SPECIAL SUPPLEMENT

Sound Synthesis

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THIS is an introduction to sound synthesis and synthesisers for beginners and presents the basics necessary to quickly understand and use synthesisers.

THE CASE FOR AND AGAINST SYNTHESISERS

In the two creative areas of synthesis, namely music and sound effects, synthesisers are often used to provide imitations of things not readily to hand. For example if you require a tape of a "seascape", live in Birmingham, don't have the right BBC sound effects record and are in a hurry, then it is very easy to knock up quite convincing surf and seagull sounds on a synthesiser. Other examples that come to mind are aeroplanes, motorbikes, horns, sirens, bells, dawn choruses, crickets and various other animals, wind, rain, running water, explosions, etc. On the other hand, while it is quite possible to synthesise the sound of two dustbin lids being banged together, unless you are a synthesiser freak with lots of equipment, the time involved and complexity of the task may make it a rather pointless exercise especially when it is easier, cheaper and probably more fun to get two dustbin lids and simply bang them together!

On the musical front, synthesisers can frequently produce close copies of conventional instruments, and it is this latter facility that polarises peoples' attitudes to them quite markedly. There are those, generally non-musicians, who think it marvellous to play a keyboard and have it sound like a clarinet rather than sweat for several years over a real clarinet. Then there are those, generally musicians, who feel that synthesisers shouldn't be allowed, because they can become a ticket for persons lacking any real ability to cheat their way into the domain of real musicians. Arguments rage interminably but I do not wish to dwell overmuch on this, except to say that as with any creative activity the question should not concern whether synthesisers are being used, but rather *how* they are used.

Even accomplished musicians are often grateful for the imitative capacity of synthesisers when they wish to add a particular instrument's sound to a piece of music, but have neither the instrument to hand or anyone to play it. For example, have you tried getting your hands on a fairground engine? In live work, many bands use synthsisers to provide a wide variety of voices where it would be impractical to actually use all the appropriate instruments.

This aside, the real potential of synthsisers lies not in their capacity to sound like conventional instruments, but in creating unique voices that cannot be achieved by conventional means, which can then be used to complement the more traditional instruments. Many fine examples of this have been produced in recent years.

MONOPHONIC KEYBOARDS

Before we get down to the nitty-gritty, one popular misconception about synthesisers must be cleared up. This is that just because they tend to have keyboards and look like pianos or organs, they should be expected to operate like pianos or organs in that more than one note may be played at a time. They do not. Most synthesisers costing up to several hundred pounds are monophonic, that is only one key may be pressed at a time. In this respect they are more akin to wind instruments, and the keyboard is there merely as a convenience to operating them. In general if more than one key is pressed then either the highest, or the most recent, note selected will sound.

FROM MECHANICS TO ELECTRONICS

All sounds are of course vibrations carried in the air, and all vibrations originate in an oscillator of some sort. In conventional instruments, the oscillators are vibrating strings, reeds or diaphragms which are variously excited by bowing, plucking, hitting or having air blown over them. The vibrations are amplified and transferred to the air by the body of the instrument, witness old fashioned needle and horn gramophones. In this respect the instrument body acts as a mechanical transformer, converting the small, high energy vibrations of the oscillator into large, low energy vibrations of the surrounding air. The size, shape and mechanical properties of the body of the instrument also has a dramatic effect on the character of the sound. Metal or wooden tubes or boxes act as mechanical filters, removing certain harmonics and emphasising others. The way in which the oscillator is excited (blowing, hitting, plucking, bowing, etc.) also determines the sound character. These processes are all entirely mechanical.

In the middle ground we have the electric instruments, most notably the electric guitar. Here although the oscillators are still vibrating strings, very little mechanical sound is produced, the vibrations being detected by coils, amplified electronically and reproduced through loudspeakers. The analogy here is that of a modern record player, which electronically amplifies the vibrations of a stylus, but the sound originates in the record grooves and not in the electronics. Having said that, just as a record player has tone controls, the electronics used to amplify electric guitars generally permits the character of the sound to be changed. Often a whole array of electronics is employed to change the sound quality dramatically, the best known being the use of an overdrive or fuzz unit to generate new harmonics, followed by various electronic filters to modify the resulting harmonic spectrum, such as waa-waa pedals, flangers, and the like. Here we are getting into the realms of sound synthesisers: since the body of the instrument is solid to avoid damping the vibrations of the strings (that is, to give good sustain) and so contributes virtually nothing to the sound character, most of what is heard is arguably due to the electronics. The strings remain as a means of selecting groups of notes, bending the pitch, introducing vibrato, and so on. Whether the strings are plucked or bowed (as in electric violins) still affects the sound character.

Purely electronic instruments go the whole way and replace the mechanical oscillators as well. The oscillators are now electronic circuits generating fluctuating (a.c.) voltages. The resulting waveforms may be similar, but unlike their mechanical counterparts they oscillate continuously as long as the power is switched on.

