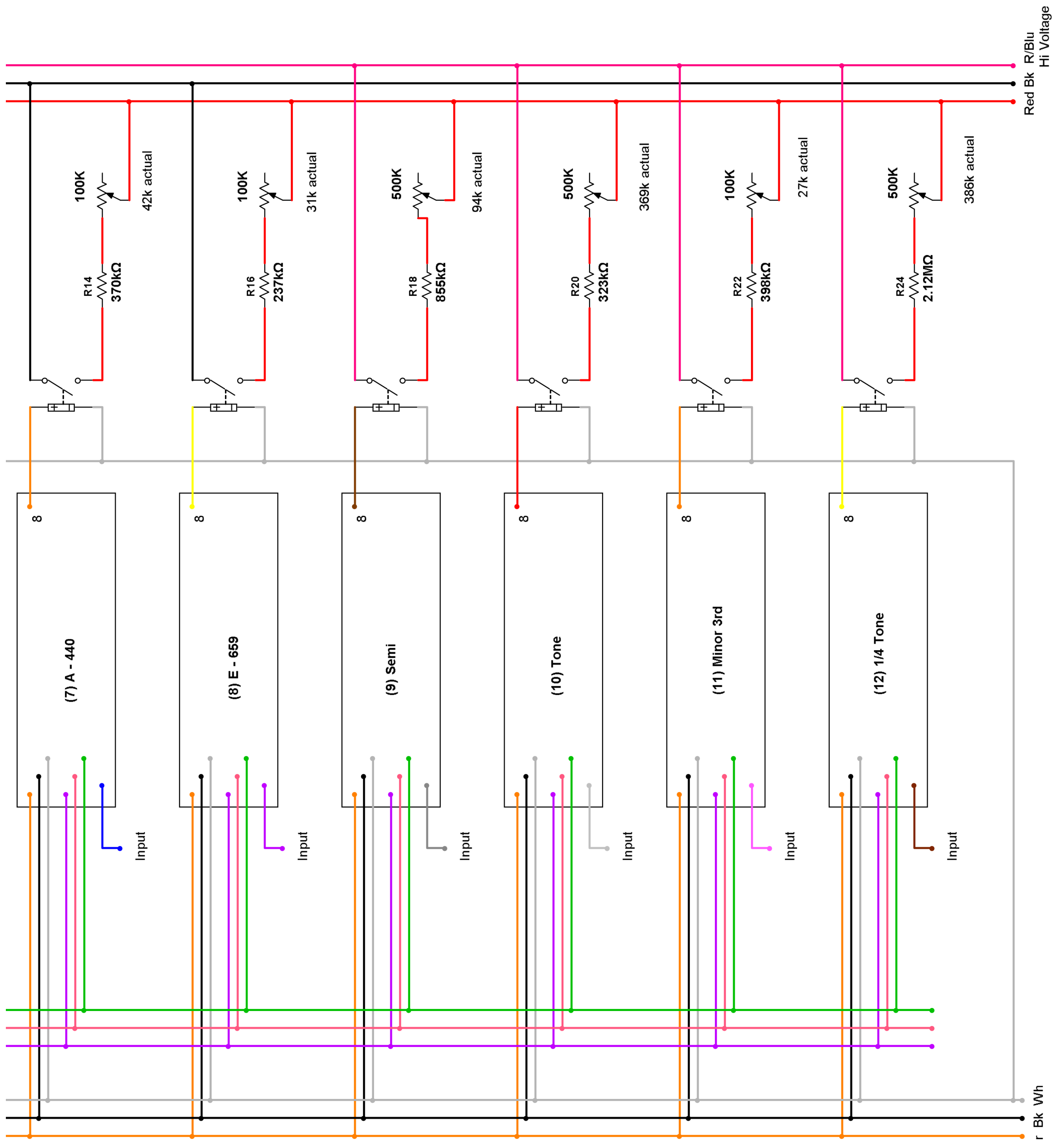



J1
J1: Inputs from 16x 50K Slide potentiometer
each variable between 12v and 0v
+12v
U1
D0
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
D14
D15
A
B
C
D
~E
IO
VDD
24
VSS
12
4067
J4: DC Out, AC Out and GND
AC (Audio Out) to low-pass VCF and VCA
R7
10kΩ
TL081ACP
U9
R14
1kΩ
C2
10µF
J4
HDR1X3
R15
1kΩ
R12
10kΩ
R13
10kΩ
U2
R8
10kΩ
Switch between 16 step
and '32 step' resolution

