This article is the first of a series that will describe the construction of two music synthesizers — the international 3600 and the international 4600,

The 3600 is a relatively inexpensive model that is basically designed as a portable, limited capability instrument for stage work. It does however offer a performance superior to most small synthesizers at present on the market.

The larger 4600 is a full scale unit. It uses the same electronics

The larger 4600 is a full scale unit. It uses the same electronics but has more modules, a programming patchboard and many additional features which make it more suitable for studio use.

The flexibility of both units, in particular the larger, allows individual constructors to tailor an instrument to their own requirements.

EXPERIMENTATION in electronic music has been carried out since the arliest days of vacuum tube technology. One of the earliest pioneers in the field was B.F. Meisner who published the article "Design Considerations for a Versatile and simple Electronic Musical Instrument" in 1935. By the late 40's the electric piano and organ had become well established, but very few real advances were made. Even in the early 60's, the electronic-music studio consisted simply of a variety of tape recorders. filters and other devices which were used to modify the sounds of conventional instruments.

The first real breakthrough came in 1965 with the introduction of the first commercial Voltage Controlled Electronic Music Synthesizer designed by Robert Moog. Since then development has been rapid indeed, and in just eight years synthesizers have become one of the most versatile and flexible of electronic musical

instruments. Today they are used extensively by both popular and classical musicians to create new and exciting sounds.

Very soon after Moogs' revolutionary voltage-control concepts were introduced, the use of a digital computer was proposed as a means of extending the basic system and providing real time control of synthesizer operation. During recent years much work has been pioneered on digitally generated "computer music". This concept however, despite its incredible potential, is still in its infancy, and dependent for advancement on further technological developments.

The basic genius of voltage control is its conceptual simplicity, and although the method of implementation has changed much since 1965, the concept itself has not. Moog proposed that the basic sound sources, such as electronic oscillators and random generators, be electronically generated and that these sources be modified in amplitude and frequency by other electronic devices. The resultant signals would then be processed conventionally with reverberation and multi-track tape techniques. This in itself was not revolutionary but Moog proposed that all these generation and modification functions be VOLTAGE CONTROLLED. He then designed such circuitry - and the Voltage Controlled Music era had begun.

Voltage control implies that the oscillator frequencies land/or harmonic structure), the gains of mixer/amplifiers and the cut-off timbral-determining frequencies of filters could all be changed by a control voltage. It need not be a constant voltage, indeed one oscillator could control another's frequency which in turn could control another, and so on. The complexity of sounds generated defy classical description, some of them are subjectively very pleasant, some are not, but they all are creative. Conventional sounds that can be specified in terms of amplitude, frequency and timbre can now be artificially produced and, if desirable, the specifications can be changed to "improve" the basic effect.

It was indeed fortunate that much research had been previously conducted into the structure of conventional instrumental sounds and consequently musicians such as Walter Carlos (responsible for the recording "Switched on Bach") were able to speedily demonstrate the versatility of the voltage controlled synthesizer and thus ensure its widespread acceptance.

#### **DESIGN PHILOSOPHY**

The International Voltage Controlled Synthesizer has been developed as a

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Commercial manufacturing organisations should clearly understand that such copyright extends to all plans, drawings, circuit diagrams, photographs etc. published by this magazine.

The act of manufacturing for sale or lease, any apparatus or device based on material published in this magazine is a breach of such copyright unless prior arrangements have been made with the Editor to under manufacture an licence of assignment or copyright,

Such an arrangement is currently being negotiated to enable assembled and tested International Music Synthesizers to be commercially available.

Full details of these completed units will be published as soon as full details are to hand.

Commercial organisations are also asked to note that certain aspects of this design are the subject of provisional patents. These are:—

Provisional Patent 3650, — method of generating sawtooth waveforms.

Provisional Patent 3651, — method of switching resistors in voltage controlled filters.

# INTERNATIONAL MUSIC SYNTHESIZERS

"state of the art" system. Extensive use has been made of digital techniques and CMOS has been used as the primary logic family.

No compromises have been made that would hinder expansion of the system to keep pace with the ingenuity or finances of its owner. The basic modules have been selected so that the unit will be just as suited to studio use as it is for a live "on-stage environment."