VOLTAGE CONTROLLED OSCILLATORS

The oscillators used in synthesisers generate five basic waveforms (Fig. 1 a-e) at a frequency (pitch) set by the d.c. voltage applied to their voltage control inputs. With mechanical oscillators, the waveform is a picture or graph of how the string or diaphragm moves with respect to time, while the waveform from electronic oscillators is a picture of how the output voltage changes with time, and the shape is inherent in the design of the circuit. These pictures are all very well, but what do they sound like? The first one, the sinusoid, is a pure tone, that is, only one frequency is present and no harmonics. It sounds very bland or flat, and is also rather irritating to listen to on its own. The other waveforms all sound different (and more interesting) but to understand why we must digress and examine what we mean by the harmonic structure of a sound.

HARMONIC SPECTRA

Imagine that we have the sine wave of Fig. 1a, and we add another, smaller sine wave to it at three times the frequency (Fig. 2a). Quite a different waveform is produced. Now let us add another sine wave, smaller still, to the resulting waveform at five times the frequency of the first sine wave (Fig 2b). Already the resultant waveform is beginning to look more like the square wave of Fig. 1d. In fact this process need only be continued a little further to produce a very good square wave.

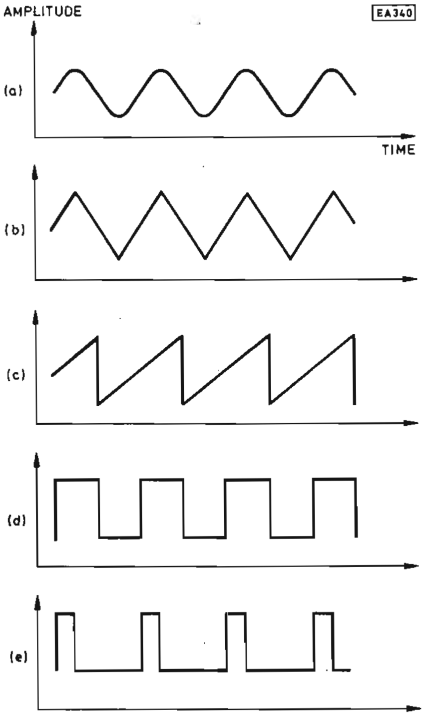


Fig. 1 Showing the five oscillator waveforms

(a) Sine

(b) Triangle

(c) Ramp

(d) Square

(e) Pulse

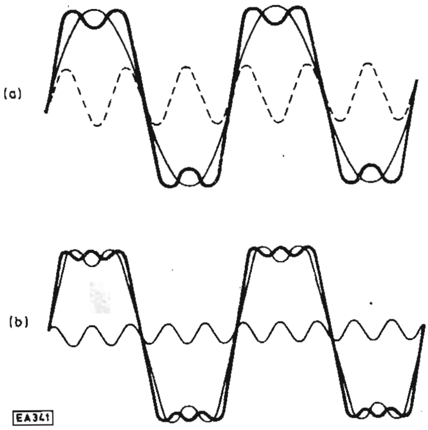


Fig. 2 Showing how the progressive compounding of the constituent sine waves go to make a square wave
(a) Sine wave with a reduced amplitude component at three times fundamental
(b) Sine wave with a reduced amplitude component at five times fundamental

Now then, if adding lots of pure tones together in this manner can create a square wave, then it follows that a square wave sounds like a mixture of pure tones. In fact it consists of a pure tone called the fundamental which is at the same frequency as the square wave, plus another one third as big at three times this frequency, another pure tone one fifth the size of the fundamental at five times the frequency and so on. This can be represented graphically as in Fig. 3, where each sine wave is represented by a vertical line. The hortizontal position of each line denotes its frequency while the heights denote the relative contributions to the overall sound. A diagram of this sort is called a frequency spectrum, and gives a visual representation of what a particular waveform sounds like. Now we can go back and look at our oscillator waveforms. Fig. 4a-e shows the waveforms and their spectra.

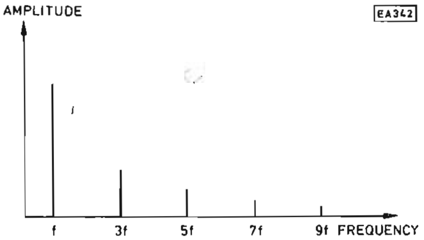


Fig. 3 Frequency spectrum for a square wave

The sine wave as we have said, sounds pure (because it is) and bland. The square wave contains odd harmonics which are odd whole-number multiples of the fundamental frequency, and has a rich, fruity sound. The triangle also contains odd harmonics but a much smaller proportion so it sounds more like a pure sine wave, but warmer. The ramp, or sawtooth, contains both odd and even harmonics and so is an even richer sound than the square wave, but one that is harsh and rasping. The rectangular waveform has a greater proportion of higher frequency harmonics. It is also a rasping sort of sound but rather thinner than that of the sawtooth.

Now we can compare these with some typical spectra of conventional instruments, whose sound we are familiar with (Fig. 5a-c). Notice that the waveforms give little clue as to the character of the sound, but analysis of their frequency spectra reveals the harmonic structure which underlies these widely differing sounds. Bear in mind that these are spectra of continuous tones—the harmonic content also changes with volume and the way instruments are played generally.

