Engineers Australia

Engineering Heritage Victoria

Nomination

Engineering Heritage Australia Heritage Recognition Program

SYNTHI 100

MUSIC SYNTHESISER

May 2016

Front Cover Photograph Caption

Part of the control panel of the SYNTHI 100 analogue music synthesiser at the Melbourne Conservatorium of Music. Electronic Music Studios (London) Ltd built the synthesiser between 1971 and 1973. This machine is one of only three SYNTHI 100 synthesisers restored to original condition and operating in the world.

Image: ABC News, Melbourne.

TABLE OF CONTENTS

1 Introduction

There is only one key variable in music production as important, and as ubiquitous, as the natural human voice: the synthesiser.

The underlying basic concept is simple enough; an electronic circuit generates a tone, and the tone can then be controlled by any kind of selected input, human or otherwise. It is an axiom that has provided the backbone for countless electronic instruments over the last century. Consequently, it has influenced the direction of modern music both in the mainstream and in the underground.

To this day, the exemplary harmonious unison between the musical artist and their synthesiser epitomises a most constructive bond between man and machine.

Figure 1 shows a musical composer during the production of one of his pieces using one of the most prominent modular synthesisers in the history of analogue music; the Synthi 100.

Figure 1: A musical composer working on a piece using his synthesiser.
Image: Tim Stinchcombe

The early 1970s saw a significant evolution in the technical aspects of music synthesis. The two primary entities who pioneered in the field of analogue music industry were Electronic Music Studios (EMS) in the United Kingdom and Moog Music in the United States of America.

Miniature models of analogue synthesisers have grown in sophistication and size until this evolution culminated in the design of complex powerhouse modular synthesisers. The most significant prototype of which is the monstrous Synthi 100 model which was developed by EMS as a combination of three of their smaller efficient synthesiser systems.

This enormous model in particular is the main subject of discussion in this nomination, whose primary aim is to establish the worthiness of one of the remaining operational Synthi 100 units to be nominated as a prominent example of rare engineering heritage. This nomination is based on the rarity, precedence, innovativeness, social ramifications and current rekindled role as a historical relic of audio engineering both nationally and internationally.

2 Heritage Award Nomination Letter

Learned Society Advisor
Engineering Heritage Australia
Engineers Australia
Engineering House
11 National Circuit
BARTON ACT 2600

Name of work: **Synthi 100 Music Synthesiser**

The above-mentioned work is nominated for an award under the Heritage Recognition Program.

The restored Synthi 100 unit is located at The Melbourne Conservatorium of Music, The University of Melbourne, 12 Royal Parade, Parkville VIC 3052

Owner: The University of Melbourne.

The owner has been advised of this nomination and a letter of agreement is attached.

Access to site: The site is not open to the public. Access must be specially arranged with the supervising senior technician, The Melbourne Conservatorium of Music.

The Nominating Body for this nomination is Engineering Heritage Victoria

David LeLievre
Chair
Engineering Heritage Victoria

Date: 31 May 2016

3 Heritage Assessment

3·1 Basic Data

Other/Former Names: Nil
Location: Melbourne Conservatorium of Music
Address: The Conservatorium Building, The University of Melbourne, 12 Royal Parade, Parkville VIC 3052
Local Govt Area: City of Melbourne
Owner: Melbourne University
Current Use: Exhibition for Music Synthesis students after restoration
Former Use: Creating and producing Electronic music
Designer: David Cockerell
Maker/Builder: Electronic Music Studios (EMS)
Year Started: 1971
Year Completed: 1973
Physical Description: The dimensions of the Synthi 100 are about 2 meters long, 1 meter wide and over 1 and a half meters high. Therefore it was designed for permanent installation in music studios.
Physical Condition: Fully restored and overhauled. Over 90% functional. The circular oscilloscope is not yet operational.

3·2 Historical Notes

Harry Olson and Herbert Belar were American acoustical engineers who have developed the first electronic sound synthesiser in 1955 at the Radio Corporation of America Laboratories at Princeton [3], New Jersey. The information was fed to the synthesiser encoded on a punched paper tape. It was designed to research the properties of sound and it has attracted composers who were seeking to extend the range of sound available at the time, or to achieve total control of their music.

In the early 1960s, came the man most often credited with the invention of modern electronic instrumentation, Dr Robert Arthur Moog. He studied electronics at Cornell University. He started working with electronic instrument when he was nineteen years old. Moog (see Figure 2 below) created his first company, R A Moog Co to manufacture and sell Theremin kits. But the limitations of the Theremin were clear and Moog wanted to develop something more flexible [9].

Figure 2: One of the early pioneers in synthesiser design, Robert Arthur Moog.
Image: John Isner

Moog was introduced, by his New York sales agent to Herbert Deutsch, (see Figure 4) a music instructor who worked on experimental tape compositions. He showed great enthusiasm for Moog’s prototype voltage controlled modules [3].

Moog and Deutsch had been absorbing and experimenting with ideas about transistorized modular synthesisers from the German designer Harald Bode. They developed the specification for a complete modular synthesiser system. Also they showed the ideas to Myron Schaffer, head of the University of Toronto electronic music studio. After that, Moog began to manufacture the electronic music synthesiser in 1964. His first synthesiser became the first instrument to make the crossover from the avant-garde to popular music.

Figure 3: Deutsch working on the Development of the Moog Synthesiser c 1963.
Image: John Isner

The Moog synthesisers were used to record Wendy Carlos's album "Switched on Bach". This brought the Moog to public attention and changed conceptions about electronic music and synthesisers in general. An expensive modular Moog was sold to the artist Mick Jagger in 1967 [3].

Moog had his own more portable synthesiser in mind, which after going through various supposedly futuristic prototype cabinet designs as Models A, B and C, settled down to become the Mini-Moog Model D which is illustrated in Figure 4 [9].

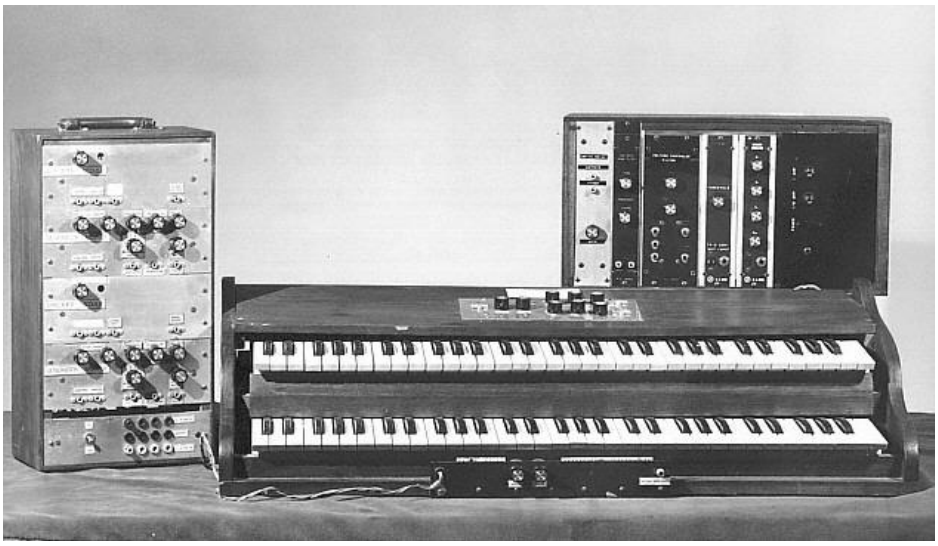

Figure 4: Early version of the Mini-Moog Model D, Modular, 1964.
Image: Moog Music.

Moog started to get the Mini-Moog out of the specialist electronic music studios and into the general music stores. Therefore, the Mini-Moog came onto the market in late 1970 and early 1971 (see Figure 5). It was sold to high-profile players such as Chick Corea, Keith Emerson, Rick Wakeman and Jan Hammer [9].

The Mini-Moog has become perhaps the all-time classic analogue synthesiser, both for its sound and its logical design and layout. It was a comfortable performance instrument.

Figure 5: Mini-Moog model D early model by R A Moog, 1970.
Image: Moog Music.

The Mini-Moog was still not creating huge profits, but the Thomas deal briefly made Moog Music appear extremely lucrative and it was sold to the large music conglomerate Norlin. Moog was more interested in working on research and development. Therefore, he tried to develop the huge Constellation which would play polyphonically as well as offering bass pedals and other facilities. Therefore, he produced the Polymoog.

The Polymoog model 203a (see figure 6) was a fully polyphonic preset-based synthesiser released in 1975. Its eight preset sounds consist of Strings, Piano, Organ, Harpsichord, Funk, Clavi, Vibes and Brass [4]. There was also a variation mode that allows any one of the preset sounds to be fully modified into unique and wild analogue sounds using all of the available synthesis parameters on board.

Figure 6: Polymoog 203a.
Image: Moog Music.

The fact that Moog apparently solved the problems involved one at a time probably led to the modular nature of the early synthesisers. His designs set a standard for future commercial electronic musical instruments with innovations such as the 1 volt per octave CV control that became an industry standard.

In 1965 a synthesiser company was founded by Dr Peter Zinovieff. He set up the studio in the back garden of his home in Putney, London. This company was named Electronic Music Studios (EMS). The EMS Company was the hub of activity for electronic music in the UK during the late sixties and seventies with involvement from composers such as Harrison Birtwistle, Tristram Carry, Karlheinz Stockhausen and Hans Werner Henze [12].

Running the EMS Company privately was expensive and Zinovieff found himself running into financial difficulties. Therefore, it was decided that the EMS could be saved by creating a commercial, miniaturized version of the studio. The EMS Company produced its first commercial and affordable synthesiser (VCS 1) in 1969. This synthesiser was designed by David Cockerell and was called the Voltage Controlled Studio 1. It has two oscillator instruments built into a wooden rack unit [4].

The VCS1 was soon followed by a more commercially viable design, VCS 3 (see Figure 7). David Cockerell designed the circuit of the VCS 3 and its case was designed by Tristram Cary. The VCS 3 has three oscillators and a unique matrix-based patch system [4].

The VCS 3 utilizes a patch-bay grid in which the synthesiser components were laid out and signal routing was accomplished by placing small pins into the appropriate slots. This system was a modular type synthesiser reduced down to an extremely portable size. Therefore, the portable line of EMS synthesisers were quite miniaturized and fairly sophisticated for their time.

Figure 7: Very early VCS3.
Image: Graham Hinton.

The aim of the EMS Company was to create a versatile monophonic synth that would retail for only 100 pounds. The VCS 3 retailed for about 330 pounds [5], less than its American competitor, the Mini-moog which was designed by Robert Moog. The Mini-moog was smaller and more portable than the modular systems that Moog had come up with earlier.

The VCS 3 (see Figure 7) was intended as a music box for electronic music composition. Also it was modified with the addition of a standard keyboard that allowed tempered pitch control over the monophonic VCS 3. Therefore, the VCS 3 was brought to the attention of Rock and Pop musicians who could not afford the huge modular Moog systems. The VCS3 had been used by some bands like Alan Parsons Project, Pink Floyd and Roxy Music [6]. Also it generated familiar Sci-Fi and other truly analogue sounds. The EMS Company also sold the VCS 3 in a plastic brief-case which was called the Synthi A (see Figure 8). This system was released in 1971, two years after the launch of the VCS 3.

Figure 8: The prototype Synthi A.
Image: Graham Hinton.

The VCS3 and Synthi A were also widely used for education. The EMS Company published tutorial handbooks explaining their facilities in a highly systematic manner. Also they created Synthi-E which was a simplified version specifically for the educational market.

In 1971 the EMS went into direct competition with Moog when David Cockerell designed the Synthi 100. The EMS Synthi 100 was a large analogue synthesiser which used the same technology as the VCS3. This system was mounted in a free standing console cabinet. Also the Synthi 100 was so large that it has required some composers to demolish walls in order to fit one into their studios. The Synthi 100 was very expensive and cost £6,500 [12]. Therefore, only forty units of this system were built and sold to universities and radio stations mainly. The most famous model belonged to the British Broadcasting Corporation (BBC), Radiophonic Workshop. It was responsible for creating a large amount of widely heard and highly influential music for television such as the music for the infamous Dr Who series [8].

The Synthi 100 was the main synthesiser used throughout the 70s. One of the most important upgrades to the Synthi 100 synthesiser was to transform it from an analogue into a hybrid system combining both analog parts and digital parts. Such transformation was realized in the United States by Max Mathews in the late seventies [4].

The EMS Company also built some small devices such as an early pitch-to-voltage converter in 1971 which would allow any instrument to trigger a voltage-controlled synthesiser. While EMS Company has never really gone out of existence, the company never surpassed the glory days of the VCS 3. However, one of its prominent designers David Cockerell certainly flourished and later worked on the Akai range of digital samplers.

In the late 1970s and early 1980s digital synthesisers were great innovation of electronic music instruments. These synthesiser were large and expensive at the beginning. One of the earliest and best-known of these was the Yamaha DX-7, which was based on the results of John Chowning's research in FM Synthesis. Introduced in 1983, the DX-7 was polyphonic, had a five-octave touch-sensitive keyboard, and offered a wide choice of timbres, which the player could adjust or change to suit his requirements. They were sold for upwards of $100,000. However, the introduction of low-cost digital samplers made the technology available to more musicians in the mid-1980s. Therefore, from the late 1970s onward a lot of popular music was developed on digital synthesisers [15].

3.3 Heritage Listings

None known.

4 Assessment of Significance

4.1 Historical significance:

The earliest seeds of modern electronic synthesisers began in the twilight years of the 19th century. In 1896/1897, an American inventor named Thaddeus Cahill applied for a patent to protect the principle behind an instrument known as the Telharmonium, or Dynamophone (photographed in Figure 9). Weighing in at a staggering 200 tons, this mammoth electronic instrument was driven by 12 steam-powered electromagnetic generators. This was played in real time using velocity-sensitive keys and, amazingly, was able to generate several different sounds simultaneously. The Telharmonium was presented to the public in a series of "concerts" held in 1906 [11].