APPENDIX Section 5

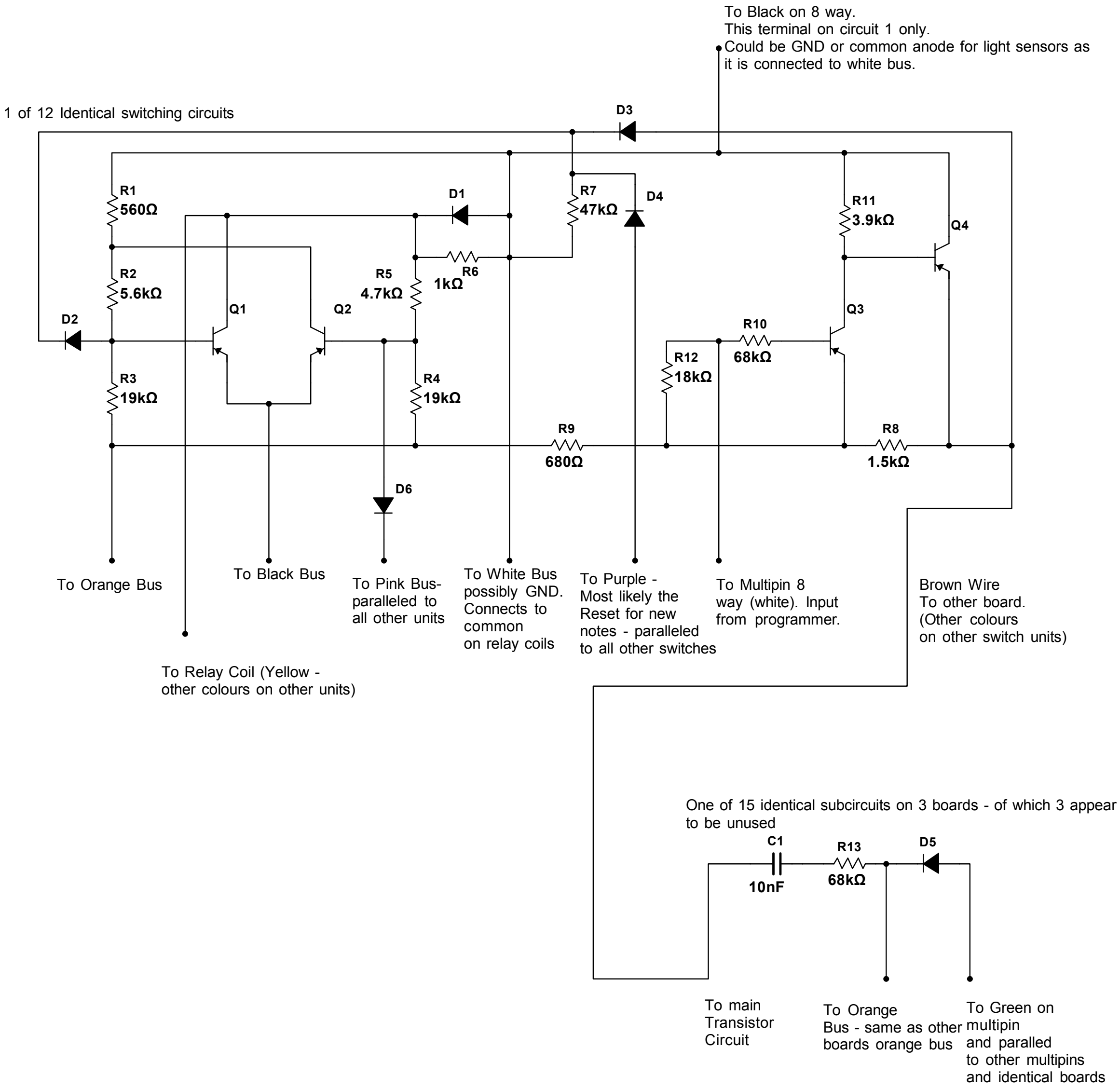
Oramics Pitch Control Circuitry – schematised from the Oramics Machine at the Science Museum London: Overview with cabling coloured as per actual unit.




Red Bk R/Blu
Hi Voltage
100K
R14
370kΩ
42k actual
100K
R16
237kΩ
31k actual
500K
R18
855kΩ
94k actual
500K
R20
323kΩ
369k actual
100K
R22
398kΩ
27k actual
500K
R24
2.12MΩ
386k actual
8
(7) A - 440
Input
8
(8) E - 659
Input
8
(9) Semi
Input
8
(10) Tone
Input
8
(11) Minor 3rd
Input
8
(12) 1/4 Tone
Input
r Bk Wh

APPENDIX Section 5

Oramics Pitch Control Circuitry – schematised from the Oramics Machine at the Science Museum London: Detail of Switching Circuit (J-K Flip Flop)



RESEARCH OUTCOMES

Lectures

Alternative Histories of Electronic Music, Science Museum, April 2016 (conference)

Computer Arts Society, hosted by Goldsmiths, June 2014 (public)

F(Glitch), Stony Brook, New York State University, March 2014 (conference)

Curating the History of Science, MA Module, UCL, hosted by the Science Museum, February 2014 (teaching)

Lates event, V&A Museum, January 2014 (public)

Seeing Sound, Bath Spa University, November 2013 (conference)

Music Technology BA course, UEL, October 2013 (teaching)

Research & Curating teams at the Science Museum, October 2013 (internal)

Women in Science, London Metropolitan Archives, March 2013 (conference)

Arts and Computational Technology MA course, Goldsmiths, January 2013 (teaching)

Music MA course, Goldsmiths, December 2012 (teaching)

Manchester Metropolitan University, October 2012 (public)

RESEARCH OUTCOMES

Selected Music Performances and Workshops using Wave-Scanning Prototypes and the new Mini Oramics.