In the larger unit, a 484 point patchboard system is used to facilitate the rapid selection of various equipment configurations.

Separate headphone and main output level controls and switches are provided to ease on-stage cueing of the device.

All control voltages and generated waveforms have the same limits (zero and +5 volts), so that control and signal voltages are directly interchangeable.

The unit requires only a 240 volt ac supply (the synthesizer is not critically dependent on either the voltage or frequency of this supply), and an external power amplifier and speaker for normal operation. The headphone output will supply in excess of one watt. This is adequate to drive a small monitor speaker if an external amplifier is not available. Any do offset voltages inherent in the circuitry are nulled in the initial construction. The keyboard intervals are also tuned during initial construction and will not require readjustment unless the unit is unusually roughly handled.

# VOLTAGE CONTROLLED OSCILLATORS (VCO)

Four VCO's are provided in the 4600 unit, three in the 3600 unit. Each VCO is switchable to the output waveforms listed below:—

Sine, Triangular, Sawtooth, Reverse sawtooth, Pulse wave (including square-wave with variable mark-space ratio).

The fourth oscillator (provided in the larger unit) can provide two simultaneous outputs. In all oscillators, great care has been taken in the design to ensure purity of waveform.

Each oscillator covers the frequency spectrum 0.1 Hz to 10 kHz in eight ranges. There are LO, 32ft, 16ft, 8ft, 4ft, 2ft, 1ft and ½ft. The seven top ranges are tuned exactly one octave apart and the "LO" range is provided to generate sub-audio frequencies for special effects.

The oscillators are completely linear over the upper 10 octaves of their

range and several fed from the one control voltage will "track" accurately over the entire keyboard.

# CONTROLLER

The model 4600 has a Controller unit which provides an adjustable dc voltage and an ac coupled modulation level control.

In the model 3600 this facility is replaced by a Modulation unit which has the outputs of Oscillator 3, the transient generator and the noise generator available as modulation sources. Each function has a separate level control.

### THE KEYBOARD CONTROLLER

The keyboard is fully digital. Forty-eight separate voltages are generated as a four octave x 12 semitone matrix. These are normally adjusted to produce an equal tempered scale. The output voltages (and hence oscillator pitch) have negligible temperature dependence nor will they change significantly as the unit ages.

This method used for voltage generation is completely different from, and its performance superior to, all other keyboard controllers details previously which have been published. Most other keyboard controllers generate a linear pattern of voltages which are then converted to the required semitone values in an exponential converter, or by using an exponentially controlled oscillator. These exponential converters usually rely upon the characteristics of a transistor emitter base junction in which the temperature drift is substantial, resulting in the semitone interval having to be retuned every time the unit is played.

On the larger unit only, a fully variable "glide" (or "portamento") facility is provided, with a companion on/off switch. An "Absolute Pitch" control allows continuous transposition over several semitones.

The keyboard also generates a trigger output which goes from -7 to +7 volts whenever a key is pressed and returns to -7 volts when the key is released. A sample and hold circuit acts as a "memory" to maintain the control output voltage at the value of the last key pressed. (This enables the oscillators to maintain the last pitch selected until another key is pressed).

# **VOLTAGE CONTROLLED FILTERS**

Two VCFs are provided in the large unit and one in the smaller unit. They provide three separate filter characteristics: lowpass, bandpass and highpass. The cut-off slopes in all

modes are 40 dB decade, using easily reproduced two-pole active filters. The cutoff frequencies are a linear function of control voltage over a minimum range of 50 Hz to 5 kHz. Thus a filter and an oscillator fed from the keyboard (or, of course, any other control source) will track each other automatically. This also, is a feature not usually availabe in commercial equipment.

The filter characteristics do not change with a change in control voltage, that is, the Q factor is independent of frequency.

# **NOISE SOURCE**

This generator produces an almost purely Gaussian white noise. A digital shift register with feedback is used to generate a pseudo-random binary sequence 2<sup>18</sup> bits long (262 14% random points). Every second, about 30 000 are generated and these are integrated (filtered) to provide a random noise signal.