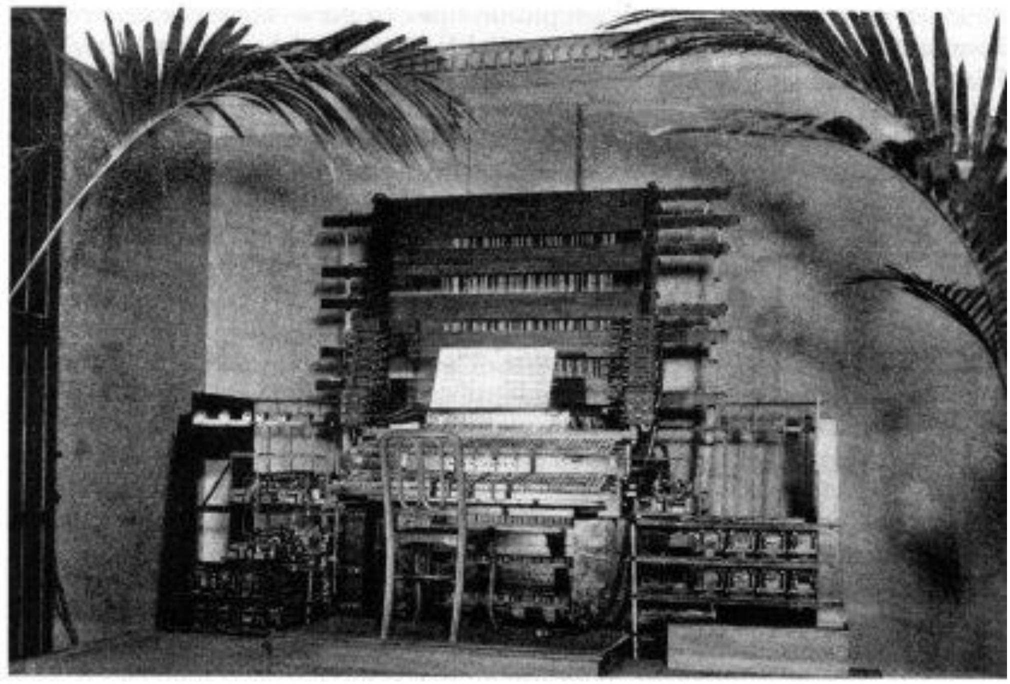

Figure 9: Telharmonium console by Thaddeus Cahill, 1897.
Image: Alex Di Nunzio.

In 1919, Russian inventor Leon Theremin took a markedly different approach. Named after the man who masterminded it, the monophonic Theremin (shown in Figure 10) was played without actually touching the instrument. It gauged the proximity of the player's hands, as they were waved about in an electrostatic field between two antennae, and used this information to generate sound. This unorthodox technique made the Theremin enormously difficult to play [13]. Its eerie timbre made it a favourite on countless horror movie soundtracks. Incidentally, R A Moog, whose synthesisers would later garner worldwide fame, began to build Theremins at the tender age of 19.

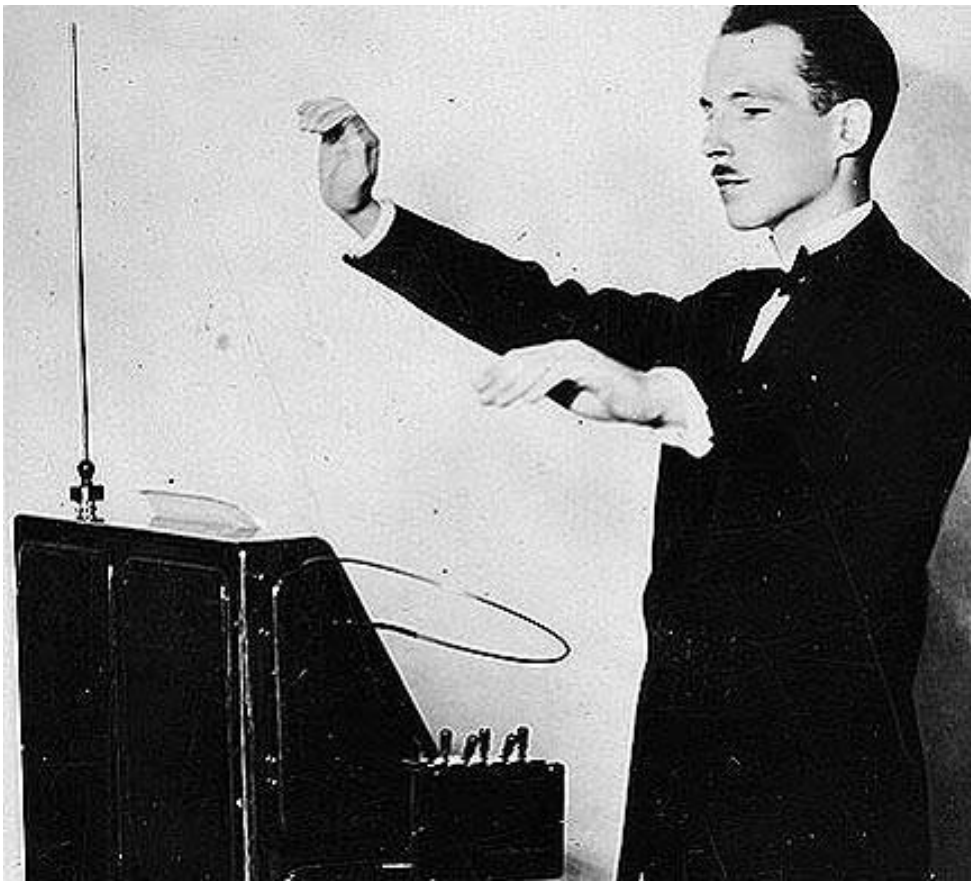

Figure 10: Leon Theremin playing his own instrument.
Image: Encyclopaedia Britannica

In Europe, the Frenchman Maurice Martenot devised the monophonic Ondes Martenot in 1928 [13]. The sound generation method of this instrument was akin to that of the Theremin, but in its earliest incarnation it was played by pulling a wire back and forth. This device can be seen in Figure 11.

Figure 11: The eponymous Ondes Martenot set.
Image: Encyclopaedia Britannica.

In Berlin during the 1930s, Friedrich Trautwein and Oskar Sala worked on the Trautonium, an instrument that was played by pressing a steel wire onto a bar as demonstrated in Figure 12. Depending on the player's preference, it enabled infinitely variable pitches, much like a fretless stringed instrument, or incremental pitches similar to that of a keyboard instrument [12].

Figure 12: Friedrich Trautwein using the Trautonium model. ***Image: Peter Forrest.***

Sala continued to develop the instrument throughout his life, an effort culminating in the two-voice Mixturtrautonium in 1952. He scored numerous industrial films, as well as the entire soundtrack of Alfred Hitchcock's masterpiece "The Birds," with this instrument as illustrated in Figure 13. Although the movie does not feature a conventional musical soundtrack, all bird calls and the sound of beating wings heard in the movie were generated on the Mixturtrautonium [13].

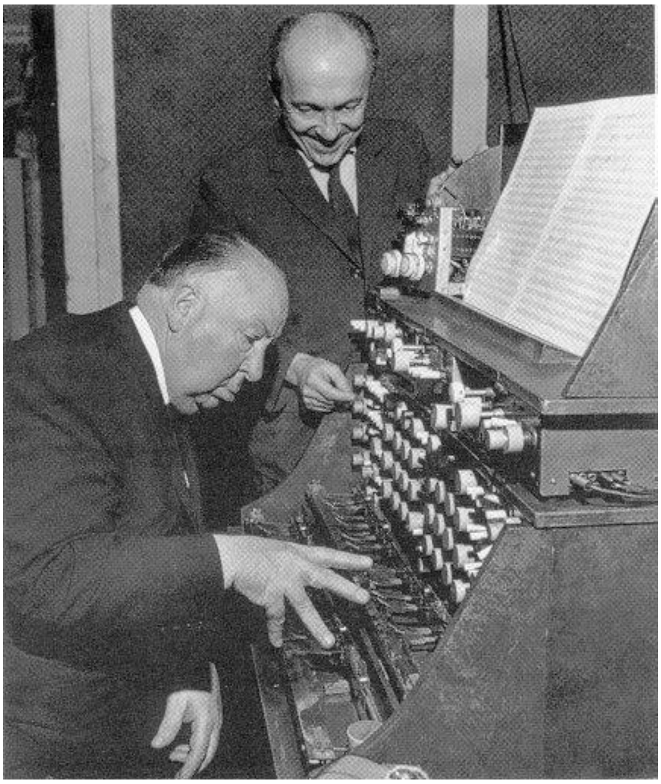

Figure 13: Alfred Hitchcock and Oskar Sala using the Mixturtrautonium model.
Image: Peter Forrest.

In Canada, Hugh Le Caine began to develop his Electronic Sackbut in 1945. The design of this monophonic instrument resembled that of a synthesiser as seen in Figure 14, and it featured an enormously expressive keyboard, which responded not only to key velocity and pressure but also to lateral motion [13].

Figure 14: Hugh Le Cain demonstrating the electronic Sackbut model.
Image: Peter Forrest.

The instruments discussed thus far were all designed to be played in real time. Relatively early, however, people began to develop instruments that combined electronic sound generators and sequencers. The first instrument of this kind was presented by the French duo Edouard Coupleux and Joseph Givelet in 1929; the inspirationally named Automatically Operating Musical Instrument of the Electric Oscillation Type. This hybrid, seen in Figure 15, married electronic sound generation to a mechanically punched tape control. Its was named Coupleux-Givelet Synthesiser by its builders.

This was, incidentally, the first time a musical instrument was called a “synthesiser” [13].

Figure 15: Edouard Coupleux playing on the Coupleux-Givelet model.
Image: Peter Forrest.

The term was officially introduced in 1956 with the debut of the RCA (Radio Corporation of America) Electronic Music Synthesiser Mark I, developed by American engineers Harry F Olson and Herbert Belar. Its dual-voice sound generation system consisted of 12 tuning forks, which were stimulated electromagnetically [7]. The machine can be seen in Figure 16 along with the inventors. For its time, the instrument offered relatively sophisticated signal-processing options. The output signal of the sound generator could be monitored by loudspeakers and recorded directly onto two records. A single motor powered both turntables and the control unit of the Mark 1. The synthesiser was controlled by information punched onto a roll of paper tape, which actually enabled continuous automation of pitch, volume, timbre, and envelopes. It was quite complicated to handle [13].

Figure 16: Harry P. Olsom at the Keyboard and Herbert Belar at the control panel operating RCA's Electronic Music Synthesiser Mark I.
Image: Steven Smith.

With the exception of the Telharmonium, which was conceived prior to the advent of the thermionic valve, these precursors to the modern-day synthesiser were all based on tube circuitry. This made these instruments relatively unwieldy and certainly volatile. After the transistor became available in 1947, more rugged, smaller, and thus portable instruments were contemplated.

At the end of 1963, R A Moog met the composer Herbert Deutsch, who inspired Moog to combine a voltage-controlled oscillator and amplifier module with a keyboard in 1964, the first prototype of a voltage-controlled synthesiser. This collaboration with the German musician prompted Moog to extend his range of modules and to combine them into entire systems. It wasn't until 1967, however, that Moog actually called his diverse mix-and-match systems “synthesisers”.

Moog's achievements spread by word of mouth, and Moog, always keen to elicit the feedback of his customers, continued to add further modules to his line. Wendy Carlos' LP release “Switched On Bach” (1968) was responsible for the breakthrough of Moog's instruments [9]. The record featured Moog's modular synthesisers and was one of the earliest commercial multitrack recordings. The album's success introduced the synthesiser to a wider audience and made the name Moog synonymous with the instrument. Hoping to capitalize on the new sounds that synthesisers made available, and match Carlos' commercial success, numerous studios, producers, and musicians acquired Moog modular synthesisers. In 1969, as many as 42 employees produced two to three complete modular systems every week at Moog's production facility [15].

Working independently, an engineer named Donald Buchla had conceived and implemented the concept for a modular, voltage-controlled synthesiser. This coincided with Moog's version. Buchla also developed his first instruments in close cooperation with users. The inspiration for his first synthesiser originated with composers Morton Subotnik and Ramon Sender, of the San Francisco Tape Music Center. Although he began working on this instrument in 1963, it didn't make its public debut until 1966. By design, Buchla's instruments catered primarily to academia and avant-garde musicians, so they never garnered the public attention and acclaim of Moog's synthesisers [15].

The Synthi 100 is one of those historical engineering fables that loads of people know about and talk about, but only a small handful have ever actually seen. It's a colossal instrument in so many ways; its physical size, its massive weight, its 20 oscillators, its double keyboard with both microtonal and conventional tonal capabilities and its expansive timbrel possibilities. It has developed an undeniably legendary status in the history of electronic music, subject to all the usual myths and rumours of legends as people throughout the world claim to know someone who knows someone who knows someone who has one.

Melbourne certainly does have one and Leslie Craythorn has worked with the devotion of the very best of zealots to restore it to its original splendour. Leslie's love for the instrument and its extraordinary capacities is palpable. It has been an astonishing feat to painstakingly restore the Synthi 100 to its now pristine condition, vacuuming off the dust and manually cleaning and refurbishing each part. It is an extraordinary treat to be able to hear it live in Melbourne in an actual concert, rather than just a bare demonstration. Something which is really a world first for an instrument which, even in its early days, was housed in studios rather than in concert halls.