Frequency analysis of time dependent waveforms is a fairly advanced branch of mathematics known as Fourier analysis. Simple oscillator waveforms such as those of Fig. 4 are easy enough to analyse if you have studied mathematics to university degree level but sorting out more complex waveforms requires sophisticated computer programs. But don't worry, no one has to know the first thing about mathematics in order to use synthesisers! The reason is that your ears and brain perform Fourier analysis for you every time you listen to a given sound. Not mathematically, but by sensing the relative volumes in many different frequency ranges. It should be no surprise that this sort of spectrum analysis can also be carried out electronically.

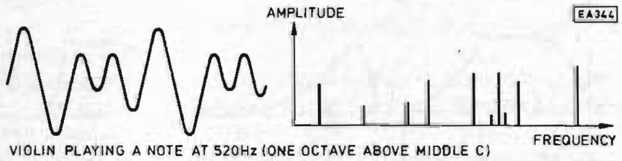
Next we must look at how the spectra from our electronic oscillators can be modified so as to change the character of the sounds they create, but before we move on there is one other important source of sound used in synthesis, and this is called "white noise".

Just as white light can be split into all the colours of the rainbow using a prism, white noise consists of a mixture of equal sized sine waves of every conceivable frequency. It sounds like a high pressure jet of steam, or blast of wind, or tumultuous applause (minus the cheering). White noise is the one case where the time dependent waveform looks like the frequency spectrum and vice versa (Fig. 6).

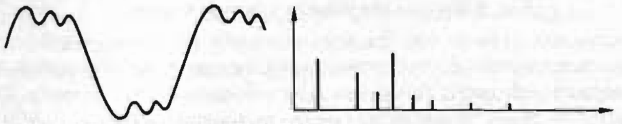
VOLTAGE CONTROLLED FILTERS

A filter, as you might expect, lets some frequencies through but not others. There are four basic types (Fig. 7a-d) and all are characterised by a particular frequency called the roll-off (sometimes cut-off) frequency, beyond which remaining frequencies are increasingly attenuated. The low-pass filter (Fig. 7a) lets through frequencies lower than the cut-off frequency but removes higher frequencies, while the high-pass version (Fig. 7b) does exactly the opposite. Band-pass filters only allow frequencies through which are close to the centre frequency and notch-filters have the inverse response. The rate at which frequencies beyond the cut-off frequency are attenuated is referred to as the slope or roll-off.

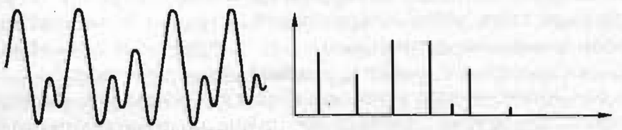
Introducing some positive feedback into the filter increases the gain in the region of the cut-off frequency (or centre frequency) and produces a peak in the frequency spectrum as shown in Fig. 7a-c. It can be seen that making this peak bigger also has the effect of increasing the slope. The two other types of basic filter are shown in Fig. 7e-f. These are multiple notch and multiple band-pass respectively.



VIOLIN PLAYING A NOTE AT 520Hz (ONE OCTAVE ABOVE MIDDLE C)



MOUTH ORGAN AT 220Hz (A BELOW MIDDLE C)



TRUMPHET PLAYING MIDDLE C (260Hz)

Fig. 5 Waveforms and spectra of (a) Violin note of 520Hz (b) Mouth organ at 220Hz (c) Trumpet at 260Hz

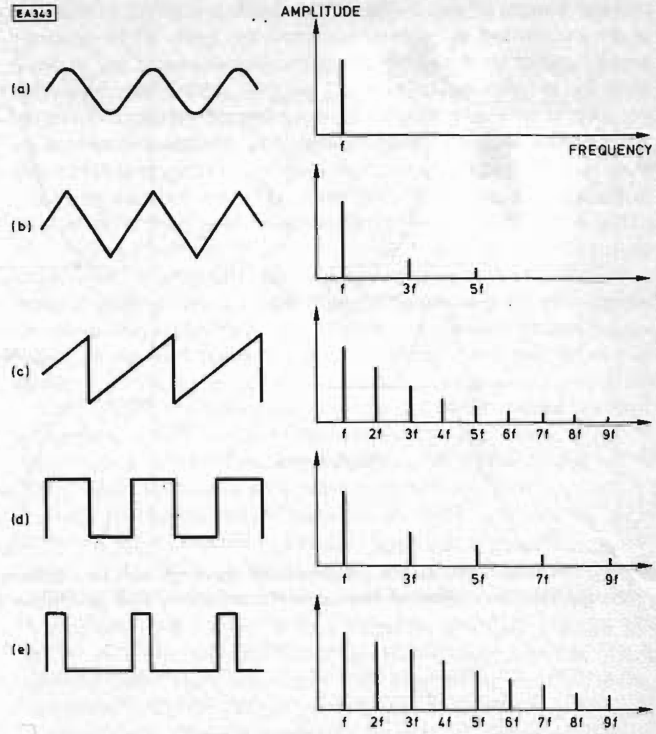


Fig. 4 Oscillator waveforms with spectra

In the case of VCFs (the sort used in synthesisers), the roll-off frequency is movable and where it is depends on the d.c. voltage applied to the VCF control voltage input. As with VCOs, the frequency can usually be varied manually or automatically by a voltage from another part of the synthesiser. Generally the degree of feedback, that is the size of the resonant peak is manually variable, though in more sophisticated synthesisers this function may also be voltage controlled. Either way, the function is variously referred to as "feedback", "resonance", "slope", or "Q".