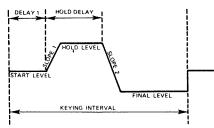
The spectral purity of this white noise is much better than those methods which use a Zener diode or noisy transistor as the source. In addition no component selection or tuning procedure is required.

# THE ENVELOPE GENERATOR

This module modifies the amplitude-time characteristic of a continuous input tone to give it "attack" and "decay" characteristics. A unique envelope is generated as shown in Fig. 1A.

All slopes are variable over a minimum range of five milliseconds to five seconds and the delay is adjustable from "off" — in which mode slope? initiated only when the keybo trigger goes to zero - to a maxim of approximately three seconds. This unique feature allows simulation of very fast attack-decay instruments (vibraphones, for example). envelope generator contains a voltage controlled amplifier that is switchable to either linear or square-law control characteristics. Provision is also made for an external trigger (other than that from the keyboard) to initiate the envelope.

Fig. 1A. Characteristics of envelope generator.



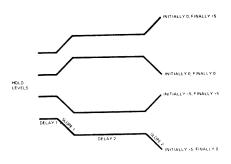


Fig. 2A.

# THE TRANSIENT GENERATOR

Two types of transient generator are used, type A and type B. Type A is rimarily used to modulate the eyboard output voltage, such that transients can be generated on oscillator and filter outputs during the formation of a single note. The International 3600 has only one transient generator which is of type A. The 4600 has two generators, one type A known as TRANSIENT 2, and one type B known as TRANSIENT 1.

The type B generator is basically similar to the envelope controller but does not include a voltage controlled amplifier. Hence its output is a dc waveform and not a modulated envelope as in the envelope generator. This unit may be used as an envelope control if required in conjunction with one of the ring modulators.

The type A transient generator is a unique feature, as an infinite variety of output functions are available.

When a trigger is received, nothing ppens until a preset delay (delay) nas elapsed. Slope is then initiated until the hold level is reached. Delay 2 is initiated on the completion of delay 1 after which Slope 2 begins and continues until the final preset level is reached.

For example if the following settings are made:—

are made.	
START LEVEL	0
DELAY 1	2
SLOPE 1	2
HOLD LEVEL	+5
HOLD DELAY	2
SLOPE 2	2
FINAL LEVEL	-2

then the keyboard output voltage when a key is pressed would be modified as shown in Fig. 2A.

Such an output would, when applied to an oscillator, cause it to commence the note in tune, raise it say one octave higher and then drop one octave lower. This frequency

modulation of the oscillator can create some very interesting and pleasing sounds. The number of semitones or octaves shifted up or down is uniform over the entire keyboard range, the plus or minus two design range octaves. Usually however this signal would be used to control a VCF (in the bandpass mode) being fed from a complex waveform (considerable harmonic content). Upon pressing a key the above waveform would cause the filter to commence at the timbre as selected by the VCF "tune" control, sweep up to the higher overtones and finish on the lower components.

Although this diagram may be ypical, the start hold and final levels may be varied as required.

This timbral change allows the simulation of instruments such as the piano as well as the generation of new sounds which are quite different to those from basic instruments.

# **AMPLIFIERS 1 AND 2**

These units are fitted to the International 4600 only and are in effect voltage controlled amplifiers which serve a dual function as selected by a mode switch.

When the "Ring modulator" mode is selected the unit effectively multiplies the two input functions. Thus if either is zero, the output is zero. If one input is a dc control voltage varying between zero and +5 volts then the output will consist of the other input function with an amplitude linearly controlled by the dc control voltage.

The other mode merely ac couples the input and in this mode the unit may be used as a general purpose amplifier.

#### **MIXERS**

Five mixers are used in the 4600, all are direct coupled and hence may be used for control voltages or signals.

Mixers 1 to 3 are used solely for mixing the outputs of oscillators 1 to 4 and there is no access to their inputs. Mixers 4 and 5 have two inputs each, their outputs however may be paralleled to provide one four-input mixer.

A special mixing arrangement is provided in the 3600. This will be described in detail in a later article.

# JOYSTICK CONTROL

A joystick is fitted to the model 4600. It is accessible via the patch board and may be used to control, for example, two oscillators simultaneously, but differentially.