4.2 Historic Individuals or Association:

Examples of recordings of this spectacular instrument in action do exist throughout its time in the Melbourne Conservatorium, including Leslie himself performing Percy Grainger's Free Music 1 on it in 1975. Back then, the much limited digital capacities of the time meant that around 2,400 sound events had to be individually entered into the instrument's sequencer to enable it to navigate the beautiful electronic glissandi of this astonishing piece, composed back in 1935. Another famous piece of notable work from this era, using the Melbournian Synthi 100 unit as its primary source of music synthesis, is Karlheinz Stockhausen's SIRIUS [8]. In this piece of remarkable work, four interstellar visitors; a trumpet, a soprano, a bass clarinet and a bass come to earth and play with stellar constellations as the music vividly conveys the electronic tunes of space and stars.

Following Stockhausen's work, a pupil of his emerged to further explore this unique genre of music and compose new elaborate pieces of music. This pupil is John

McGuire, who in his Pulse Music III series brought together the minimalism of mid 1970s America and the explorative serialism that emerged in Germany throughout the second half of the twentieth century [10]. In this piece, pulses, gathered into Reich-esque clusters of notes, are phased across the stereophonic spectrum in intricate mathematically calculated patterns, which demonstrates the technical and innovative potential of the Synthi 100 in the field of music production.

The variety and creative potential of this marvellous instrument is further highlighted through the work of York Höller on the piece “Mythos” [10]. This piece was very different from previous work and the Synthi 100 was joined by a small instrumental ensemble. The resultant piece was quite esoteric and slightly hypnotising. It has explored the fluidity between electronic and acoustic sound which later has served as a profound musical illustration of the archetypal images of Carl Jung's collective unconsciousness psychoanalytical theories [13].

The Biographies of some prominent and highly relevant key figures in the field of Analogue music synthesis are discussed further in Appendix 3.

4.3 Creative or Technical Achievement:

The Synthi 100 model designed and produced by EMS is a modular analogue audio synthesiser in the most fundamentally theoretical sense. Such device converts electric signals to sound through the utilisation of amplifying instruments, which maximise the audibility of a given incoming electronic signal. This input electronic signal is produced by musical instruments such as electric keyboards, electric guitars and electric organs and it is often quite faint and inaudible. In order to amplify this input signal created by an electronic musical instrument, amplifiers are used to output an electronic signal through speakers and microphones.

Figure 17 shows one of the early successful and popular miniature models designed by EMS; the VCS3 (Voltage Controlled Studio No.3) which was clearly an early prototype for bigger multi-modular synthesisers developed by the company. It is noted that the Synthi 100 has the minimum capacity of three of these relatively smaller models.

Figure 17: The VCS3.
Image: EMS.

Figure 18 shows a clear image of an EMS Synthi 100 unit. All the sections are encased by a sturdy shiny wooden frame protecting all the internal circuitry. As observed by its large sheer size, it was designed to be the centrepiece of a recording studio. The dimensions of this device were suitable for permanent installation as the core of a musical production. The machine can be further equipped with two keyboards, duo phonic, that are able to play two voices simultaneously, for a total of four. The features of the Synthi 100 made it a very versatile tool. Furthermore, the availability of numerous external modules ensured a great potential for its continuous expansion.

Figure 18: The Synthi 100 model in its pristine condition.
Image: EMS.

The intricate combination of systems in the Synthi 100 has led to more stability, control and almost endless sonic possibilities. The two 64 x 64 pin matrix systems observed in Figure 18, ingeniously incorporated, enable routing signals from different modules in limitless configurations which can produce all sorts of unusual yet authentic sounds.

Figure 19 shows the filter/oscillator section of the Synthi 100 which illustrates its potential and capacity of pitch and phase manipulation. The comprehensiveness of the broad control panels makes the device very tactile and prone to meticulous fine tuning.

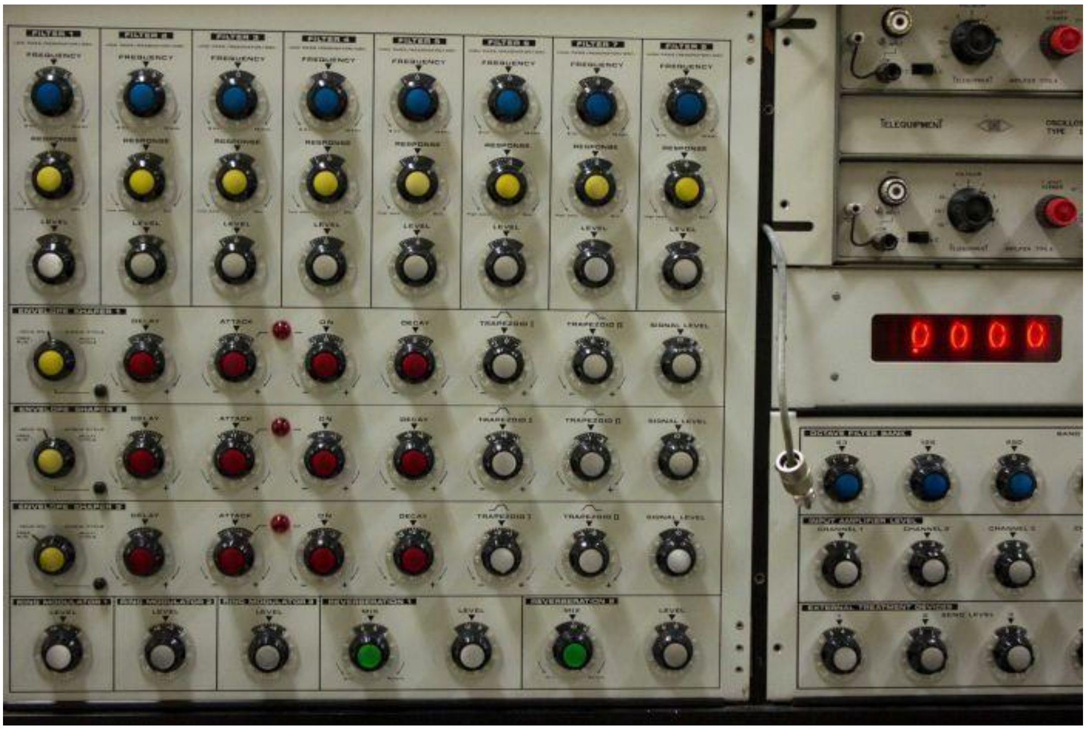

Figure 19: Filter/Oscillators control panel.
Image: EMS.

Figure 20 shows the original advertisement of the Synthi 100 model by EMS which details all the technical specifications of the enormous and imposing machine. An additional piano style keyboard was separately and optionally sold as an extra attachment by EMS as seen in this brochure.

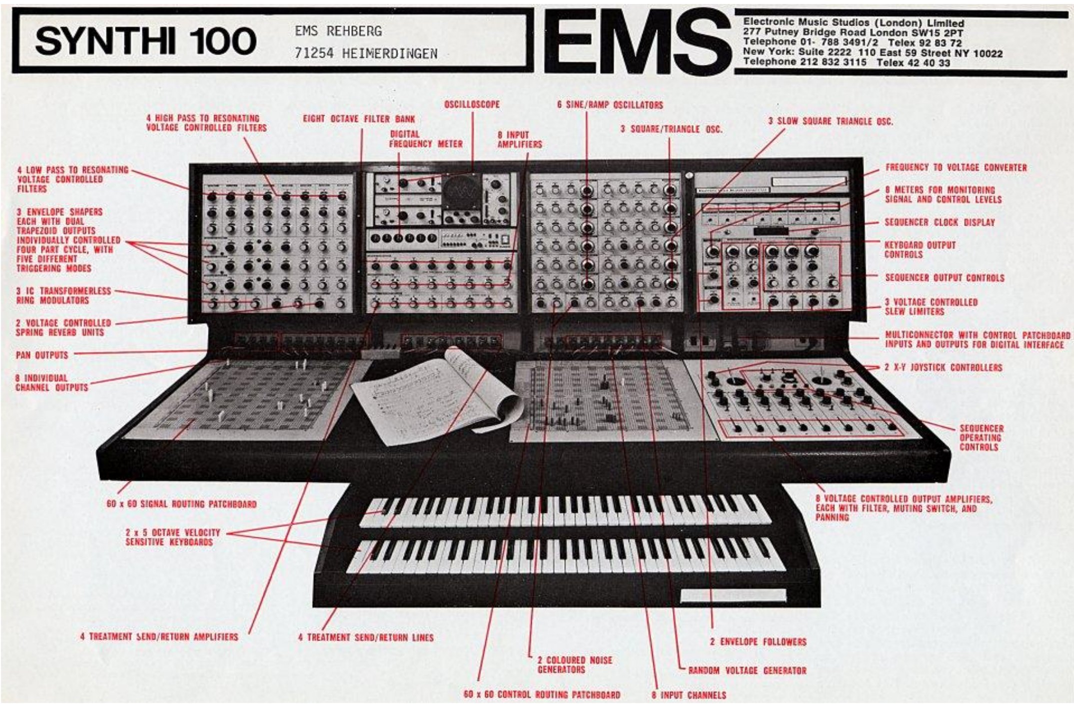

Figure 20: Synthi 100 advertisement. ***Image: EMS.***

The Synthi 100 is the analogue type of synthesiser since its circuitry incorporates analogue electronics and samplers in some cases. Samplers are electronic musical instrument, similar to synthesisers, but different in terms of functionality. Samplers do not generate sound intrinsically; they rather use “samples” of sound signals and allow for the playback and manipulation of extrinsically recorded signals by means of triggering devices and the imbedded sampler program. These triggering devices can vary from electronic keyboards to sequencers. Digital synthesisers on the other hand process signals discretely rather than continually as do analogue synthesisers. Digital Signal Processing (DSP) is the technique used to numerically and sequentially manipulate signals into discrete domains of frequency and time [10]. Therefore, digital synthesisers are essentially computers attached with electronic musical instruments and potentially other digital interfaces. Although analogue synthesisers are different to their digital counterparts, they can play back digital recordings of electronic musical instruments or acoustic sounds through the inclusion of sampler devices.

Figure 21 graphically illustrates the difference between a continuous smooth analogue signal (top) and its digital discrete counterpart at (bottom).

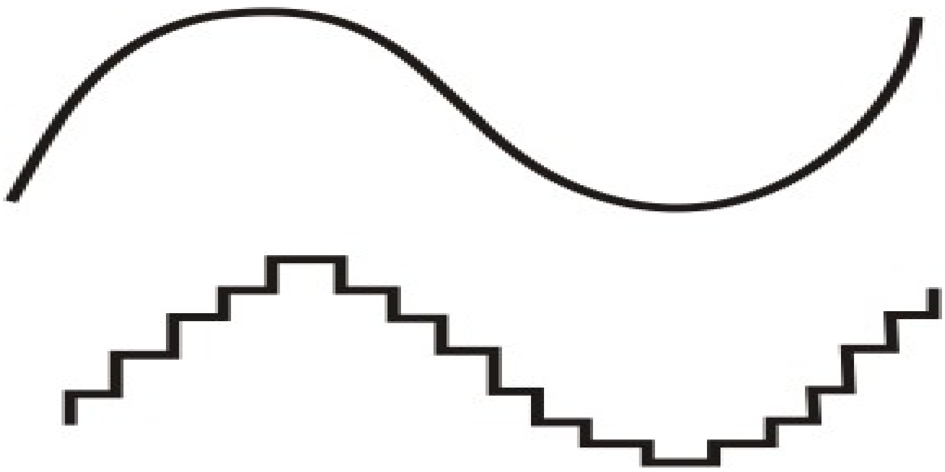

Figure 21: A digitised analogue signal.

As audio synthesisers evolved throughout the history of music production, different types of audio waveform synthesis emerged; Additive, Subtractive, Frequency Modulation, Phase Distortion, Granular, Physical Modelling, Sample-Based and Imitative are the main ones. Many synthesiser models use a combination of these types in conjunction. The Synthi 100 emphasises primarily subtractive synthesis; this type implements the attenuation of the harmonically rich parts of an audio signal through the use of voltage controlled low-pass filters.

Subtractive synthesis is the basis of many early models of analogue synthesisers. It can metamorphose the quality of a musical note, or more specifically, its “timbre”; the distinctiveness of a note which relies on the inherent physical characteristics of the sound irrespective of pitch or loudness.

The Synthi 100 is a “modular” synthesiser, which consists of separate specific modules connected together via two pin matrix panels; one for the signals and one for the voltages. It has built-in controllers and a large number of fixed modules. The modules can be visually observed on the machine schematic in Figure 20, and they include:

- 12 Voltage Controlled Oscillators
- A Noise Generator.
- 3 Ring Modulators.
- 4 Voltage- Controlled Low Pass Filters.
- 4 Voltage-Controlled High Pass Filters.
- 3 Trapezoid Envelope Generators.
- 2 Voltage-Controlled Reverberations.
- An Octave Filter Bank.
- A Slew limiter.
- An Envelope Follower.
- A Pitch-to-Voltage Converter.
- 8 Input Amplifiers.
- 9 Stereo Output Amplifiers.
- 2 Joysticks.
- 2 5-Octave Dynamic Keyboards (optional).
- 3-track 256-Step Digital Sequencer.
- A Circular Oscilloscope (When in pristine condition).

- A Frequency meter counter.

Appendix 1 contains the original brochure of this model which includes all the details and specifications for a more in-depth viewing of the design and function [1].

Figure 22 shows one of the aforementioned matrix grids and how pins are used to route audio signals via activating a combination of modules simultaneously. The trend in music in this era was geared more towards the electronic theme, lacking both pitch and beat. This is very crucial when demonstrating how impactful this model was at the time and how it promoted this genre of music.