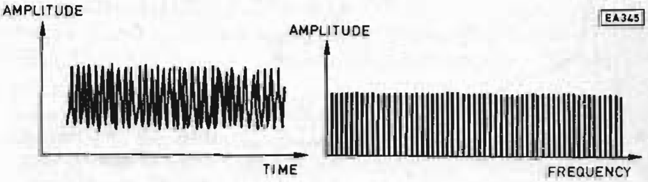


Fig. 6 Noise waveform and spectrum

ENVELOPES

We can, by using different waveforms, adding them together, and filtering, create virtually any sound spectrum we like, and change it around at will using voltage controlled devices. But so far we have been talking about continuous sounds. Some sounds of course, such as the sea, the hubbub of a city, politicians talking, etc are continuous, but joking aside, almost all sounds whether from instruments or the environment have one thing in common. They start and they stop. And in between they may fluctuate in volume (and also harmonic content). The graph of volume versus time is called the envelope of a sound, and some typical envelopes for various instruments are shown in Fig. 8a-d. Strings for example, when struck or plucked have a very sharp peak at the start of the note, after which the volume dies away much more slowly. A bowed string gives a more gradual increase in volume, but stops vibrating fairly abruptly when the bow stops moving. Removing the bow in a smooth continuous motion would of course leave the strings vibrating though

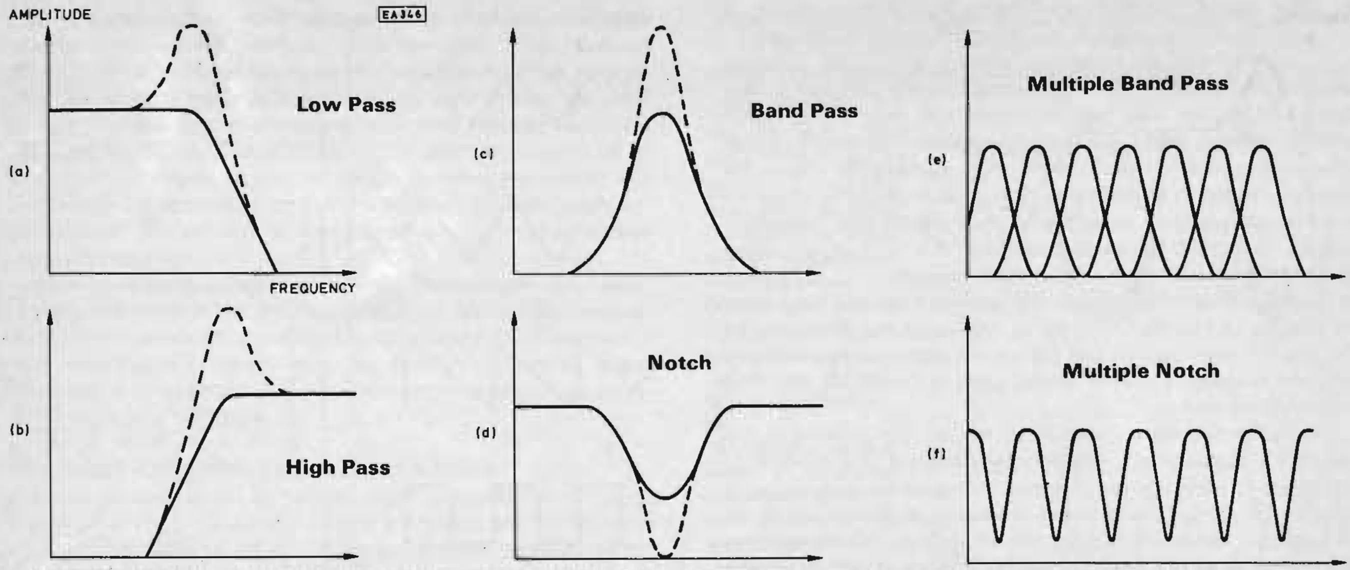


Fig. 7 A filter lets some frequencies through but not others. Introducing some positive feedback into the filter increases the gain in the region of the cut-off frequency and produces a peak as seen in Figs. 7 (a–c).

less fiercely and the reduced sound would then die away slowly like the plucked string. Wind instruments vary quite widely in their envelopes, but generally start more slowly than plucked strings, and die away rapidly. Organs, whether pipe or electronic both start and stop abruptly. Pipe organs often appear to die away slowly, but this is due to reverberation time of the room they are in. In other words although the direct sound from the pipes stops suddenly at the end of each note, the quieter residue of the sound already in the air reflects around the room for some time, gradually diminishing. Reverberation can also be created electronically using delay lines, either electro-mechanical or solid state, through which the sound signal is repeatedly passed.

