other Formant modules, the resonant filter module requires no calibration or adjustment procedure. The operation of the circuit can be checked by feeding in a white noise input from the noise module. Varying the three filter parameters should produce clearly audible changes in the resulting sound. It will also be apparent that rapid variation of the Q- and f_O controls produces effects similar to phasing, thus the filter module can be used to provide manual phasing.
The scale on each of the f_O potentiometers on the front panel is calibrated with five nominal frequencies. The three middle settings in particular should be viewed as rough guidelines, since the resistance curve of logarithmic potentiometers can exhibit fairly wide tolerances.
The filter module should be placed between the COM-module and the power amp. However, if one wishes to use the headphone output on the COM-module, the resonant filter module can be connected directly before the latter.

Appendix

With the component values given in the circuit diagram, the centre frequency of the filters can be varied between roughly 50 and 2300 Hz. To calculate the correct values for higher frequencies than this, the procedure is as follows:
Firstly, the desired maximum frequency of f_O can be used to calculate the value of C2 = C3 = C4 = C5 = C6 = C7 = C from the following equation:

$$C = \frac{16}{f_O \text{ max}}$$

where C is in nanofarads and f_O in kHz.
Secondly the value of resistor R (see figure 2) can be determined on the basis of the desired minimum centre frequency f_O min:

$$R = \frac{16}{C \cdot f_O \text{ min}}$$

where C is in nanofarads, R is in kΩ, and f_O in kHz
The value of R_O = R11 = R14 = R26 = R29 = R41 = R44 can be calculated from:

$$R_O = \frac{10}{R - 2}$$

where R and R_O are in kΩ. These equations can be used to check the values of figure 4.

chapter 9

ADSR

The ADSR (Attack-Decay-Sustain-Release) shaper is used to control the VCF and VCA modules and thereby determine the dynamic harmonic structure and dynamic amplitude characteristic of the VCO signals.

It is often not realised, even by musicians, how much the character of an instrument is determined by the dynamic amplitude and harmonic behaviour, rather than by the steady-state harmonic content of the instrument. If the attack and decay periods of a note are artificially modified, then the whole character of the sound is altered. An interesting and amusing experiment is to record the sounds of several musical instruments, but to remove the attack and decay periods by bringing up the recording level after the note starts and fading it down before the note ends. Then ask some musical friends to identify the instruments. They will no doubt be amazed how characterless the sound of an instrument becomes when robbed of its particular amplitude envelope.
On the other hand, starting with a single basic waveform such as the triangle output of the Formant VCO, a whole range of instrument sounds can be produced simply by varying the amplitude envelope, ranging from 'soft' sounds such as flute and some organ voices, to 'hard', percussive sounds such as piano and xylophone.
Envelope control of the harmonic content using the VCF allows even greater variation in the character of the sound.

Types of envelope curves

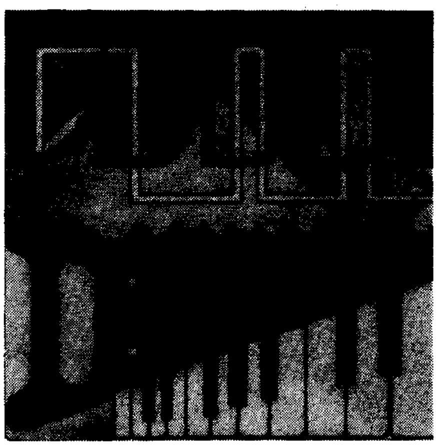
The envelope shaper of the synthesiser must be able to simulate the envelope contour of conventional musical instruments when the synthesiser is used in an imitative capacity, and also to produce envelopes that are purely synthetic in character (i.e. not found in sounds produced by normal acoustic methods).
Fortunately, there are relatively few types of envelope contour that are musically important, and these are all fairly easy to generate electronically.