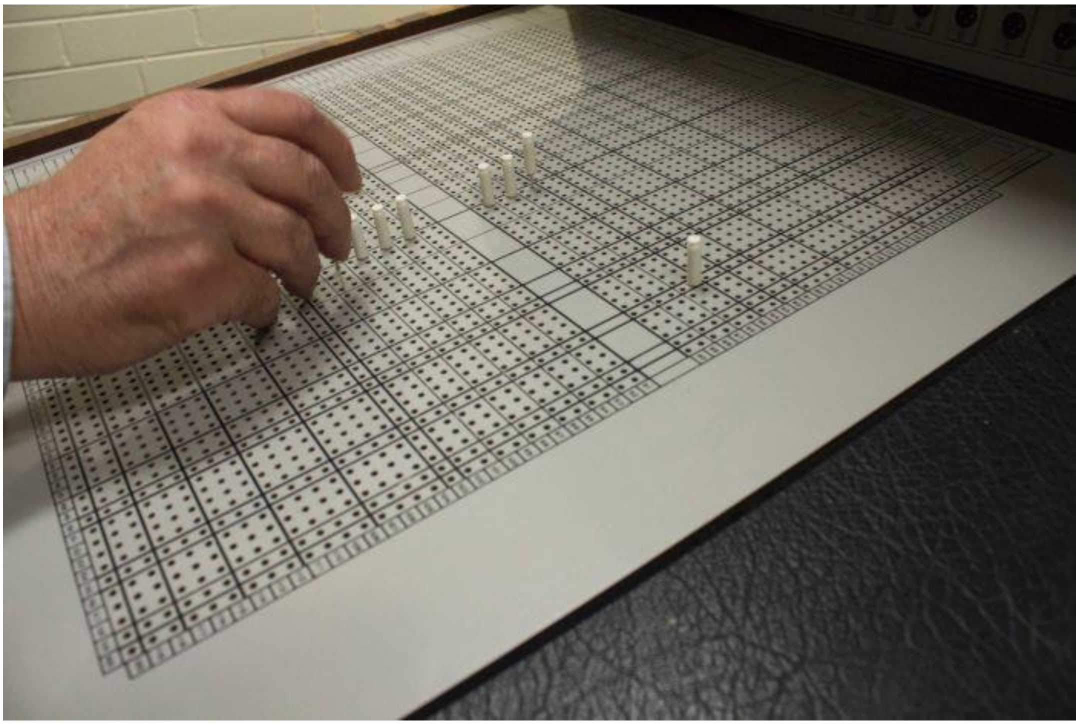

Figure 22: Matrix grids on the Synthi 100 showing how they are connected.
Image: ABC News.

The Synhti-100 also features an LED display, twin digital cassettes and a switch button control panel as seen in Figure 20. The two add-on keyboards are Duo-phonic which enables the possibility of concurrently playing four notes at once.

[1] The model described in the brochure includes a digital sequencer, which appears to be part of the basic Synthi 100 rather than an optional extra.

An extra add-on computer interface which contained a PDP-8 minicomputer and 4 kb of random access memory is available. Figure 23 demonstrates an image of a Synthi 100 with such an add-on attached.

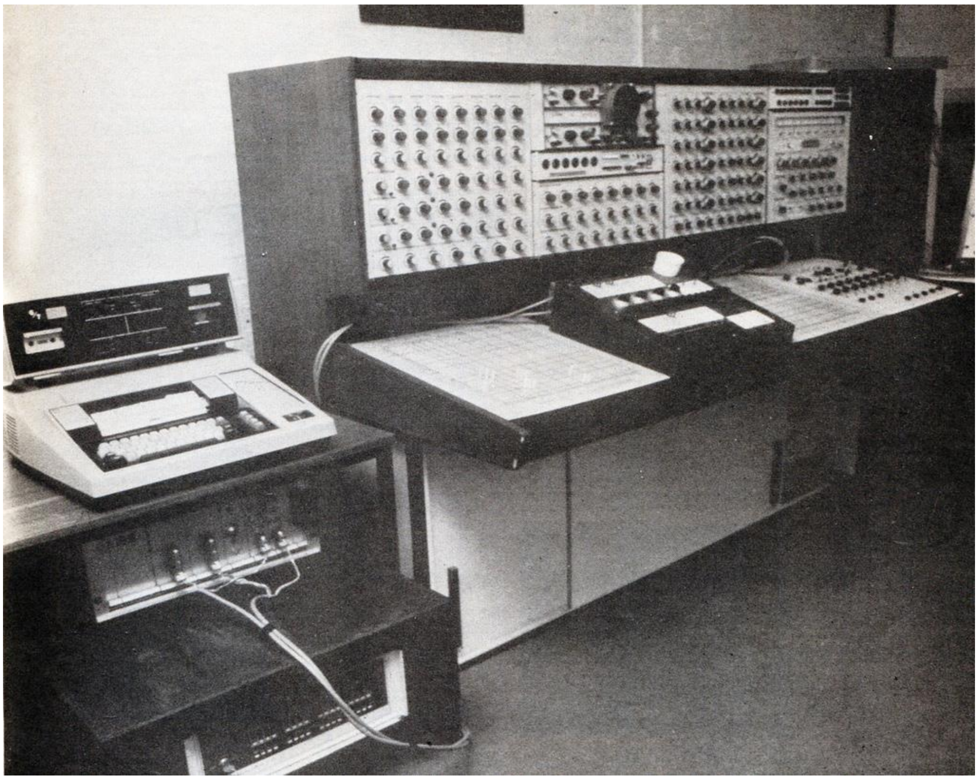

Figure 23: Computer interface add-on next to a Synth-100.
Image: Vintage Synthesisers.

Another popular add-on of the Synthi 100 was the "Studio Vocoder" series. The Vocoder 5000 version contained a 22 band filter, a small 22 × 22 matrix pin system, Microphone/Line inputs, two oscillators and noise sources, a frequency shifter, pitch-to-voltage extractor and a spectrum display driver. Figure 24 shows an image of this separate module that could be added to further enhance the electronic scope of the whole system.

Figure 24: the EMS Vocoder Add-on.
Image: EMS.

Table 1 lists and succinctly defines some examples of key components in the Synthi 100.

Component	Description	Role
Voltage-Controlled Oscillator (VCO)	An electronic circuit that produce periodic signals via converting Direct Current (DC) into Alternating Current (AC). For this particular type, the oscillation frequency is controlled by the input voltage.	Frequency and Phase modulation of an audio signal which creates raw with a distinct timbre depending on the generated waveform.
Ring Modulator	An analogue circuit that processes two input signals using a particular arrangement of diodes in a “ring” formation. This allows for amplitude modulation and frequency mixing.	It works by taking two inputs and multiplying them together. One of the input signals is often a sound wave whilst the other is a simple waveform. The result is a characteristic distortion of the two inputs.
Low-pass Filter	An analogue circuit which passes signals with frequencies lower than a certain cut-off frequency and attenuates signals	Frequency modulation of an input signal and attenuation of the treble range mostly. It is commonly used in the

	with frequencies higher than the cut-off frequency.	subtractive type of synthesis.
High-Pass Filter	An analogue circuit which passes signals with frequencies higher than a certain cut-off frequency and attenuates signals with frequencies lower than the cut-off frequency.	Frequency modulation of an input signal and attenuation of the bass range mostly. It is commonly used in the subtractive type of synthesis in conjunction with Low-Pass filters.

The inclusion of the 256-step digital sequencer in the Synthi 100 placed it at the forefront at a time when 10-step digital sequencers were the standard in rival models produced by Moog. This truly indicates how contemporary and trendsetting this model has become at this era before the fast takeover of digital synthesis by the early 1980s.

4.4 Research Potential:

Although music synthesis today is more software based and digitised, the interest in modular analogue synthesis has grown and it has been experiencing a major revival around the globe. Old school analogue modular synthesisers produced by EMS, Moog and others have started exploring new avenues in music back then. Unfortunately, this explorative journey into the realms of analogue music was cut short too quickly, leaving a lot that could have been accomplished in this unique field. The current renewed interest in analogue synthesis has enticed musicians and interactive arts students to investigate study and learn from the remaining rare units.

The restored Synthi 100 unit in the Melbourne Conservatorium provides the valuable opportunity to rejuvenate attentiveness to this field. There is a great deal of potential that is yet to be realised there and this specific Synthi 100 unit is an imperative element in this resurgence through widened recognition. It represents a grand milestone in the history of audio engineering and music evolution.

To witness the full functionality of the Synthi 100 in the Melbourne Conservatorium is akin to travelling back in time 30 years or teleporting into a sci-fi movie. It would have been a shame if it was left unrecovered, collecting dust in the corner of a storage room.

To this day, the debate is still ongoing when comparing analogue synthesis with digital synthesis. With the true nature of sound innately analogue, the music paradigm is shifting back more towards its original property before digitisation has taken place. The new hybrid models of synthesisers that combine elements of both types seem to be testimonial to the fact that the shift has already started. Analogue Music is being resurrected thanks to increased interest in some of its surviving hallmarks such as the Melbourne Conservatorium Synthi 100 unit.

4.5 Social:

Today, there are only three restored units remaining of the EMS Synthi 100 which are working and in their original unaltered state, from a production of about 40 units. One of which is in the Melbourne Conservatorium of Music at the University of Melbourne. This unit was restored to a working condition, after a period of idle storage, by Mr Leslie Craythorn; the senior technical officer in the Conservatorium. Mr Craythorn has maintained and worked on the unit over the span of 12 years [2].

Figure 25 shows Mr Craythorn besides the Synthi 100 which has become an eminently integral part of his lifework in the conservatorium's electronic music lab, especially nearing retirement.

Figure 25: Leslie Craythorn next to the Melbournian Synthi 100 unit.
Image: ABC News.

The Synthi 100 model was famous for the ability to generate uniquely analogue sounds, which has popularised its use in creating sci-fi themed tunes and tracks. At the time it was produced, it was very costly and would probably cost the equivalent of few family vehicles by today's financial standards. Of the few units that were made, most have been snatched up by universities, recording studios, artists and celebrities.

Today, the unit at the Melbourne Conservatorium reflects the musical vibe of its era and focus of composers. The designers of the prototype were preoccupied with pushing the boundaries of music and creating new sounds. Although the rise of the digital era since the 1980s was swift, the Synthi 100 was at the forefront of analogue music synthesis. The model features a powerful computerised sequencer and an extensive array of sound-shaping tools.

4.6 Rarity, Integrity and Intactness:

The Melbourne Conservatorium of Music Synthi 100 unit has been delivered from EMS in London to the University of Melbourne in 1973. It was used by students from the art department, throughout its long history there, to create new experimental music that had flair and boldness. It has quickly become the core of the Melbourne Conservatorium studio. It was also used to compose electronic music records, such as a vinyl LP released by the university in 1975. This record was edited by none other than Mr Craythorn who was back then a technician in the electronic music laboratory at the Conservatorium. This record includes astonishing work by Peter Tahourdin [3]. It features sounds created by the Synthi 100, such as ocean-like wave noises, rapid-fire beeps and UFO sounds. Mr Craythorn explained in an interview how this record was a reflection on the leading genre of electronic music from the era of analogue modular synthesisers [8].

The appeal of using modular synthesisers has grown due to the fact that models like the Synthi 100 can route signals in limitless way, from module to module, allowing full control and liberty to adjust the signal from any electronic musical instrument accordingly without altering the sound itself at any stage.

Due to the rarity of devices such as the Synthi 100, the price for one can be up to $200,000 each. Only 16 units remain today, only 3 of which are restored to original working state. The unit in the Melbourne Conservatorium has been restored to up to “90% functionality” according to Mr Craythorn and it is identical to the unit used by BBC Radiophonic Workshop to make the music for the Doctor Who series [8].

The unit in Melbourne University has been kept idle for 20 years until students of interactive composition, in particular, have expressed their passionate desire to study this rare piece of musical marvel and engineering heritage.

Throughout the restoration process, Mr Craythorn had to individually remove each of the Synthi 100's 84 circuit cards and 185 dials, cleaning them using specialty lubricants and an ultrasonic bath. Figure 26 showed the internal circuitry of the machine.

Figure 26: Circuit cards in their respective banks in the restored Synthi 100.
Image: ABC News.

Figure 27 shows an individual circuit card in clear detail where all the analogue circuit components can be observed. Within the span of 12 years, Mr Craythorn has checked each of the 84 circuit cards for faulty or missing parts. He was able to obtain them with the aid of EMS technician Mr Robin Wood.

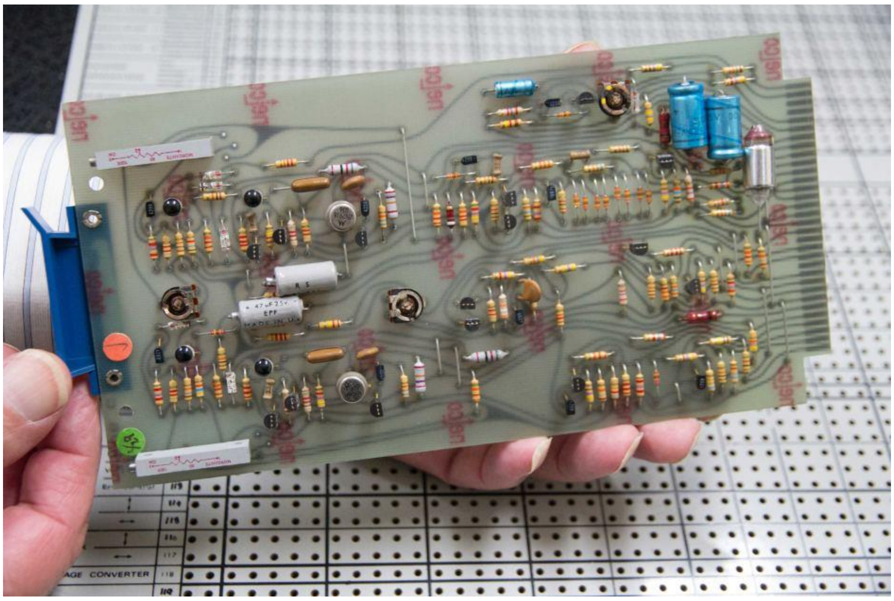

Figure 27: A fully restored circuit card held by Mr. Craythorn.
Image: ABC News.