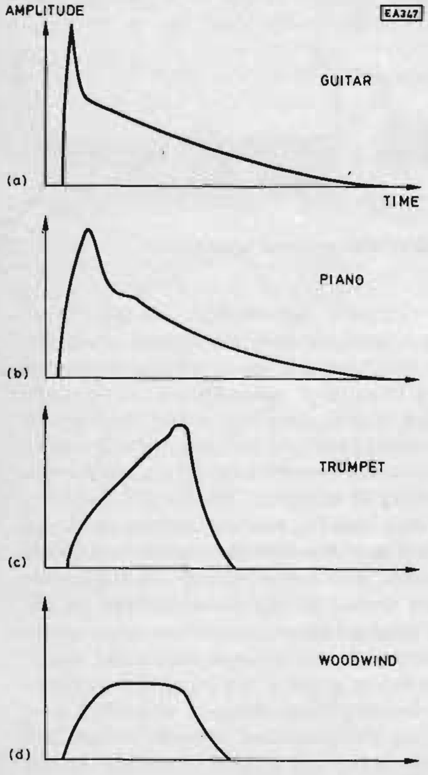


Fig. 8 Showing typical instrument sound envelopes. The guitar and piano have quite sharp peaks at the start of the note after which the volume dies away slowly

The trumpet and woodwind instruments start more slowly than strings but die away rapidly

VCAs AND ENVELOPES SHAPERS

Voltage controlled amplifiers vary the sound level coming out of the synthesiser from zero to maximum, depending once again on the d.c. voltage applied to their voltage control inputs.

Envelopes shapers generate, on demand, a changing voltage reproducing the shapes of Fig. 8, the actual shapes being set by the controls on the envelope shaper (manually, or in sophisticated machines, also by voltage control).

The simplest sort are known as "Attack-Sustain-Release" (or "A-R" for short) and operate as follows. When triggered, for example by pressing a key on the keyboard, the output voltage rises from zero at a rate set by the "Attack" control until it reaches maximum (or the key is released). The output remains at maximum for as long as the key is depressed and then when the key is released the output voltage falls back to zero at a rate set by the "Release" control. Varying the attack and release times as well as the key depression time enables a continuous variety of envelope shapes to be produced (Fig. 9). Comparing these with Fig. 8 shows that

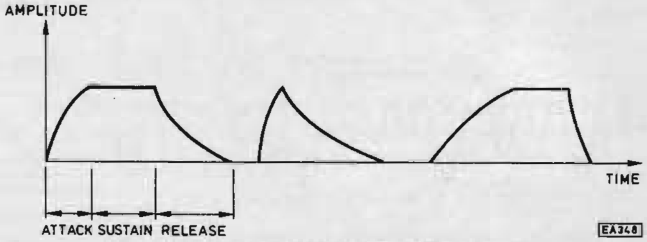


Fig. 9 Simple electronic envelope shapes

many instruments may be approximated with an A-R shaper, but not the more percussive instruments (meaning guitars, harpsichords, etc., as well as more obvious forms of percussion). A more versatile envelope shaper in common use is known as an A-D-S-R, "Attack-Decay-Sustain-Release", which gives full control over the parameters shown in Fig. 10. Even more complex envelope shapers are found on the most expensive synthesisers, but simple envelopes can always be added together to produce elaborate shapes.

For added realism envelope shapers are usually provided with a "single-shot" mode of operation, where one complete cycle is produced each time a key is pressed. To get another one the key must be re-pressed, corresponding to pianos, guitars, etc.

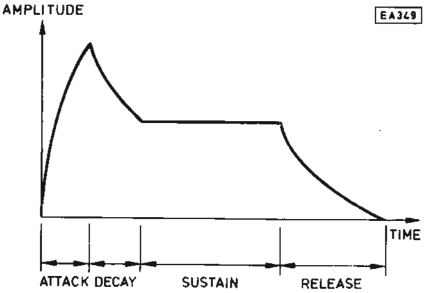


Fig. 10 More complex envelope shape

Note that the voltage output shape from an envelope shaper is also referred to as a waveform, but should not be confused with "audio waveforms" from oscillators. Audio waveforms fluctuate at audible frequencies, namely from about 10Hz to 10kHz (that is tens, hundreds or thousands of times per second), while envelope voltages change far more slowly, sometimes taking as much as several seconds to complete one cycle.

DYNAMIC FILTERING

As was hinted earlier, another feature characterising a particular instrument's "voice" is that not only does the volume of the sound change with time, but the harmonic structure of the sound can also change within the duration of each note. The sound of a trumpet, for example, becomes richer in harmonics as it gets louder. A plucked string is characterised by a burst of harmonics at the start, but decays to a pure tone as the sound dies away.

Now here voltage control really comes into its own. Not only can the envelope voltage be used to control the volume of the sound, but it can also be fed into the filter to vary the harmonic structure with time. This can either be the same envelope which is controlling the VCA so that the harmonic structure is related to the volume of the sound, or a different envelope from another envelope shaper, so that the changes in sound quality are unrelated to changes in volume.

The most obvious example of dynamic filtering is that of using the envelope to sweep the resonant peak of a filter through the harmonics of the sound, producing a waa-waa effect as notes are played. The next most obvious thing to do is to turn the envelope upside down for an inverted waa-waa, and most synthesisers generate both positive and negative envelopes for this reason — the possibilities become endless.