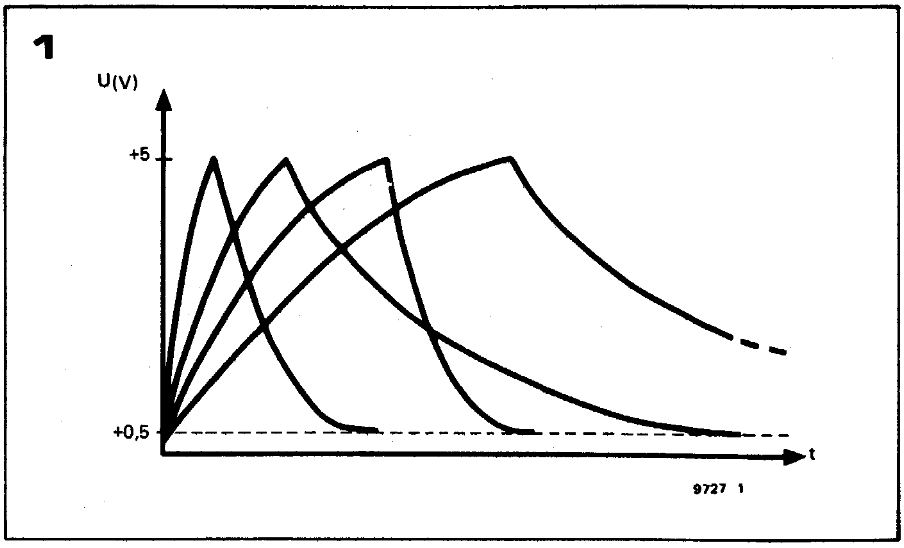
1. Attack/decay contour

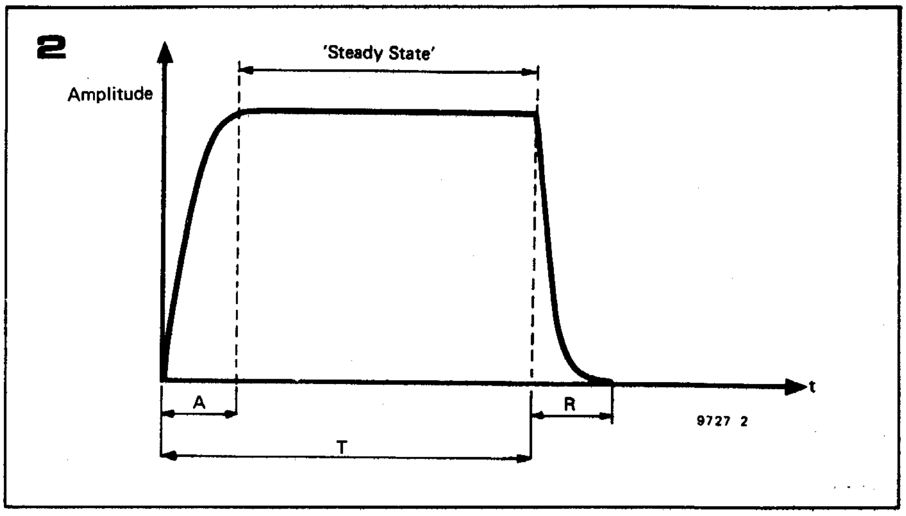
The simplest type of envelope curve is that consisting only of attack and decay periods. The envelope contour rises to a peak when the note is played, and begins to decay immediately the peak is passed (see figure 1). By varying the attack and decay times a wide variety of sounds can be produced.
For example, if a rapid attack and slow decay is applied to the VCA control, then a percussive sound like a piano results. Applied to the VCF in the low-pass mode, the same envelope contour can produce very bright, metallic sounds, depending on the input waveform.
If the attack period is made long and the decay period short, then applying this to the VCA will produce completely synthetic 'fantasy' sounds similar to those obtained by playing a recording backwards. Applying this type of envelope contour to the VCF can produce sounds similar to those of a brass instrument played staccato.
However, the main use of this type of envelope curve is for the production of percussive sounds such as xylophone, marimba, glockenspiel, bells and gongs, cymbals, and struck or plucked strings such as guitar, banjo, harp, other string instruments played pizzicato, harpsichord, and of course, piano.