Although the machine is 90% operational, one of the current remaining issues Mr Craythorn has been working on is restoring the original circular oscilloscope housed in its own compartment in the device. Figure 28 illustrates how he is temporarily attaching an external oscilloscope to visualise the waveforms of processed signals.

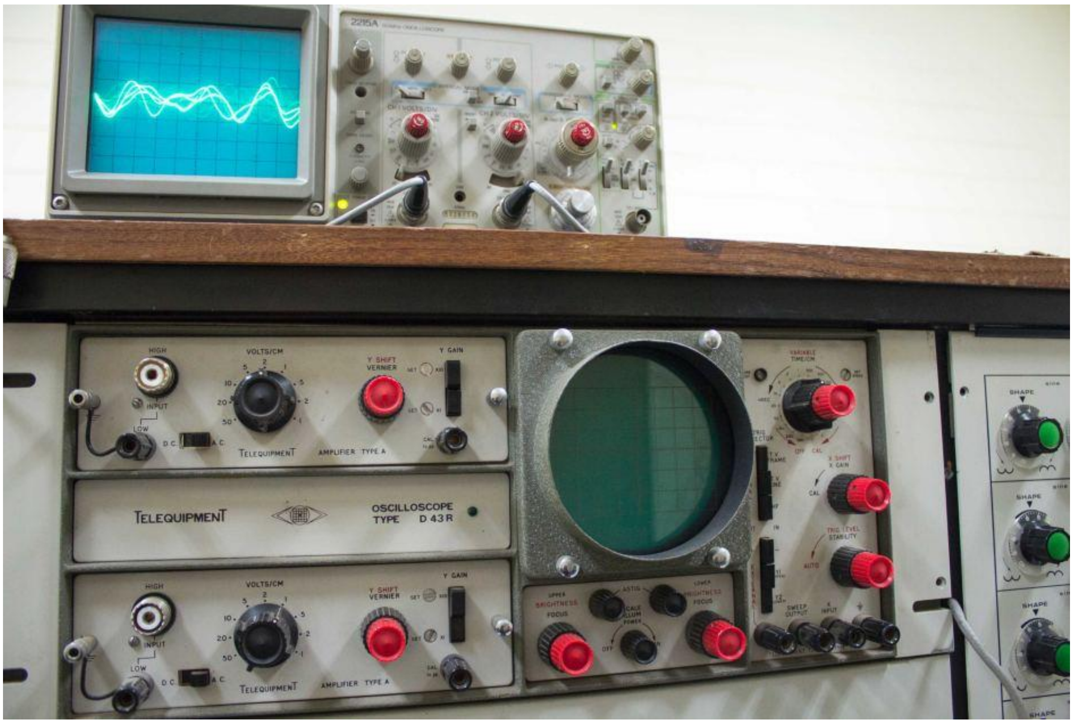

Figure 28: The external Oscilloscope replacement above the original Oscilloscope. Image: ABC News.

"When you're operating this instrument, nudging the joystick or tuning an oscillator, it's very tactile, you're very much in touch with the instrument" [8]. This quote from Mr Craythorn conveys his uttermost joy and happiness when he was able to play the Synthi 100 again. In the era of computer interfaces and digital processing, the rare chance to personally operate this spectacular device must be all the more exclusive and nostalgic.

4.7 Representativeness:

The only major manufacturers of analogue music synthesisers were EMS in London and Moog in the United States. The two companies manufactured instruments with similar purpose but they differed in detail and appearance. The Synthi 100 is typical of the products of EMS in the United Kingdom although this model was more comprehensive and less portable than other products. Nevertheless, all models incorporated much the same suite of components and design philosophy. The Synthi 100 is therefore highly representative of analogue synthesisers of that era.

4.8 Statement of Significance:

What is significant?

The extensive sonic palette and operational complexity inherent in the Synthi 100 provide endless possibilities of sound compositions. It is rightfully fabled as an engineering landmark in the field of music synthesis and analogue electronics, historically and socially. Moreover, the astonishing fact that the unit, which forms the centrepiece of the Melbourne Conservatorium of Music, is one of only three operational units remaining in the world makes it extremely rare and exclusive. This surviving unit is being revived and it continues to be used in concerts in Melbourne, drawing admiration and renewed attention to analogue music.

How is it significant?

The Synthi 100 is significant under the following Criteria[17] as defined for the purposes of the Victorian Heritage Act 1995:

CRITERION A
Importance to the course, or pattern, of Victoria's cultural history.

The Synthi 100 has provided musicians studying in Victoria with access to resources for the writing and experimentation with a sophisticated analogue music synthesiser over approximately 40 years. The Synthi 100 was cutting-edge technology when it was first acquired by the Conservatorium of Music and is now a central part of a "retro" revolution to go back to the use of analogue techniques after a period when digital technology proved somewhat disappointing in this area of artistic development.

CRITERION B
Possession of uncommon, rare or endangered aspects of Victoria's cultural history.

The Synthi 100 is one of the most advanced models of analogue music synthesisers from their heyday in the 1970s. It is now one of only three instruments of this type still in operation in the world and the only one in Australia. It is therefore a rare example of a 1970s analogue music synthesiser.

CRITERION C
Potential to yield information that will contribute to an understanding of Victoria's cultural history.

The Synthi 100 remains in service with the Conservatorium of Music and is still being used for classwork and research in the field of electronic music. There is therefore a continuing potential for it to yield a better understanding of electronic music.

CRITERION E
Importance in exhibiting particular aesthetic characteristics

In the field of electronic music the 1970s analogue music synthesisers are now regarded as the peak of originality and quality in the production of electronic music. The aesthetic beauty of this style of music is now firmly established as a legitimate genre in the music industry and has been used widely in many areas of musical appreciation.

CRITERION F
Importance in demonstrating a high degree of creative or technical achievement at a particular period.

The manufacture of advanced analogue music synthesisers was limited to two major international companies (Moog in the United States and EMS in England) and it is now accepted that exceptional technical innovation was incorporated into instruments such as the Synthi 100 and its contemporaries.

CRITERION G
Strong or special association with a particular community or cultural group for social, cultural or spiritual reasons.

The music community, both in the popular and classical genre, accepts the contribution of electronic music to the development of their respective art forms. That creativity is well demonstrated by the iconic music synthesisers of the 1970s, of which the Synthi 100 stands amongst the very best.

Why is it significant?

The Synthi 100 unit in the Melbourne Conservatorium of Music is more than 90% operational after years of rigorous restoration by a senior technician. It has been an integral historical part of the Conservatorium since its purchase in the early 1970s by the University of Melbourne. It has been involved in prominent musical productions in that era and it now continues its social impact on the music community both nationally and internationally after its restoration. It can be regarded as one of pinnacles of music production technology in the 1970s before the rise of the digital era and it represents the end of a short-lived age of electronic music exploration. It has been highly valued and revered by musicians who have worked with it. Moreover, it now also serves a profound educational role in the Melbourne Conservatorium. The authenticity of this iconic engineering feat entices a significant number of upcoming students to expand upon the research in the field of analogue music and regenerate its evolution.

4.9 Area of Significance:

The Synthi 100 is significant at a State Level as it is located at the Melbourne Conservatorium of Music at the University of Melbourne which is the highest level music teaching institution in the State. The use of the instrument is embedded in classwork and research work at the Conservatorium.

The Synthi 100 is significant at the National level as it is the only Synthi 100 in Australia and this instrument is regarded as one of the premier instruments of its type from the 1970s.

The Synthi 100 is significant at an International level as it is one of only three Synthi 100 instruments still in operation worldwide. The resurgence of analogue music synthesisers has added to the importance of the Synthi 100 and similar instruments.

5 Interpretation Plan

5.1 General Approach

The ceremony is planned to be held on **Saturday 10 September 2016** at a time convenient to the Conservatorium of Music. The ceremony should be held at or near the Synthi 100.

The interpretation panel should be located as close as possible to the Synthi 100.

Arrangements have yet to be finalised with the Conservatorium of Music.

5.2 The Interpretation Panel:

A mini-panel will be most appropriate for this recognition. It is hoped to be able to mount the panel in the room where the Synthi 100 is located. As the room is not very large a full size panel would overwhelm the space. It is considered more important in this instance to have the panel located near the instrument although this places a restriction on its size.

The panel should contain:

1 A title "Synthi 100 Music Synthesiser".

2 Logos of Engineers Australia, Conservatorium of Music and the University of Melbourne.

3 A small-scale representation of the EHA marker plate.

4 The date and other details of the marking ceremony.

5 Text should be 24 point Arial Bold.

6 Brief captions for each photograph including attribution.

7 Total text should not exceed 100 words.

8 The panel should be constructed of digitally printed vinyl reflective film on an aluminium substrate and it will be wall mounted.

9 Size to be nominally 500 mm wide by 800 mm high.

10 The panel to be constructed with flanges as per drawing at Appendix 2.

5.3 Possible Interpretation themes for Interpretation Panel

The following subjects have been assessed as possible themes for the interpretation panel:

a) The history of the analogue music synthesiser.

b) The restoration of the Melbourne Conservatorium of Music Synthi 100.

5.4 Preliminary Text Blocks for Interpretation Panels

a) The history of the analogue music synthesiser.

The early 1970s saw a significant evolution in the technical aspects of music synthesisers. The two primary entities who pioneered the field of analogue electronic music were Electronic Music Studios (EMS) in the United Kingdom and Moog Music in the United States of America.

Miniature models of analogue synthesisers had grown in sophistication and size until this evolution culminated in the design of complex powerhouse modular synthesisers. The most significant example is the impressive Synthi 100 model which was developed by EMS as a combination of three of their smaller synthesiser systems.

99 words

b) The story EMS.

In 1965 a synthesiser company was founded by Dr Peter Zinovieff. He set up the studio in the back garden of his home in Putney, London. This company was named Electronic Music Studios (EMS) and became the hub of activity for electronic music in the UK during the late sixties and seventies.

EMS originally provided studio resources but Zinovieff ran into financial difficulties and decided to manufacture a miniaturised version of his studio for sale.

This was designed by David Cockerell and was called the VCS1 (Voltage Controlled Studio 1). It went onto the market in 1969.

This was followed by the VCS3 and Synthi A portable models. In 1971 features of the three EMS portable synthesisers were combined into the much larger Synthi 100 which was expensive but became an industry standard.

The Synthi 100 competed with the larger units from Moog in the United States.

149 words

c) The restoration of the Melbourne Conservatorium of Music Synthi 100.

This particular Synthi 100 was delivered to the Melbourne Conservatorium of Music in 1973.

This instrument was restored to working condition, by Mr Leslie Craythorn, a senior technical officer at the Conservatorium. Mr Craythorn has maintained and worked on the synthesiser for over 12 years but now says that over 90% of its functionality has been restored. He continues, in retirement, to work on the instrument.

There are now only three Synthi 100 music synthesisers in operation in their original form in the world.

92 words

TOTAL 340 words to be refined down to 100 words during design to give maximum WOW factor.

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7 Acknowledgments, Authorship and General Notes

7.1 Acknowledgments

We wish to acknowledge the staff of the Melbourne Conservatorium of Music including Yvonne at External Relations and James Hutchinson, Performance Manager for their assistance and support in arranging for the heritage recognition of the Synthi 100.

7.2 Nomination Preparation

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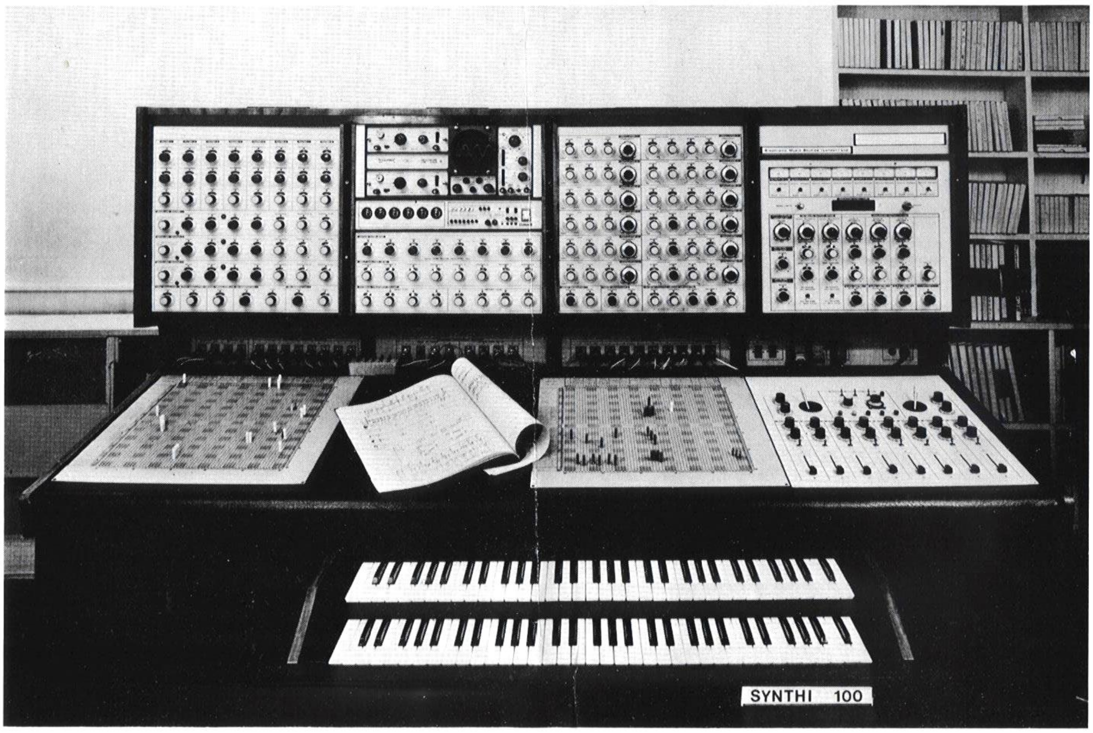
7.3 General Notes

This document has been prepared in accordance with the Commonwealth Government Style Manual for authors, editors and printers, Sixth Edition, revised by Snooks & Co, 2002.