So far we have seen the four basic elements used in sound synthesis, namely:

VCO	Generates various audio waveforms at a pitch proportional to the applied control voltage (generally in the range 10Hz to 10kHz).
VCF	Modifies the harmonic content of oscillator spectra or white noise spectrum, depending on the applied control voltage, the type of filter and the degree of resonance.
Envelope	Generates a cycle of relatively slowly changing voltage on demand, for modulating the voltage controlled devices.
VCA	Modifies the sound level according to the control voltage applied from the envelope shaper.

Now let's put a synthesiser together. The most basic set up is shown in Fig. 11. One thing that has not been mentioned until now is the keyboard. Clearly something has to provide the control voltages for the VCOs, and for a harmonic spectrum to remain constant regardless of the VCO pitch, this same voltage must also be used to control the cut-off frequency of the VCF. VCOs and VCFs are generally adjusted so that they all track each other, that is, the same change in control voltage produces the same change of frequency in all the voltage controlled units. This control voltage is often derived from a chain of resistors in the keyboard, but it need not be. Guitar synthesisers convert the pitch of the notes played on a guitar into a control voltage in order to control the VCOs and VCFs, so that the synthesiser tracks (accompanies) the guitarist.

Drum synthesisers have neither, but use the envelope shaper or other oscillators to control VCO pitch, resulting in the strange noises commonly heard in disco and reggae music. The envelope shapers are triggered either by hitting a special pad, or by a microphone placed next to an existing drum, while in the case of the guitar synthesiser, the trigger signal is derived from the amplitude of the signal from the guitar.

Guitar synthesisers then, provide accompaniment for solo guitarists, while drum synthesisers are generally used to augment a conventional drum kit, and so both are, as it were, dedicated, unlike keyboards synths.

Back to keyboard synthesisers; in order to play a musical scale on an electronic keyboard, the keyboard voltage must cause the VCOs (and VCFs) to double in frequency as ascending octaves are played. In other words a linear change in voltage from the keyboard must be converted into an exponential (or as people will insist on calling it, a "logarithmic") change in voltage in order to control the VCOs. This may either be done in the keyboard itself and multiplied up and down in the VCOs, or alternatively the conversion may be carried out independently in each VCO and VCF. The new generation of digitally controlled synthesisers generate the exponential numerically in digital circuits, but however the musical scale is produced, the basic idea is the same.

PORTAMENTO

A simple circuit determines the rate at which the keyboard voltage may change. Thus instead of jumping from one note to the next, a control is provided to enable the VCOs to glide smoothly between pitches.

LOW FREQUENCY OSCILLATORS

These produce similar waveforms to the VCOs, but are not intended to be heard, rather to produce control voltages for other devices. The output frequency is variable from about twenty cycles per second down to one cycle every ten seconds or so, and may be either manually or voltage controlled. The size of the output voltage is variable between zero and maximum.

LFOs have numerous applications. For example, feeding a small amplitude sine or triangle wave at a frequency of a few Hz into a VCO generates a vibrato, while feeding the same thing into a VCA gives tremolo. Feeding a slow, large amplitude triangle into a VCO will give a siren effect, while the same thing controlling a VCF filtering a white noise input can be used to create sea or wind effects, depending on the resonance setting of the VCF. A fast, descending ramp waveform fed into a VCO will give birdsong. A squarewave into a VCO will give a two-tone, police car effect.

A slow running LFO can also be used to repeatedly trigger an envelope shaper, for rhythmic effects. For example, fairly rapid envelope shaping of a VCO tone can be used to create mandolin type effects, while the same technique applied more slowly using white noise as the sound source can produce steam trains or marching feet and the like.

RING MODULATON

Thus far we have only considered adding waveforms together, which simply results in the harmonics of one