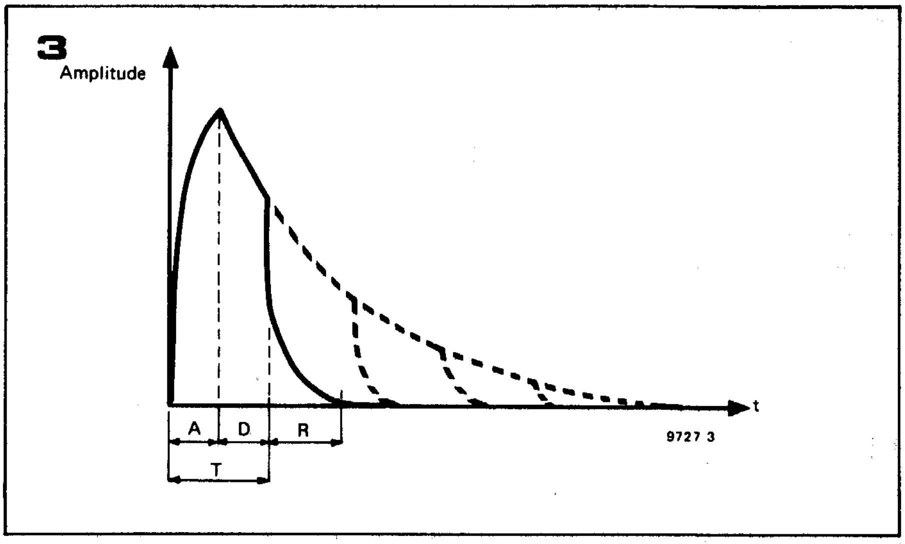
2. Attack-sustain-release contour

The attack/decay characteristic previously described is typical of instruments where the sound is initiated by a short pulse of energy (e.g. by striking or plucking a string), after which the sound dies away since there is no further excitation to sustain it. The envelope contour shown in figure 2 is typical of instruments in which a note is sounded and sustained, such as a pipe organ, woodwind instruments, and bowed string instruments. In a pipe organ the note builds up fairly rapidly after a key is depressed as standing wave modes are established in the pipe, and the note is sustained by virtue of the fact that air is continuously blown into the pipe. When the supply of air stops on releasing the key the note terminates more or less rapidly.
The same basic contour applies to woodwind instruments and to string instruments played with a bow, since the note is here again sustained by blowing or bowing. However, with such instruments much greater expression can be obtained by modulation of the









steady-state level, since this is determined by the player, and not by a mechanical blower as is the case with a pipe organ.
With a synthesiser, a degree of expression can be obtained by modulating the VCA using the low-frequency oscillators or noise source.

Figure 1. The attack-decay envelope contour is the simplest contour found in music.

Figure 2. The attack-sustain-release contour is used to simulate instruments where the note can be sustained at a constant level, such as organ, woodwind, and bowed string instruments.

Figure 3. Instruments such as the piano can be simulated using the attack-decay-release contour. As long as the key remains depressed the decay path is followed, but once the key is released the note is ended more abruptly, following the release contour.

3. Attack-decay-release contour

A variation on the attack-decay contour is shown in figure 3. Here the slow decay is allowed to continue for only a certain time, and the note is then terminated by a more rapid release. The most common example of this type of contour is provided by our old friend, the piano. When a note is sounded and the key remains depressed, then the damper is held off the string and the note decays over a period of a few seconds. If, however, the key is released after playing a note, the felt damper contacts the string and the note terminates after about 500 ms.

4. Attack-decay-sustain-release contour

Most of the examples given so far relate to envelope control of the VCA, since the amplitude contour of a sound is somewhat easier to visualise than its dynamic tone colour behaviour. However, the most complex envelope contour, shown in figure 4, is a good illustration of envelope control of the VCF.
Many brass instruments, such as the trumpet, are characterised by a rapid build-up of harmonics during the attack period of the note, which gives the instrument a very strident sound. Once the note is established, however, the harmonics die away somewhat, and the tone is much more mellow during the steady state period. Finally, during the release period at the end of the note, the note dies away fairly rapidly.
This type of characteristic can be obtained by using the VCF in the low-pass mode and controlling it with an envelope contour similar to that shown in figure 4. As the control voltage rises during the attack period, so the turnover frequency of the VCF increases, passing more harmonics. During the decay period the VCF turnover frequency falls until the steady-state value is reached, and finally, during the release period the VCF turnover frequency drops very rapidly.

Envelope shaper requirements

It is apparent from figure 5 that the envelope contours shown in figures 1 to 3 are merely special cases of the more general attack-decay-sustain-release contour illustrated in figure 4. Any of the four contours can be generated by an envelope shaper having the following four functions:

- variable attack time (A)
- variable decay time (D)
- variable sustain level (S)
- variable release time (R)

These four parameters can be preset manually using the ADSR controls of the envelope shaper. The envelope shaper is controlled by the gate pulse output of the keyboard. When a key is depressed the gate output goes high and this initiates the attack-decay sequence. The output of the envelope shaper then remains at the sustain level until the key is released, when the release period begins.