The method of citation used in this document is the Vancouver System. See page 190 of the above Style Manual.

Appendix 1: EMS Synthi 100 Brochure



The Synthi 100

Professional Electronic Music Studio

The SYNTHI 100 studio has at its heart a digital sequencer, which makes conventional analogue controllers, with their gigantic array of knobs, seem old-fashioned, inaccurate and cumbersome. With a solid state storage capacity of 10,240 bits, the new sequencer is capable of precisely controlling 6 different simultaneous parameters over a sequence of 256 successive events. There are several modes of operation and full, easy to operate editing facilities, so that any or all of the 256 stored items and their time relationships may be changed without difficulty.

For example, two five-octave dynamically proportional keyboards are included, to operate the studio in real time, on six tracks, with the sequencer remembering what is played. This performance can then be played back backwards or forwards, at any speed, and edited to any degree of precision, prior to recording on magnetic tape.

The SYNTHI 100 also contains new electronic devices exclusive to EMS, such as voltage controlled slew limiters, a frequency to voltage converter and a two-output random staircase generator with controllable time and amplitude variances. Also included are a very full complement of 12 drift-free oscillators, eight dynamic filters and three transformerless i.c. ring modulators (which can be cascaded for double and triple modulation), as well as eight voltage controlled output channels with full panning facilities, eight input amplifiers, two X-Y joystick controllers, a filter bank, three elaborate envelope shapers and followers, noise generators and reverberation units. A double-beam oscilloscope and six-digit crystal-controlled counter/timer/frequency meter ensure accurate setting up and logging of parameters, and patching is by cordless pin matrices (two boards each with 60 x 60 locations).

In the same price range as the larger voltage controlled synthesizers, the SYNTHI 100 offers far more, and is intended for really exacting composition and realisation work in professional recording and electronic music studios, broadcasting companies and universities. First customers include the BBC, Radio Belgrade and the University of Wales.

◄

This photograph shows the EMS Synthi 100. The patching matrixes are on the main desk; the right hand matrix is used for control voltages and is connected to the Digital Interface via two 60 way junctions. The knobs above the desk are used as presets when the SYNTHI is controlled by computer.

General Points

Appearance

The SYNTHI 100 is presented in an afrormosia case, with padded black leather. A cupboard stand and seat are available as extras. The working surfaces are illuminated by dimmer lights, and all outputs and inputs are available behind a sliding screen in the front of the unit, while the input/output cables are channelled on to the rear. The SYNTHI 100 is designed for computer interface, and therefore all control inputs are available for direct connection to digital/analog converters on multiway connectors. The overall size base of the SYNTHI 100 is 79 in. length by 37½ in. depth, the height is 33 in. and the height from the underside to the ground is 30 in.

Signal Levels

The levels of all signal outputs available at the patch-board are controlled by panel mounted potentiometers. In fact, these potentiometers provide control voltages which operate on voltage controlled amplifiers. The advantages of this system include:

- Constant low output impedence.
- No 'fader scratch' as levels are changed
- Less conveying of signals at high impedance (where they are susceptible to crosstalk)
- Much simplified wiring system
- Ideal logarithmic control of level

In general, signal levels are about ±1V p-p, although most outputs can deliver much more than this. Most devices which have signal inputs are adjusted for optimum operation at this level, although it can be usually considerably exceeded without serious distortion.

Control Voltage Levels

All EMS control voltage outputs are bipolar, that is to say they go both positive and negative. This allows control signals and audio signals to be interchanged, and also allows the magnitude of a control output to be adjusted without altering the mean level of the parameter controlled.

Input Impedances

All input impedances are approximately 10 KOHM. This comparatively high figure was chosen as a compromise between the conflicting requirements of 'fan out' (i.e. the number of inputs an output may drive before it runs out of power) and susceptibility to crosstalk when an input is left open circuit. Screened cable is used for all signal paths in the studio, and impedance at certain central inputs is made infinitely low so that secondary control parameters can be added without readjusting the magnitude of the primary ones.

Noise Levels

The signal to noise ratio of all voltage controlled amplifiers is better than 74 dB for an input signal level which produces a T.H.D. of 3%. This ratio is constant over the upper 30 dB of the control range. In other words, as the amplifier gain is reduced, the noise is proportionally reduced as well. When the amplifier is cut off, the noise at its output is immeasurable.

Specification

Source Modules

Three Voltage Controlled Audio Waveform Generators, Sine and Ramp

Manual Frequency Range: Greater than 1Hz - 10 KHz (extendible by voltage controls in both directions — to 0.25 Hz and 20 KHz).

Sine Purity: Better than 50% total distortion between 10 Hz and 10KHz.

Ramp Output Linearity: Departure from linearity ± 1% of best straight line between 10Hz and 10KHz.

Voltage Control: 5v/octave. Accuracy 0.3% departure from best straight line between 100 and 2000 KHz.

Frequency Stability: Generally better than 2% from month to month, but the oscillators usually hold their setting to within 2 cycles in a thousand during a working session.

A sine shaper is included by which variable amounts of even harmonic distortion may be added.

Three Voltage Controlled Audio Waveform Generators, Triangle and Square.

These can be varied from triangle to sawtooth ramp, and from symmetrical square to short pulse, in either polarity.

Manual Frequency Range: Greater than 1 Hz to 10 KHz.

Triangle Symmetry: ±5% rise time to fall time equality.

Other specifications as for sine/ramp oscillator.

Three Voltage Controlled Low Frequency Waveform Generators

Same details as before, but oscillators are twenty times as slow.

Frequency range: Greater than 0.025 Hz (40 secs. per cycle) to 500 Hz.

Voltage Control: .5v/octave.

These three oscillators are intended mainly as control sources, but can be used for tone generation at the upper end of the range.

All nine of the above oscillators have synchronisation inputs so that they can operate at an integral multiple of another oscillator, providing a huge variety of waveforms which can be used in additive synthesis.

Three Noise Generators.

Variable from white (central position of colouration control) to dark or light positions (low or high pass filters).

Distortion: In white position, frequency content is flat ±3 dB from 100 Hz - 10 KHz.

We recommend several noise sources, because with different filterings more than one can be used for different purposes.

Dual Output Random Control Voltage Source

This device produces two control voltages which move abruptly from one level to another. The distribution of levels is rectangular rather than Gaussian, and the two outputs are uncorrelated in level, but synchronous in time. The mean time between changes, and the variance about that mean are manually controllable. The distribution of times is rectangular, and in common with all other time controls devices in the studio, a control range of at least 1000:1 is available.

Controls:

Amplitude Variance. Up to 2.5v symmetrically positive and negative (x2, each output separately controllable).

Time Range: From approximately 10 secs to 10 ms if no time variance is applied.

Time Variance: From equal steps to 1000:1 variance. Effect of variance control is obviously limited when time range control is at either entrance.

Treatment Modules

Three Voltage Controlled Trapezoid Generators with Integral Envelope Shapers

These devices might be described as voltage programmable four segment curve synthesizers, the output being available as two control voltages and as the modulation of an audio signal.

The basic waveform produced (at each control output) has four stages:

1 **Delay.** The output remains constant and negative for a controllable time after the generator is triggered.

2 **Attack.** The output rises to a fixed positive value at a controlled rate.

3 **On.** The output remains constant and positive for a controllable time after the completion of 'attack'.

4 **Decay.** The output falls at a controlled rate to its initial value.

In addition, there is a second output which lags behind the first by one quarter of a complete trapezoid cycle. Thus the time set for, say, 'on' in respect of output 1, becomes the time for 'attack' from output 2, and so on.

The amplitude and polarity of both outputs may be adjusted independently so that if they are summed (on the patchboard) any continuous four line function which ends at the value at which it starts may be produced. This arrangement gives an extraordinary flexible range of envelopes.

The envelope shaper portion consists of a logarithmic voltage controlled amplifier permanently connected to one of the trapezoids.

The overall control of each cycle of operation may be in a number of ways selected by a switch, having the following positions:

1 **Signal threshold.** Any signal above a certain level initiates a single cycle.

2 **Hold** sequence starts when control is positive. Decay does not start until control goes negative.

3 **Single shot** positive zero crossing initiates a single cycle.

4 **Free run.**

5 **Gated free run** positive level allows the sequence to free run. Sequence stops at the end of a cycle when level goes negative.

Panel Controls

Initial delay time	2 ms to 20 sec.
Attack time	2 ms to 20 sec.
On time	2 ms to 20 sec.
Decay time	2 ms to 20 sec.

(these parameters may also be voltage controlled over their entire range.)

Trapezoid phase 1 output level (centre zero knob)
Trapezoid phase 2 output level (centre zero knob)
Signal level control
Push button (to initiate cycle)
Trigger mode selector switch

Envelope shaper is logarithmic to within 3 dB over its 60 dB range.

Voltage control function of time parameters is ideally exponential to within 10% (of dependent parameter) over a range of 1000:1: Departure from ideal is gradual beyond these limits. This permits a single voltage applied to all inputs to compress the time scale.

Four Voltage Controlled Filter/Oscillators (Low Pass to Resonating)

Operation as a sine source.

Frequency Range:
Greater than 5 Hz–20 KHz.

Sine Purity:
Better than 3% total distortion between 10 Hz and 10 KHz.

General Noise Figure for Oscillators:
Spurious outputs not greater than 0.1%.

As filters, they are adjustable from Low Pass to Resonating Filters, covering the entire sonic range.

Frequency Range:
Greater than 5 Hz to 20 KHz.

Low Pass Position.
Cut off rate 12 dB for first octave and 18 dB per octave thereafter.

Resonator Position:
Maximum stable 'Q' factor–20.

Accuracy of Exponential Voltage Control Function:
± 1% between 100 Hz and 2000 Hz.

Note: Operation as a voltage controlled oscillator is limited by the time taken to respond to an abrupt change. Maximum slew rate is about 2 ms per octave.

Four Voltage Controlled Filter/Oscillators (High Pass to Resonating)

Similar, but complementary to Low Pass Filters.

One Octave Filter Bank

This consists of eight resonating filters, fixed-tune one octave apart, in the range 62.5 Hz–8 KHz, seperately controllable.

Two Voltage Controlled Reverberation Units

Each spring unit has two elements with delays of 35 and 40 ms.

Maximum Reverberation Time:
2.4 seconds.

Useful Frequency Range:
30 Hz–12 KHz.

Voltage Control Range:
±2v from no reverberation to maximum reverberation.

Three Voltage Controlled Slew Limiters

This device is a unity gain amplifier in which the output exactly follows the input at a rate whose maximum (slew) is defined by a control voltage. One application might be to interpose the device between the pitch control voltage from a keyboard and the oscillator whose pitch is to be controlled. If the key velocity voltage were then applied to the slew control input, the player could produce a glissando between any two notes that he played, the rate of glissando being controlled by his touch.

Steady State Gain:	1 ± 1%
Steady State Linearity:	± 0.05% (BSL)
Range of Slew Control:	1 ms to 10 sec.

Voltage control of slew is exponential.

Note: Unlike all other devices, no output level control is provided as the device has unity gain.

Three Integral Circuit Transformerless Ring Modulators

These very efficient modulators also include amplifiers, and can therefore be used in series for double or triple modulation.

Maximum Input for
Undistorted Output: 1.5v p-p to each input.
Breakthrough with 1.5v
on one input only: 5mV p-p (—60 dB)

One 256 Event, 6 Simultaneous Parameter Digital Sequencer

This machine is, in fact, a small special purpose digital computer, complete with analog to digital and digital to analog converters. It provides a sequence of control voltages which may be used on any of the devices in the studio.

The operation of the sequencer may most easily be described in terms of conventional music, although it must be remembered that the design by no means limits it to this kind of operation.

The sequencer stores 256 'notes' and plays each note at the correct time and for the correct duration. It simultaneously provides two voltages, one of which might be used to define pitch and the other loudness. It is capable of controlling three voices, each with duration, pitch and loudness. The 256 note storage may be distributed to each voice in any proportion, for instance, 254 notes may go to one voice and one each to the others. In fact, the second and third voices need not be used as such, their voltages could be used to control parameters (filtering, decay time, etc.) of the first voice.

The information which is to be stored and subsequently reproduced is presented to the machine as control voltages, which are most easily supplied from the keyboards.

All timing data is entered by playing the keys. To record a sequence the composer sets the speed of a clock and starts it running. As he plays each note, the machine at that instant records how many clock pulses have elapsed since the start of the sequence, and how many during the time that the note was held down. It simultaneously remembers which note on the keyboard was pressed and with which velocity it was struck. (The second parameter, or, indeed, the first, could equally be derived from any voltage source.) The composer continues until he has recorded perhaps sixty notes. He then restarts the clock and turns a switch which tells the machine that the next notes he plays will be directed to the second envelope shaper. While recording each sequence, he can simultaneously hear the results of what he has previously recorded.