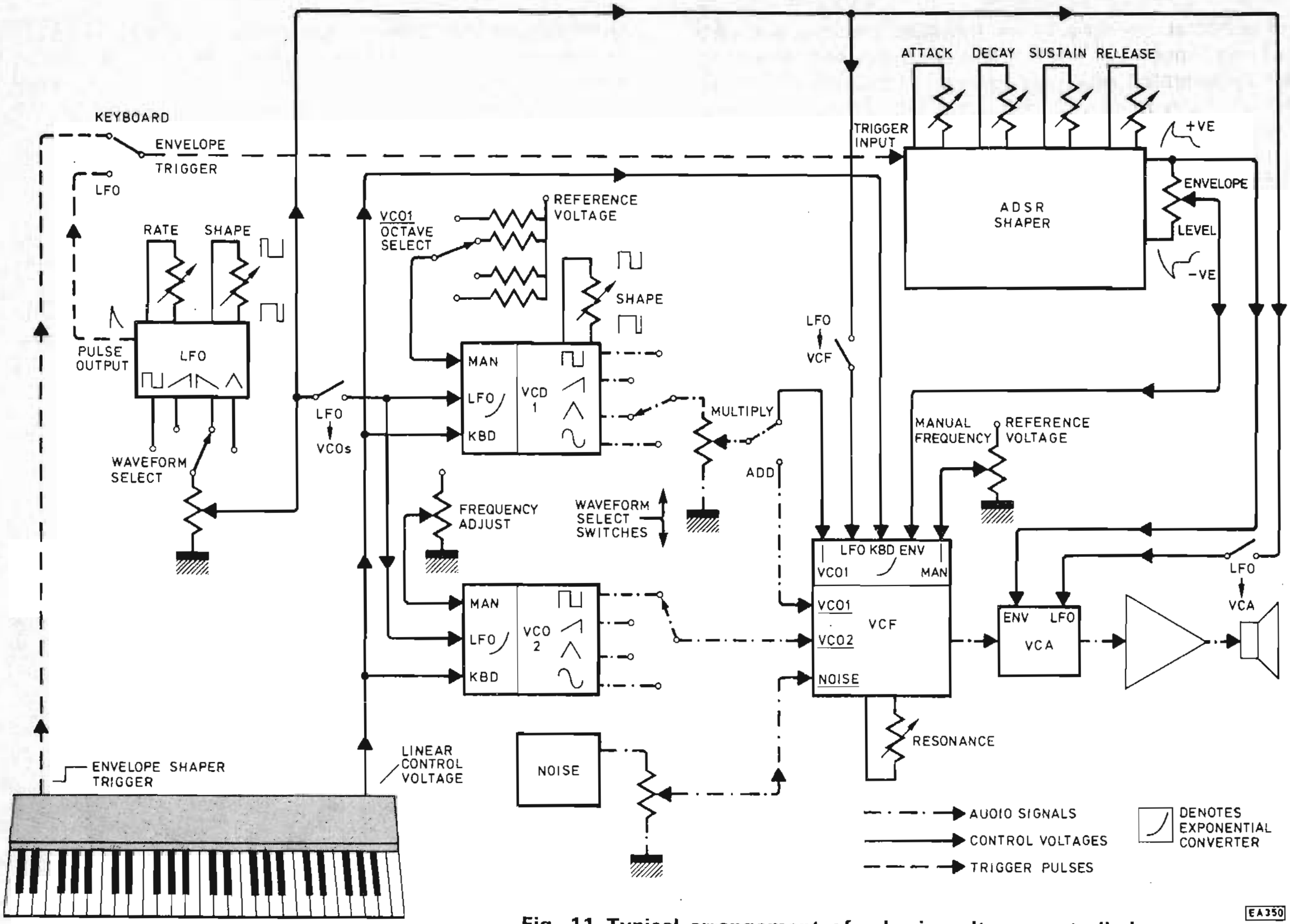


Fig. 11 Typical arrangement of a basic voltage controlled synthesiser

waveform being added to those of the other. Using the audio output of a VCO as a control voltage for a VCA which is determining the size of the signal from a second VCO, has the effect of multiplying the two waveforms together. This process generates entirely new harmonics. Taking the simplest case of two sine waves, frequencies A and B, basic trigonometry tells us that:

$$\cos A \times \cos B = \tfrac{1}{2}\cos(A+B) + \tfrac{1}{2}\cos(A-B)$$

so the resultant is two new sine waves, respectively the sum of and the difference between the two original frequencies. Multiplying other waveforms results in more complex spectra, and if the one frequency is not an integral multiple of the other, that is not in tune, then the harmonics generated are also no longer integral multiples of one another. This can be very useful, for example, close inspection of Fig. 5a reveals that the harmonics of a violin are not integral multiples of the fundamental. This arises from the "stick and slip" action of the bow on the strings, which creates a "non-Fourier" mixture of harmonics.

If the two VCOs are set at some musical interval apart, but very slightly off, bell-like tones are generated, while detuned VCOs give rise to metallic sounds, once suitably envelope-shaped. Using a VCF instead of a VCA as the multiplier facilitates the creation of tremendously rich sound structures.

SAMPLE AND HOLD

This is an analogue memory, that is, when triggered it instantaneously samples the output voltage from an oscillator or envelope shaper or noise source and then stores that voltage until it is next triggered. The output voltage from the sample and hold therefore moves in a series of steps. The sampling is usually triggered by a pulse from an envelope shaper or a slow running LFO, or by pressing a new key on the keyboard. For example, repeatedly sampling a slow ramp waveform from an LFO results in an arpeggio scale when the sample and hold output controls a VCO. Alternatively sampling the voltage from a noise source or a fast running VCO means that the sample and hold output voltage will change apparently at random. This can be used for such varied effects as random filtering and syncopation.

SEQUENCERS

A sequencer is a digital memory note storage system, programmed either manually or directly from the synthesiser keyboard, a voltage corresponding to each note being entered sequentially into a separate memory location.

On playback the memory locations are stepped through in turn by an internal LFO, and the resulting sequence of output voltages is used to control the synthesiser VCOs. Thus any sequence of notes, from a simple repeating arpeggio pattern to an entire piece of music can be stored in the memory and replayed automatically at any time via the synthesiser. The memory also stores trigger pulses in order to trigger the envelope shapers at appropriate times in the sequence. An entertaining analogy is that of the old automatic pianos, which were played by a roll of punched paper drawn through a mechanical control mechanism by a clockwork motor.

The advantages of modern sequencers however, is that they are useful for composition since notes can be entered and edited at any time, at the musician's leisure, and since the replay speed can be set to any desired tempo, sequences can be generated which are beyond the capacity of any normal musician to play in real time. Furthermore, the electronics can take over the drudgery of playing repetitive patterns while the musician concentrates on more inventive lead playing.