Moogfest, Durham North Carolina, USA, April 2017

Fort Process, Newhaven Fort, September 2016

Brighton Modular Meet, Sussex University, July 2016

Seeing Sound, Bath Spa University, April 2016

Music: Tom Richards, Camden Arts Centre, August 2014

The Exponential Horn, Media Space, Science Museum, May 2014

Data, Contemporary Arts Society, July 2013

Hydroacoustics, MS Stubnitz (touring ship venue), May 2013

Puregold, QEH, South Bank Centre, May 2013

Perspectives on Daphne Oram, Non Classical/EAVI, The Macbeth, March 2013

Exhibitions

Daphne Oram: Public Dreams and Private Nightmares, Sho-Zyg Exhibition, Goldsmiths, Sept 2012 (Co-Curator with James Bulley)

Who was Daphne Oram? Special Collections, Goldsmiths Oct 2013
(Digital Content Research and Design)

RESEARCH OUTCOMES

Mini Oramics Press

Journals:

Allan, J, L. 2011. Light Fantastic, *The Wire,* No. 391, 12.

Radio:

BBC Radio 4, World at One (feature). Broadcast 4th July 2016

Web:

BBC News. (2016). *'Old school' synthesiser built 40 years on - BBC News*. [online] Available at: http://www.bbc.co.uk/news/technology-36651270 [Accessed 31 Oct. 2016].

The Wire Magazine - Adventures In Modern Music. (2016). *Daphne Oram Kickstarter launched plus student builds Mini-Oramics - The Wire*. [online] Available at: http://www.thewire.co.uk/news/42085/daphne-oram-kickstarter-student-builds-mini-oramics [Accessed 31 Oct. 2016].

FACT Magazine: Music News, New Music. (2016). Watch Daphne Oram's unfinished synth brought to life over 40 years after its design. [online] Available at: http://www.factmag.com/2016/06/07/daphne-oram-mini-oramics-synthesizer-goldsmiths/ [Accessed 31 Oct. 2016].

Resident Advisor. (2016). *A student built Daphne Oram's unfinished Oramics synth*. [online] Available at: https://www.residentadvisor.net/feed-item.aspx?id=94229 [Accessed 31 Oct. 2016].

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Reichardt, J. ed. 1968. *Cybernetic Serendipity: The Computer and the Arts* [exhibition catalogue]. London: Studio International.

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Rodgers, T. 2010. *Pink Noises: Women on Electronic Music and Sound.* Durham and London: Duke University Press.

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Schaeffer, P. 2012 *In Search of a Concrete Music.* London. University of California Press Ltd. (Translated from the 1952 original French version by Dack. J and North. C.)

Smirnov, A. 2013. *Sound in Z: Experiments in Sound and Electronic Music in Early 20th Century Russia.* London: Sound and Music / Koenig Books.

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Candlish, N. 2012. The Development of Resources for Electronic Music in the UK, with Particular Reference to the Bids to Establish a National Studio.
Ph.D. Thesis, Durham University.

Mullender, R. 2011. Silent Light, Luminous Noise Photophonics Machines and the Senses.
Ph D. Thesis, University of the Arts, London College of Communication

Waller, L. 2014. Exhibition as experiment: a study of science and culture at the Science Museum.
Ph D. Thesis, Goldsmiths, University of London

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Ph D. Thesis, Birkbeck, University of London

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Cary, T. 1967. Superserialismus: Is There a Cure?
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Collins, N. 2004. Composers Inside Electronics: Music After David Tudor
Leonardo Music Journal. Volume 14, 1-3.

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Nisbett, N. 2014. Interviewed by Richards, T.

Scales, C. 2012. Interviewed by Richards, T. and Bulley, J.

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The BBC Written Archives, Caversham, Berkshire.

The Hugh Davies Collection, Science Museum, London

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LIST OF MEDIA INCLUDED

001 - *Scanner October 1965* Daphne Oram (AUDIO) Archive Number DO163

002 - *Scanner Oramics May 1966* Daphne Oram (AUDIO) Archive Number DO219 A, B, C

003 - Drawn Waves Experiment (VIDEO) Tom Richards' Studio 2013

004 - First Performance with Protoypes (AUDIO) EAVI/Nonclassical concert at the Macbeth, Hoxton March 2013

005 - Mini Oramics Transport Mechanism First Test. (VIDEO) Tom Richards' Studio September 2015

006 - 4 channel opto-logic test circuit for Legoramics. (VIDEO) Tom Richards' Studio September 2015

007 - 12 Channel opto-logic test circuit - not quite working (VIDEO) Tom Richards' Studio September 2015

008 – Mini Oramics working for the first time (VIDEO) Tom Richards' Studio April 2016

009 – Mini Oramics medley from a variety of musicians (VIDEO) Tom Richards' Studio June 2016

010 – *Bird of Parallax* 1972 Daphne Oram (Oramics) (AUDIO)

011 – Oram 1972 Interview Excerpt (AUDIO) Archive Number DO236

012 – Carolyn Scales Interview 2012 (AUDIO)

013 – Graham Wrench Interview 2012 (AUDIO)