The machine may then be set to the edit mode. In this mode the sequence may be advanced at any speed, or step by step, so that each note may be modified or erased. A special feature allows time to be *reversed*. A control rather like the spooling knob on studio tape recorders allows one to go forwards or backwards at any speed. Unlike a tape recorder, however, there is no inertia in the system, so that one can quite easily 'zero in' on a particular note.

Sequencer Controls

Ten controls are provided to adjust the amplitude of the sequencer's output voltages, and a further ten supervise the actual operation.

1 **Range of Layer 1 Output Voltage A**

This control is a slow motion dial calibrated 0-100. If Voltage A were used to control the pitch of an oscillator, then this control could be used to define the musical interval for each step of the output. At 25, for instance, a range of sixty-four quarter tones (covering about 2½ octaves) will be available.

2 **Range of Layer 1 Output Voltage B**

The range of the second parameter for each event may similarly be adjusted with this control.

3 **Range of Layer 1 Keying Voltage**

This voltage, which is positive for the duration of each note in Layer 1, would normally be used to control the envelope shaper. It can also be used to assist in the synthesis of certain instrumental sounds. For this reason, a centre zero control is provided. This inverts the polarity of the voltage when it is counterclockwise.

4 5 and 6 are controls identical to 1 2 and 3, except that they apply to the second layer. Likewise 7, 8 and 9 which apply to the third layer.

10 **Range of 'Key 4'**

A fourth kind of event may be recorded which is similar to the three layers, except that there are no parameter control voltages available with it — just the keying voltage. It is primarily intended to stop or reset the sequencer's clock, allowing one to produce a single finite sequence or a repeating pattern. If not used for this purpose it might be used in conjunction with a slew limiter and a voltage controlled amplifier to initiate a crescendo or a number of other things.

Note that all controls, 1-10, can be adjusted after the sequence is entered, without changing the basic data.

11 **Clock Rate**

This slow motion dial is a centre zero control in a rather special sense. When it is less than halfway, the sequence runs backwards. It controls the clock rate over a range of ±1000:1. That is to say, with the control near its centre position, the clock pulses occur at about 2 per second, allowing a total sequence length of over six minutes. In this case, however, the resolution in time of each event is only half a second. The control has a distinct dead space around half-way, which prevents the clock from 'drifting' during editing. A voltage proportional to the absolute clock speed is available at the control patchboard, so that it can simultaneously control all time variant parameters — envelope shapers, slew limiters and even oscillator frequencies — as the clock rate is adjusted.

12 **Note Distribution**

This control is a four way switch; it tells the machine which of the three layers is being recorded, so that on replay the voltages will appear at the appropriate output. The fourth position denotes 'Key 4' as described above.

13 **Stop at each note**

When this toggle switch is down, the sequencer clock stops at the start of each note that it reproduces.

14 **Stop at end of note**

Similar to 13, except that the sequencer stops at a time corresponding to when the key was released as the note was recorded.

These switches operate in conjunction with the note distribution switch, in that they only stop at a note in the layer defined by the latter.

The purpose of 13 and 14 is to facilitate the editing of events after a tentative sequence has been entered.

15 **Erase note button**

While this button is pressed, any notes in the layer selected by the note distribution switch which start at the time shown by the clock display, will be erased.

16 **Clear memory button.**

This is the 'bulk erase' button.

17 **Reset button**

This button sets the clock to zero, and holds it there as long as it is pressed. It does not stop the clock, it simply restarts the sequence from the beginning.

18 **Start button**

This button allows the clock counter to start or continue counting. It would be used continually during editing, to advance the sequence note by note.

19 **Stop button**

This button stops the clock from counting.

Note that 17 18 and 19 are momentary action push-buttons, not switches. They roughly correspond to the controls on a stop-watch.

When the sequencer clock is driven from pulses previously recorded on tape, or, indeed, from any external source, it will ignore them until the start button is pressed. Remote operation of the sequencer is facilitated by electrical inputs at the signal patch-board.

20 **Rewrite B, D, F**

When this switch is down, the second parameter voltages in each layer may be rewritten without disturbing the first parameter, or the event timing.

Note: In this section, 'Note' is used for musical convenience, but, it must be remembered, can be used for any parameter which has been selected.

Summary of Specification

Total storage capacity: 10,240 bits (of which 9,216 bits are normally used).

Organisation of Data

36 bit words — each word representing one event.

Start-of-event time (referred to start of sequence) 10 bits.

End-of-event time (referred to start of sequence) 10 bits.

Selection of one of three envelope shapers and one pair (out of three pairs) of digital analog converters.

Also internal functions 4 bits.

Data, for digital analog converters 2 x 6 bits.

Details of Coding

The 10 bit event time allows the start of each event to be defined to an accuracy of 1 part in 2 to the power 10 (viz. 1024). Thus, if the clock is set to a rate of, say, one hundredth pulses a second, each event may be adjusted forwards or backwards in increments of one hundredth of a second. The total sequence length would be ten seconds.

The 'end of event' time, i.e. the time at which the key is released, is similarly recorded. Thus three control signals are reproduced, each being positive during the duration of a note intended for one of the three layers of the sequence. They are available at the patchboard as switching voltages which would normally go to the supervising inputs of the envelope shapers.

Digital Analog Converters

Of the six converters, three are of accuracy appropriate to exact control of pitch on the diatonic scale. Six bits give a range of 64 notes. If greater range and/or finer resolution is required, then the output of the second converter may be added to that of the first. In this case, the player might use one keyboard to define a note on the diatonic scale, and the second to raise or lower that note by increments of one thirty-second of a tone.

The precise converters are accurate to $\pm$0.15% (BSL). The second parameter converters are accurate to $\pm$0.78% (BSL).

Eight Multifunction Output Amplifiers

These amplifiers are primarily intended to be the last link in the signal chain before the tape recorder or monitor, but they provide certain subsidiary functions which will make them otherwise useful. All eight are voltage controlled (0.5V per 6 dB).

Controls

Level: Slider type fader.

Pan: A knob which distributes the output to between the left and right bus, these being common to four of the eight amplifiers.

Filter: A single knob providing continuous transition between first order low pass and first order high pass.

Off Switch: Totally disconnect output from the pan control, allowing the amplifier to be used earlier in the signal chain.

Meter Switch: The meter may be used as a centre zero DC voltmeter, or as an AC level meter.

Two X-Y Joystick Controllers

These give continuous control of two parameters together, which is very useful in live performance. The control sticks have a range of 2 x $\pm$2V DC.

Two Five Octave Dynamically Proportional Keyboards

Five octave keyboards giving precise divisions of pitch or any other controllable parameter. In the case of pitch, the range would give anything between 4 and 40 notes per octave. This is useful for microtonal work. By setting 12 notes per octave, the keyboard can be used as a normal melodic source.

A second voltage output is proportional to touch — actually the velocity with which a key is struck.

A third voltage switches positive when one or more keys are pressed. Note that the keyboard produces only one pitch voltage at any instant; when several notes are pressed, the voltage of the highest appears.

Both the pitch voltage and dynamic voltage are 'remembered', even when a key is released.

Keyboard voltage: 0.5V per octave maximum, accurate to better than 0.15% at all points.

Dynamic voltage: ±1.5V depending on key velocity. Output function was synthesized to be a compromise between a strict proportionality to velocity over a range of about 100:1, and a function that would distribute seven subjectively equal increments of playing force evenly over the output voltage range. The keyboard feels most natural when the dynamics voltage is used to control a modulator over a 40 dB range.

Eight Way Fading/Panning Console (See Multifunction Output Amplifiers)

60 x 60 Pin Matrix Patchboards (7,200 Pin Locations) These patchboards allow any input to be connected to any output by the insertion of a single cordless pin. Each output is connected to a row of sixty horizontal holes. The holes appear as a square array of 3,600 (x2) cross-points, in any of which a jack may be inserted. The jacks contain resistors so that several outputs may be mixed into a single input. All device outputs are fed to the board at a low impedance, blocking any reverse signal paths.

Two patchboards are provided, one intended for control signals and one for audio signals. A small number of interconnection patches between the patchboards are hard wired, as some signals can be used in both domains.

It is also possible to route external signals to the patchboards by using the jacks in the conventional way. All contacts, including the jacks have a surface coating of silver.

Eight AC/DC Input Amplifiers

Maximum distortion at rated inputs: 0.1%.

Input Sensitivities: Line Input: maximum 1.8V AC (rms) or ±2.5V DC.

These amplifiers convert input signals to a suitable level and impedance to feed treatment devices. The line inputs are directly coupled and are therefore suitable for both signal and low frequency or DC control inputs. Two separate microphones amplifiers are supplied, which can feed any two of the above channels.

Four External Treatment Send and Returns

Provision for sending out to external echo plates and other equipment, and returning to the Studio.

One Frequency to Voltage Converter

This device accepts inputs from a variety of sources, including acoustical instruments (via a microphone or pickup and pre-amplifier) and produces a voltage proportional to the fundamental pitch of the note played. Sophisticated analog circuitry is incorporated to remove overtones, provided that their energy constitutes no more than 90% of the total signal.

Unlike conventional frequency measuring techniques, which count the number of zero crossings of a waveform in a fixed interval of time, the converter measures the period of the signal and transforms this data to a voltage which is compatible with the other devices in the studio. The advantage of this method is that an accurate measure of the pitch can be made in a much shorter time. The output is gated into a track and hold buffer by a discriminator, which suppresses spurious outputs when the signal is dying away.

A single output control adjusts the range and polarity of the output voltage.

Two Envelope Followers

These devices produce a voltage proportional to the mean level of an audio signal. The output is passed through a second order low pass filter to remove ripple while keeping a fast response. Cut off is about 50Hz. Output amplitude is adjustable by a centre zero knob to give positive or negative excursions of up to 1 volt per 6 dB.

Items from other Manufacturers

Dawe 3000 AR/6 Digital Frequency Meter

Brief details as follows:

Crystal frequency:	100 KHz ± 0.002%
Frequency Measurement:	Range — 0-1 MHz Accuracy — ±1 digit ± crystal accuracy Gating Time — 1 ms to 10 seconds
Period Measurement:	Range — 0-300 KHz Time Units 1 10 s to 10 ms Gating Period — 1/7 to 1,000 cycles of input frequency
Time Measurement:	Range — 10 s — 10 secs (nearly four months)

Telequipment Double Beam Oscilloscope, D43R

Rack mounted double gun laboratory oscilloscope, with 6 x 8 cm display area.

Electronic Music Studios (London) Ltd. reserve the right to vary the specification and/or price of the SYNTHI 100 studio without notice, should it be necessary or desirable.

Why a Computer?

In recent years the most important single problem in designing an Electronic Music Studio has been finding a way in which reasonable complexity is achieved without an absurd proliferation of manual controls. Essentially, the problem is one of storing and manipulating data, and for a number of reasons a small computer is suited to this task.

A large quantity of information can be stored. Using a 12 bit word, the EMS configuration can store 4,000 events in the computer's core store, 32,000 events on the magnetic Disc and over a quarter of a million on each reel of magnetic tape.

There is no redundant information. 64 levels of control are adequate for most devices and EMS use 6 data bits as standard (the other 6 bits are used to specify the device). Controls, such as oscillator frequencies for which precision is required, use converters in pairs giving a resolution of 10 bits, corresponding to 0.1 semitone over the audio range, which is adequate for glissando.

The computer is fast enough for all musical requirements. When necessary, it will perform calculations during the performance without the risk of degrading the music.

Composers can do much of their preparatory work away from the studio. They can write the score as a computer program and realise it as sound very quickly when they come to the studio.

When a composer leaves the studio, all control settings are stored digitally on his own tape, and when he returns he can start from exactly where he left off regardless of who has used the studio in the meantime. This is particularly advantageous in a University studio, where many students will be allowed short periods in the studio.

A composition stored digitally does not deteriorate as an audio recording does. A piece can be re-recorded at any time from the original program.

What Equipment is needed?

A computer studio has conventional voltage controlled equipment (oscillators, filters, modulators, etc.), a Computer to control them, and an interface which converts the digital computer information to voltages for device control. In addition, programs for the computer are required, and these are referred to as the **software** of the studio: EMS provide a studio consisting of an EMS SYNTHI 100 Synthesizer; a set of digital to analogue (DAC) and analogue to digital (ADC) converters; a crystal clock; and a computer system. The system can be enlarged at any time by adding analogue or digital equipment. The equipment provided by EMS does not include tape-recorders, monitoring amplifiers or loudspeakers. EMS will negotiate a price and delivery time based on the following equipment:

EMS Synthi 100

EMS Digital Interface and Clock

PDP8 Processor, 4K Core, 32K Disc and Teletype

EMS Software

What can it do?

The Synthi 100 is a comprehensive e.m. studio by itself.

The MUSYS software provided by EMS enables compostiions to be stored, modified and performed by the computer.

Miscellaneous chores such as tuning oscillators and measuring frequency responses can be performed by the computer.

Appropriate software is provided by EMS and additional programs can be written by the user, using the DEC assembly system.

An added bonus is that several hundred programs are available free from the computer manufacturer (DEC) which enable the computer to be used for non-musical tasks such as calculation, accounting, circuit-design, or even playing games.

Why Musys?

EMS bought its first computer four years ago, and the first public appearance of the computer was in the Royal Festival Hall in January, 1968, performing "Partita for Unaccompanied Computer" by Peter Zinovieff. Later in the same year, the system was the most spectacular exhibit at the Cybernetic Serendipity exhibition at the ICA, where it improvised and accompanied melodies whistled to it by visitors. At this time, each piece realised in the studio required a separate program, and it became apparent that each program had many things in common which could be incorporated into a single generalised program. Peter Grogono proposed that a translation program should be available to relieve the composer of the task of writing down long strings of numbers, and designed MUSYS. MUSYS 1 and MUSYS 2 were both short-lived, but they provided valuable experience and led to MUSYS 3 which was completed in early 1970 and is still the principal program used. The first two compositions which used MUSYS 3 were "Medusa" by Harrison Birtwistle and "A Lollipop for Papa" (variations on a sonata by Hadyn) by Peter Zinovieff, and the language was taught to fifteen musicians who attended the BSEM course at Putney in June 1970. Since then, MUSYS 4 has been written to control the studio's Filter Bank, and MUSYS 5 is being prepared for Autumn 1971 to allow larger compositions to be realised in one piece.