# OUTPUT EQUALIZER AND VOLUME CONTROL

The output section is identical in the 3600 and 4600 with the exception that inputs are via the patchboard in the 4600 but are hardwired in the 3600.

All signals are passed through a five section equalizer. This signal is then mixed with the same signal after passing through a spring reverberation unit. The reverberation control acts allowing like a crossfader proportions of direct signal and reverberation to be controlled. The combined signal is then passed to an output amplifier and to a headphone amplifier each of which has an independent level control. A switch is provided to switch off output if required.

# **NEXT MONTH**

This series will continue next month when we will describe the construction of the keyboard, the oscillators, and the power supply.

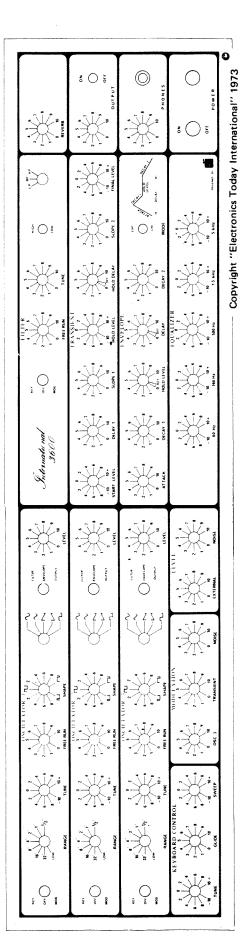
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# INTERNATIONAL MUSIC SYNTHESIZERS

# SPECIFICATION INTERNATIONAL 3600 SYNTHESIZER

2						
В	KEYBOARD			unit as source of control	Noise	controls level of noise to
	No of Keys	48 (F to E monophonic)		off position provided.		filter.
	Controls:		Range	provides 7 ranges from ½'	FILTER	
	Tuning	±2 semitones	1	to 32' plus low frequency (0.01 Hz)	Type	active, voltage controlled.
	Glide	adjustable rate 0 to 10 seconds		special effects source.	Inputs	mixed signals from oscillators
	Sweep	allows manual sweep, up or	Tune	tuning range of ± ½ octave		and level unit.
		down, from the keyed note	Free Run	internal voltage source which	Cut off Rate	24 dB/octave
		over any selected span.		manually adjusts oscillator over	Control Range	greater than 2 decades
	TO THE STREET			full range.	Controls:	
	MODULATION		Shape	varies mark/space ratio of square	Control Source	Keyboard, modulation or off
	Provides source of modulation for oscillators other than from	oscillators other than from		wave output.		(manual) by front panel switch
	the keyboard.		Waveform	selects sine, triangular,	Free Run	provides manual control of
-	Controls:			sawtooth, inverted sawtooth or		filter cutoff
	Oscillator 3	selects Osc. 3 as source		square wave as output.	Tune	tunes filter to control source
	Transient	selects transient generator as	Output Switch	routes signal to filter	High/Low	selects tuning range.
		source.		envelope or direct to output	Mode switch	selects high pass, band
	Noise	Selects output of internal		stage.		pass or low pass filter
		white noise generator as	Output Level	adjusts output level		characteristic.
		source.	LEVEL		ENVELOPE	
			Provides control of noise and	rovides control of noise and exteral input signals to input of	(see specification of model 4600)	(C)
	OSCILLATORS		the filter mixer		Input	direct from keyboard
	Number	က	Controls:		Output	to modulation level control
	Controls:		External	varies level of external signal	EQUALIZER, REVERBERATIV	EQUALIZER, REVERBERATION, OUTPUT and PHONES same
	Input	selects keyboard or modulation		from 50 mV to 2 V	as model 4600.	