While we are on the subject of memories, the latest generation of synthesisers contain memory storage systems for a different reason. Make all the functions of a synthesiser voltage controllable, including envelope shaper time constants, VCF resonance, portamento, etc, and it follows that all the relevant voltages can be stored in a memory, in other words, all the information about VCO pitches, harmonic spectra, envelope shapes, as well as all the intermodulation between the various synthesiser units. In practice then, a complete voice can be set up using the front panel controls in the normal way, then push a button and the whole program is stored. Repeat this any number of times, and any of the stored voices can be recalled, also at the touch of a button.

POLYPHONICS

As stated at the beginning, most synthesisers are monophonic which means, complexity of voice aside, only one note may be played from the keyboard at a time. Pressing a new key before the envelope from the previous key has died away simply re-triggers the envelope shaper and changes the VCO pitch—conventional chording is out!

Electronic organs and pianos are fully polyphonic, that is, chords may be played, since there is effectively an oscillator and an envelope shaper for each key. However, variability of the envelope shapes is strictly limited, filters of switchable characteristics are tacked on the end, so the advantages of dynamic filtering, portamento and complex sound creation via ring modulation and the like are lost. Many instruments which retail for a few hundred pounds claim to be polyphonic synthesisers, but in reality are just glorified electronic organs, generally with one VCF responding to the latest envelope to be triggered.

It is apparent then, that a truly polyphonic synthesiser would consist of a complete synthesiser for every key on the keyboard. In practice this is unnecessary, as one can get away with four, eight, or at the most sixteen being assigned in rotation to particular keys as they are pressed, this task being performed by digital circuitry scanning the keyboard at a very high frequency looking for pressed keys. Even so polyphonic machines generally cost several thousands of pounds to buy.

EXPRESSION PATHS

A criticism often levelled at synthesisers is that their pre-programmed, nature renders them rather mechanistic, perhaps soulless, from the musician's point of view, which (even the antagonists usually concede) is a pity in view of their tremendous potential. Indeed, with the current headlong rush towards digital waveform synthesis and control, wherein sounds can be dreamed up and music composed all from the alphanumeric keyboard of a computer terminal, even the knob-twiddling element is removed, so what price emotion and spontaneity now? Is the beauty of an instrument expressing the subtleties of innermost moods and feelings to be replaced by the aesthetic elegance of mathematical equations and the efficiency of subroutines?

This is, of course, overreacting. Computerisation of music has its own appeal and its own place just as any other human endeavour, but nevertheless, the lack of direct involvement in the control of synthesised sound has led to something of a counter-revolution in which designers go out of their way to give the musician back the ability to interact with his instrument, manually, as it is being played, which thus far has been lacking in synthesisers. It is ironic, by the by, that similar objections have never been raised during the several centuries that pipe organs have been around. These elaborate mechanical precursors of modern electronic synthesisers, while being able to chord and sound quite orchestral on their own owing to the number of spectra simultaneously available, lack any of the expression paths associated with other conventional instruments.

Such expression paths include breath control of pitch, volume and harmonic content in wind instruments, the way the guitarist can bend strings to control pitch and glide from one note to the next—as can the violinist and cellist, etc., but with bowed instruments the way in which the bow is applied to the strings also dramatically changes the sound. In keyboard instruments such as the piano and harpsichord the force with which the keys are pressed not only affects the volume and the resulting spectra but also, by virtue of the vibrations of each string being transmitted through the framework to the other strings, the keyboard controls the degrees of waveform multiplication. The pedals also give considerable control over the envelopes either by increasing sustain or damping out the oscillations and their resultant harmonics.

The point of all this is that no matter how sophisticated electronics becomes it will never out-class the human brain as a pattern-recognising feedback control system (for the implication would be one of replacing human beings altogether!) So to come back down to earth again, what can be done to provide the same degree of manual control over electronic synthesisers?

OPTIONS

Many options are available. Pedals are one obvious choice. Another is the provision of thumbwheels next to the keyboard; joysticks similarly. A more modern device in use consists of a sandwich of conductive foam between thin metal strips, which changes its resistance according to where it is pressed along its length. This is known as a ribbon controller.

Electronic pianos are usually touch sensitive in that the size of the envelopes increase the harder you press the keys, though it is generally key velocity that is measured rather than the force of impact. A more recent innovation is that of force sensitivity, a device unique to synthesisers. Here the keys are depressed in the normal way, but pressing harder on a key that is already depressed forces a spring-loaded metal bar downwards (alternatively the entire keyboard may move downwards!)

Whatever methods are employed, the result is the generation of control voltages proportional to the physical movements. The big advantage over conventional instruments is that these control voltages may be used to control any chosen parameter of the synthesiser: pitches, filter responses, envelope shapes, LFO speeds and amplitudes, etc.

One modern invention called the "Variphon" has gone one step further. It is a synthesiser right enough, but it is a wind instrument in that it is blown! There is a mouthpiece and electronic sensors around the reed generate the control voltages, in other words, a synthesiser with complete breath control.

The "Kaleidophon" is a pseudo stringed instrument. Again it is a synthesiser, but the control voltages are generated in the strings, thus giving the synthesist back some of the advantages that a guitarist has.