How is it used?

The system can be used as a Sequencer, in which case no programming is necessary: the Digital Interface has controls which permit data for each device in the SYNTHI 100 to be stored, examined, altered and played back. Alternatively, MUSYS 3 can be used, in which case the composer writes a program which constitutes the "score" of his piece. Very short "scores" may be typed directly on the computer's typewriter, but this technique is normally used only to try out ideas or test the devices. The score is **compiled** by the MUSYS Compiler, a program which translates the composer's

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This photograph shows the original computer studio in Putney. The computer and its typewriter are at the left hand side and the Digital Interface is on the fourth equipment rack, underneath the oscilloscope. In this studio the computer is used to control devices in the centre racks which were built before the SYNTHI.

score into a string of numbers for delivery to the SYNTHI 100. At each step, the process can be closely controlled by the composer or interpreter, using both hardware and software.

The requirements for a programming language for a system of this kind are simplicity, efficiency and flexibility; EMS feel that MUSYS meets these requirements adequately. In a MUSYS score, the "instruments" are given abbreviated names, so that, for example, 02., E3., F7., refer to Oscillator 2, Envelope Shaper 3 and Filter 7 respectively. In the simplest case, data is sent to a device simply by writing a number after the device name — 02.15., F7. 30., etc. The effect of the number depends on the device — for an oscillator it represents a pitch, for an Envelope Shaper the length of Attack or Decay, and so on. Arithmetic and algebra are possible, using letters to denote variables; these have an obvious use in compositions of a mathematical nature, but are also necessary for quite mundane tasks, such as transposition, repetition, calculating rests, etc. MUSYS also has structural facilities, allowing any sound or group of sounds to be given a name, and subsequently referred to by that name. This means that scores can use as much conventional terminology as the composer desires. For example, a crescendo can be called CRESC and a glissando called GLISS. There are six simultaneous systems, each with its own time control, so it is not necessary to work out time interrelationships for complex rhythms. There is a random number program which generates randomly distributed numbers in a repeatable sequence, which is useful in aleatoric composition.

The studio can be used immediately, without learning MUSYS, since the computer can be used simply as a large sequencer.

However, a unique advantage offered by the studio is programmed scoring, and for this it is necessary to learn MUSYS. The course given last year demonstrated that composers without previous knowledge of programming do not find MUSYS a difficult language to learn. EMS offer free courses in MUSYS hardware and software, each lasting one week, to purchasers of computer studios, and the computer manufacturers offer courses in computer programming.

What Software does EMS provide?

If you buy a computer studio from EMS, all the currently available EMS software and documentation is given to you as part of the studio. New programs and program enhancements will also be issued free for a minimum period of two years from the date when the studio is commissioned. In addition, as the owner of a PDP8 computer, you are entitled to all software issued by DEC, and to membership of DECUS, the DEC Users Society which issues information about new and improved sofeware. EMS will also act as a pool for programs written by owners of EMS computer studios, so you will receive software written by other users, and may contribute your own to the pool. Complete pieces will also be pooled by EMS and made available to other users, copyright permitting.

If you do not buy an EMS computer studio, you may purchase programs and documentation from EMS at the listed prices. EMS will not maintain programs run on machines they did not provide.

Specifications

Synthi 100

The SYNTHI 100 is described fully in the first half of this brochure. It contains the voltage controlled analogue equipment of the studio: the outputs are at line level for feeding to amplifiers or tape recorders.

The devices included are these:

6 sine/ramp oscillators
6 square/triangle oscillators
2 coloured noise generators
8 swept filters
3 envelope shapers
3 ring-modulators
1 random voltage generator
2 envelope followers
1 pitch-voltage converter
3 slew-limiters
8 input amplifiers
8 output amplifiers (8 line outputs, 4 panel outputs)
1 octave filter bank
6 track, 256 event Sequencer and Clock
2 keyboards

The SYNTHI 100 has a patching matrix for signals and a patching matrix for control voltages, each 60 x 60; when used with a computer, the 60 control inputs are provided by the Digital Interface.

The Digital Interface

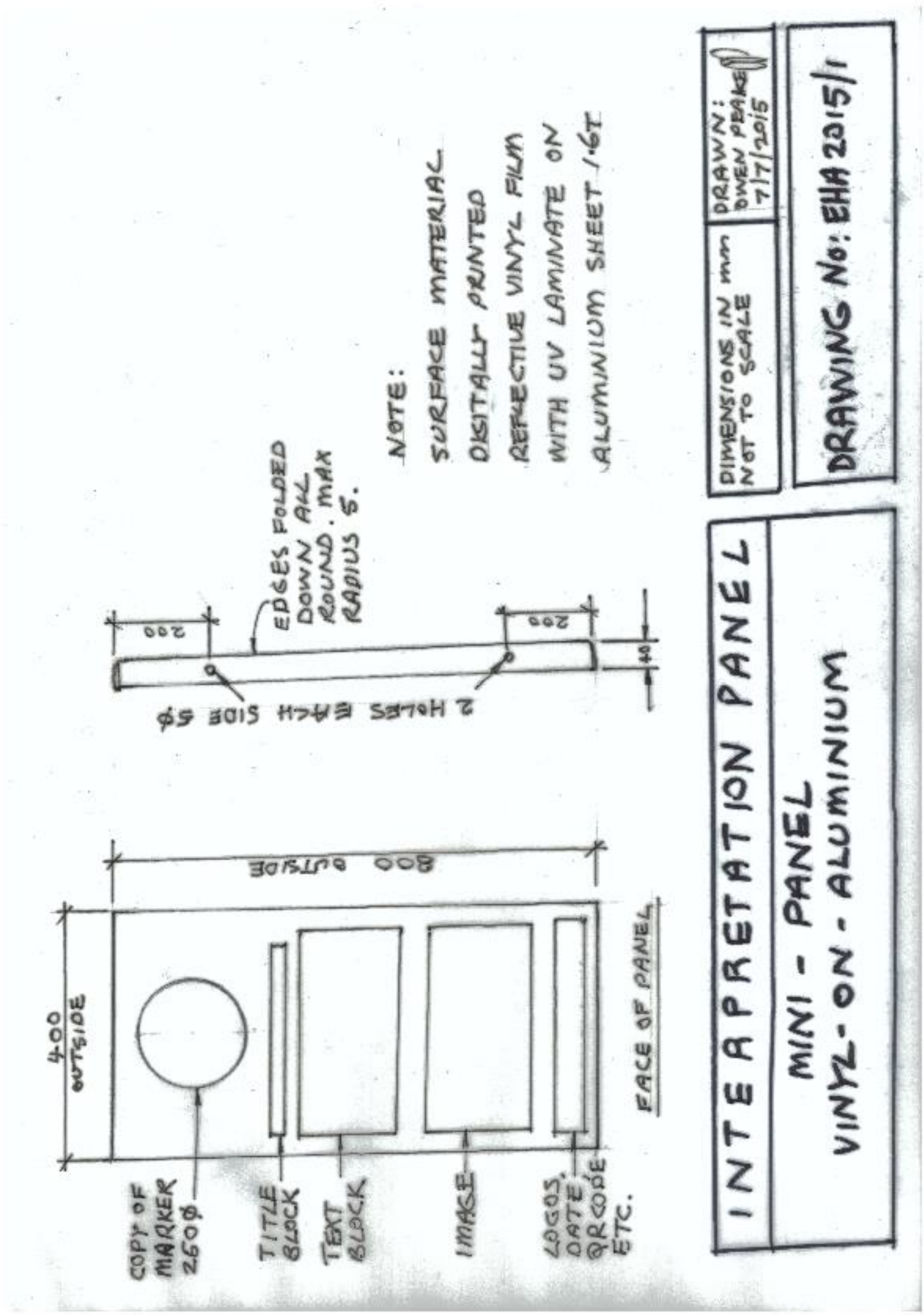
The Digital Interface has 64 6-bit DACS and 4 6-bit ADCs; the digital to analogue converters enable the computer to control all of the SYNTHI 100 devices, of which 4 have high precision (10 bit) control, and the ADCs enable the analogue equipment to signal the computer, for cueing, etc. It also contains a clock, which can be controlled by a crystal oscillator, by an external oscillator, or manually. The external oscillator is usually a prerecorded pulse train on one track of a multitrack tape, permitting exact synchronisation between tracks in a piece which is realised in several passes, and manual control is used in editing and correction.

The Digital Interface has a number of illuminated push-buttons which enable any device to be selected and controlled manually, and entire pieces can be constructed on it by using the Sequencer program and Keyboards. When using MUSYS, the manual controls are used for monitoring and making detailed changes, large scale changes being done in terms of the original score.

The Computer

The basic configuration as provided by EMS enables scores of up to 6,000 characters to be compiled, and the composition may have up to 20,000 events. Longer compositions can be realised in several sections. The clock has a maximum rate of 400 Hz, giving time discrimination to 2.5 msec which is adequate for musical applications. The basic software comprises a Text Editor, for the preparation and correction of the MUSYS scores, a Compiler, which translates the scores into lists of numbers to the devices under the control of the clock. There is also a program called Sequencer, which simply uses the storage units of the computer to store data provided by the SYNTHI 100 (from the keyboards, for example).

Appendix 2: Drawing of Interpretation Panel



Appendix 3: Associations and People Involved

A3.1: Peter Zinovieff [15]

Peter Zinovieff was born on 26 January 1933 in Fulham, London, England. His father was an aristocrat Russian émigré. Peter Zinovieff was a British engineer and inventor of Russian ethnicity. He earned a doctorate in geology in Oxford University.

Peter Zinovieff was working as a mathematician in the Air Ministry. He had a passion for electronic music and he set up the studio to create and promote electronic music in the back garden of his home in Putney, London. Zinovieff developed the synthesiser system with the help of David Cockerell and Peter Grogono. He also collaborated with Harrison Birtwistle on 'Chronometer', and wrote the libretto for Birtwistle's opera 'The Mask of Orpheus' [15].

A3.2: David Cockerell[16]

David Cockerell is an electronics engineer and designer. He started working at Peter Zinovieff's electronic music studio in Putney in 1966. He designed the EMS products such as the Synthi VCS3, Synthi AKS and Synthi 100, and one of the first digital sequencers from 1969 to 1972. From 1974 David Cockerell worked for Electro-Harmonix in New York and designed their Small Stone phaser and Electric Mistress flanger. He also worked briefly at IRCAM in Paris.

Cockerell was involved in the design of many of the samplers including the S612, S900 and S1000 when he was working for Akai in the 1980's. At present he is back at Electro-Harmonix, and continues to design ground-breaking pedals such as the POG and the Crying Tone wah.

A3.3: Robert Auther Moog [9]

Robert Arthur Moog was born May 23, 1934 in Queens, New York. He was the son of an electronics engineer father and piano teacher mother. Moog was forced to take piano lessons because his mother wanted him to be a concert pianist. However, he took after his father and was interested in building things.

Robert Moog built a Theremin, when he was 14 years old. In 1952 he formed the RA before he graduated from Bronx High School of Science. He later got his master's degree in electrical engineering from Columbia University and PhD in engineering physics from Cornell University in 1965.

In 1970, Moog developed the smaller Mini-Moog, which was great for live concerts. During the 1970s, less-expensive digital synthesisers flooded the market. Moog didn't have the financial expertise to navigate his company through competitive times. By 1973, he had sold all the rights to his company. In 1978, Moog moved to Asheville, North Carolina. He set up the Big Briar Music Company, building Theremins and analog synthesisers.

During his life, Moog was honoured by many organisations for his technical achievements. He was given the Trustee's Award from the National Academy of Recording Arts and Sciences and the Silver Medal of the Audio Engineering Society of America. In 2002, Moog received a Grammy Award for his lifetime of technical achievements. While Moog's name was primarily associated with synthesisers, he also continued to make Theremins throughout his life, until the year before his death.

In April of 2005, Moog was diagnosed with an inoperable brain tumor. He died at the age of 71 of brain cancer on 21 August 2005, at his home in Asheville, North Carolina. The Bob Moog Foundation was created as a memorial, with the aim of continuing his life's work of developing electronic music.

Appendix 4: Recorded Demonstration of the Synthi 100 at the Conservatorium

My Leslie Crayhorn, the senior technician at the Melbourne Conservatorium of Music at the University of Melbourne, illustrates the potential of electronic music on the famous restored Synthi 100 instrument.

This two-minute video was produced by the university itself and published on the 23 September 2015. The link to the aforementioned recording is listed below:

https://www.youtube.com/watch?v=-S339uKcjhI

Change Control

CHANGE CONTROL			
VERSION 1	**26 FEBRUARY 2016**		
VERSION 2	**28 APRIL 2016**	**4180 WORDS**	
VERSION 3	**3 MAY 2016**	**6838 WORDS**	**MARKED UP IN TRACK CHANGES**
VERSION 4	**22 MAY 2016**	**9178 WORDS**	**FURTHER MARKUP AND ADDITION BY TEAM**
VERSION 5	**22 MAY 2016**	**9188 WORDS**	**FINAL VERSION BY TEAM**
VERSION 6	**26 MAY 2016**	**9242 WORDS**	**INSERT APPENDIX 1 – SYNTHI 100 BROCHURE**
VERSION 7	**27 MAY 2016**	**9391 WORDS**	**CHECK READ + ADD APPENDIX 2**