# XERS 1, 2 and 3 outs SPECIFICATION INTERNATIONAL 4600 SYNTHESIZER KEYBOARD Number of K Outputs to P Trigger

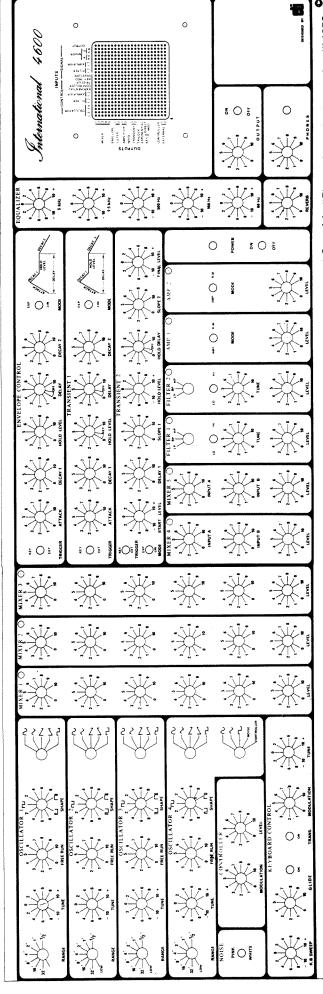
	SPECIFICAL ION IN CHIMAL POSS STREET	
KEYBOARD		MIXERS 1, 2 a
Number of Keys	48 (F to E monophonic)	Inputs
Outputs to Patchboard		
Trigger	-7 V to +7 transition at each	
3	key press. Trigger is inhibited if	Level control
	more than one key is pressed.	
Analogue (direct)	0 to + 5 volt	Overload
Analogue (modulated)	9 to + 15 volts	Output
Inputs	transient generator No 2	
•	patchboard.	
Controls:		
Sweep	allows manual sweep, up or down	MIXERS 4 and
	from the keyed note over any	vuts
	selected span.	it levels
Glide	adjustable rate 0-10 seconds	out level
	switchable.	.put

<b>4</b> 5	5 (one from each oscillator output)	ač l
	each with independant level	E 7
	controls.	Ē
	mixer.	F
	Indicated by LED lamp.	F
	to patchboard.	ت
		۵
•		₩:
	two each from patchboard	Ì
-	individually adjustable	
`	adjustable with overload india	Ċ
	to patchboard.	)

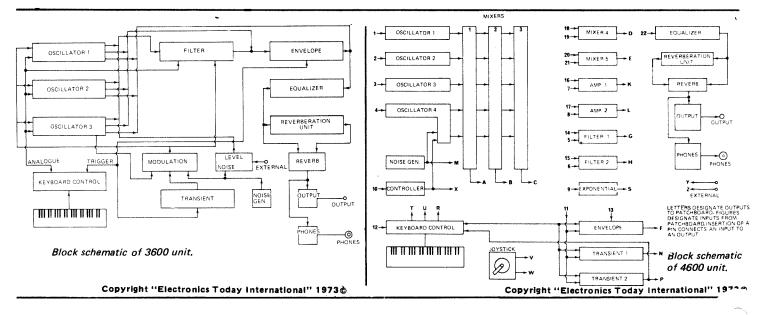
KERS 4 and 5

**TRANSIENT 1** 

Transient	selects direct modulation of keyboard by transient	FILTERS 1 and 2 (Ype	active, voltage controlled	EXPONENTIAL CONVERTER Input	0 to +5 volt from patchboard.
Modulation	generator No. 2. allows patchboard input to	Inputs	0-5 volt signal from patchboard 0-5 volt control from patchboard	Output 0 to + 5 converts linear input to exponential output.	0 to + 5 volt to patchboard. ial output.
	of $\pm 2$ octaves. tunes keyboard $\pm 2$ semitones.	Mode High/low	selects high pass, bandpass or lowpass filter characteristics	JOY STICK 2-axis control of any two functions linear or exponential	ns linear or exponential
OSCILLATORS Number	4 (oscillator 4 has dual output)	Tune	tunes filter to control source.	output as required 0 to + 5 V.	<u>.</u>
Controls: Range	provides seven ranges from ½' to 32' plus low frequency (0.01 Hz)	Cutoff Rate Control Range	overload indication. 24 dB/octave 2 decades	EXTERNAL SIGNALS Number of Inputs Input Impedance	2 signals 50 mV to 2 V 10 k ohms.
Tune Free Run	special effects source, tuning range of $\pm\%$ octave internal voltage source manually	AMPLIFIERS 1 and 2 Type	voltage controlled, ac or dc	OUTPUT EQUALIZER	
o Cert	adjusts oscillator over full range. varies mark/space ratio of	Input Signal Input Control	coupled via patchboard (0 to + 5 volts) via patchboard (0 to + 5 volts)	Number of Stages Centre Frequencies	5 60 Hz, 160 Hz, 500 Hz, 1.5 kHz.
Waveform	square wave output. selects sine, triangular sawtooth, inverted sawtooth	Mode Mod	dc coupled functions as voltage controlled amp	Type Range of Adjustment	Active filter > ±10 dB.
	or square wave as output second output of oscillator 4 provides noise or controller output.	Amp Output	ac coupled function as ring modulator to patchboard level controlled and with overload indication.	REVERBERATION UNIT Type Output	multi-spring adjustable mix-fader 
NOISE provides pink or white noise d	NOISE provides pink or white noise direct to the patchboard. Noise	ENVELOPE Input Trigger	from patchboard or keyboard		sound without reverb.
is also selectable by oscillator 4, second output.  CONTROLLER from patch Input to patchbox	4, second output. from patchboard to patchboard to patchboard	Attack Decay 1 and Decay 2. Hold Level Delay	all adjustable from 5 msec to 5 sec. adjustable 0-5 volts. adjustable 5 msec to 5 sec, or adjustable 5 msec to 5 sec, or duration of key contact closure	PHONE OUTPUT Power Output Load Impedance Output Level	TK1 1 watt 8 ohms control provided.
Controls: Level	switch of oscillator 4. sets do level, that is, centre frequency of controlled oscillator.	Control Mode	as selected. inear or exponential voltage controlled amplifier with	SIGNAL OUTPUT Level Load Impedance	0 to 1 volt RMS 1 k ohm Jevel control provided
Modulation	controls level of modulation	Output	to patchboard.		together with on/off switch.



# INTERNATIONAL MUSIC SYNTHESIZERS



# THE PERCEPTION OF SOUND

#### Loudness

The most basic characteristic of a sound is its loudness. The apparent loudness of a sound is a function of its intensity, or level, but there are three main factors which affect our perception of that intensity.

The first factor is that of the response characteristics of the ear. Our hearing can accommodate a huge range of sound intensity, but our perception of that intensity is not linear but logarithmic. To double the apparent loudness of a source, its intensity must be increased at least eight times. This is the reason for the use of exponential converters in the synthesizer, they are there to change a *linear* signal change to a *subjectively linear* (logarithmic) signal change.

The second factor is the *frequency — dependent* sensitivity of our hearing mechanism. This is expressed graphically in the well-known Fletcher-Munson equal loudness level contours (Fig. 1)

These show that as the intensity of a sound is reduced there is a considerable reduction in hearing sensitivity in the bass region relative to that in the midrange.

This phenomenon accounts for the difference in apparent loudness between (say) a 200 Hz sine wave and a 200 Hz sawtooth wave. The sawtooth wave contains high harmonic content and although its

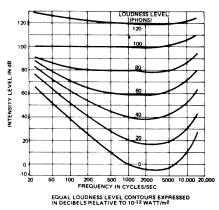


Fig. 1. **Equa**l loudness contours (Fletcher-Munson)

overtones are not the same intensity as the fundamental, our hearing is more sensitive to them. As the effective loudness of a complex sound is dependent on the algebraic sum of the loudnesses of each component of that sound, we hear the sawtooth as being much "louder" than the sine wave, although their amplitudes may be identical.

The third factor affecting perceived loudness is the duration of the sound. It takes a finite time for our hearing to react to the presence of a sound and to analyse its characteristics.

Sounds which are very short in duration (.01 seconds, or 10 milliseconds) are perceived as being of lower loudness than they actually are (in addition very little pitch information is gathered from such a short burst of sound). Further, when the ears have become conditioned to the presence of a sound there is a gradual drop in apparent loudness.

When we synthesize very short attack transients we must allow for this lack of sensitivity and this means a much larger overshoot is required than would otherwise seem necessary.

Absolute Pitch Although perception of pitch is not precisely logarithmic, an exponential characteristic comes fairly close to producing equal subjective pitch change from a linear input. (Fig. 3.).

Musical Pitch Two tones whose frequencies differ by a factor of 2 are said to be *one octave apart*. This octave is usually divided into twelve increments, known as semitones which differ from each other by

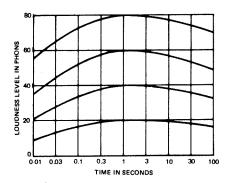


Fig. 2. Relation between loudness level and duration

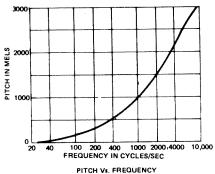


Fig. 3.



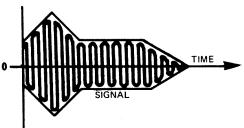


Fig. 4 The 'envelope' of a sound is the variation of its intensity with time.

a factor of the twelth root of 2 (12 $\sqrt{\approx}1.059463$ ).

Such a musical scale is termed "equal-tempered" and is used for all keyboard instruments. There are also several so called "just" or "true" scales that are based on harmonic structure. A musical textbook should be consulted if further information on these scales is required.

All previous voltage controlled synthesizer designs have been able to obtain "equal tempered" intervals only. The digital keyboard incorporates in both the

synthesizers described in this series can be adjusted to these "just" scales, this should only be considered by a competent musician and is generally unnecessary. Frequencies of the fundamental tones of each semitone in the effective musical scale are shown in Table 1

Envelope The envelope of a sound is the variation of its intensity with time as shown in Fig. 4. The rate of variation of the envelope is very slow compared with the time variation of the sound itself (sine wave shown in Fig. 4 is the base sound.) Although the envelope is symmetrical about zero it is usually referred to in terms of the modulus.

Timbre The timbre of a musical sound is the characteristic that makes it possible to distinguish between two tones having the same intensity and fundamental frequency, but different waveforms. It expresses our ability to recognize the sound of a violin as different from that of a trumpet, even though the two instruments may be playing with the same pitch and loudness.

To describe analytically the timbre of a sound we must specify the frequencies of all the constituent components (termed "Partials") of that sound and their respective envelopes. (This group of envelopes is referred to as the 'Complex Envelope' of a sound).

The partials may not necessarily be harmonic, indeed many natural sounds have partials which are inharmonic. For example, the frequency of the fifteenth overtone of middle C on a piano, is greater than sixteen times the fundamental frequency (middle C).

With an electronically generated waveform, however, the overtones are direct multiples of the fundamental, and so a miscellany of different oscillators must often be used when attempting to simulate the sound of a "natural instrument".

TABLE 1

#### THE TEMPERED SCALE

	OCT 1	OCT 2	ост з	OCT 4	OCT 5	ОСТ 6	OCT 7	OCT 8	ОСТ 9	OCT 10
F	21.8	43.7	87.3	174.6	349.2	698.5	1396.9	2793.8	5587.7	11175.3
F#	23.1	46.2	92.5	185	370	740	1480	2960	5920	11839.8
G	24.5	49	98	196	392	784	1568	3136	6272	12543.9
G#	26.0	51.9	103.8	207.7	415.3	830.6	1661.2	3322.4	6645	13289.8
Α	27.5	55	110	220	440	880	1760	3520	7040	14080
Α#	29.1	58.3	116.5	233.1	466.2	932.3	1864.7	3729.3	7458.6	14917.2
В	30.9	61.7	123.5	246.9	493.9	987.8	1975.5	3951.1	7902.1	15604.3
С	32.7	65.4	130.8	261.6	523.3	1046.5	2093	4186	8372	16744
c#	34.6	69.3	138.6	277.2	554.4	1108.7	2217.5	4435	8869.8	17739.7
D	36.7	73.4	146.8	293.7	587.3	1174.7	2349.3	4698.6	9397.3	18794.5
D#	38.9	77.8	155.6	311.1	622.3	1244.5	2489.7	4978	9956.1	19912.1
E	41.2	82.4	164.8	329.6	659.3	1318.5	2637	5274	10548.1	21096.2
32 <sup>1</sup> 16 <sup>1</sup> 8 <sup>1</sup> 4 <sup>1</sup> 2 <sup>1</sup> 1 <sup>1</sup>	Half tone factor is 12th root of 2 approximately 1.05946309 scale is based on A – 440 Hz  KEYBOARD COVERAGE OF SYNTHESIZER									