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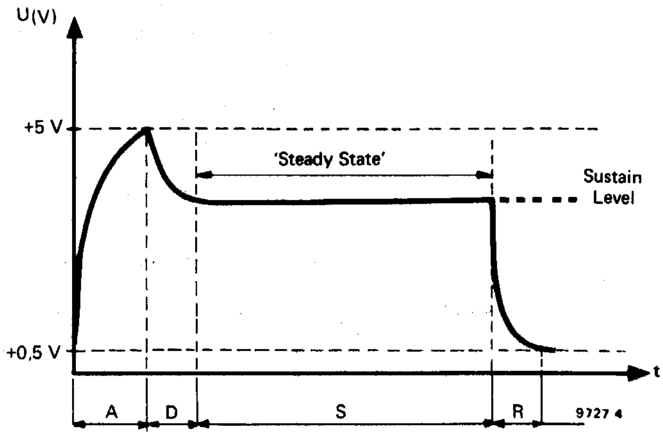

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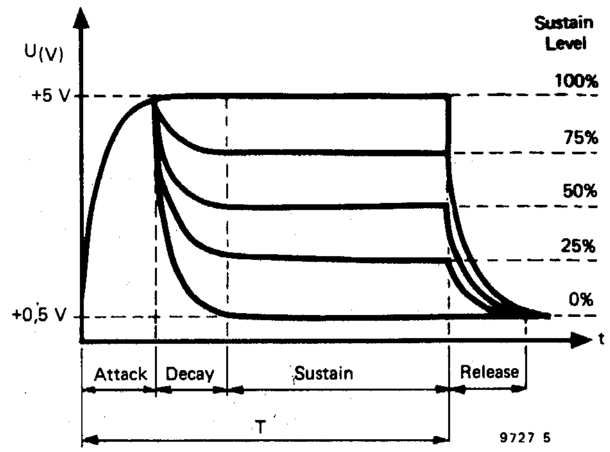

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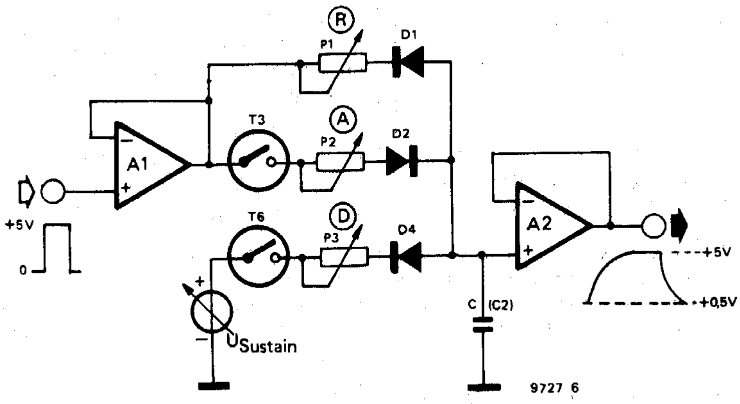

Block diagram

The required exponential attack, decay and release characteristics are easily obtained by charging and discharging a capacitor through resistors, and the sustain level by clamping the capacitor voltage to a preset D.C. level during the sustain period. The basic principle of the envelope shaper is illustrated in figure 6. The gate pulse is fed to a voltage follower A1, and when the gate pulse is high C charges exponentially through P2 and D2 (and T3).

At the end of the Attack period, 'switch' T3 is opened and T6 is closed. Capacitor C now discharges through D4 and P3 (Decay), until the Sustain level is reached. This level is maintained until the gate pulse finishes, either when the key is released or when a preset time has elapsed.

When the gate pulse finishes, the output of A1 goes to zero volts, and C discharges through D1 and P1 (Release). The capacitor cannot discharge fully, since D1 ceases to conduct once the voltage on C has fallen to about 0.5 V, but this is not important as it merely constitutes a D.C. offset which can be compensated for. The attack, decay and release times may be adjusted by means of P2, P3 and P1.

ADSR adjustment ranges:

Attack period	(A)	10 ms . . . 20 s
Decay period	(D)	10 ms . . . 20 s
Sustain level	(S)	0.5 V . . . 5 V
Release period	(R)	10 ms . . . 20 s

Complete circuit

The complete circuit, which is shown in figure 7, is, of course, more complicated. The envelope shaper has two modes of operation, ADSR and AD, which are selected by means of S1. With S1 in position 'b' (ADSR) the circuit operates as follows:

When a key is depressed the gate pulse output goes to +5 V. IC1 has a gain slightly greater than unity, so about +6 V appears at its output.

The leading edge of the gate pulse also triggers monostable T1/T2, which pro-

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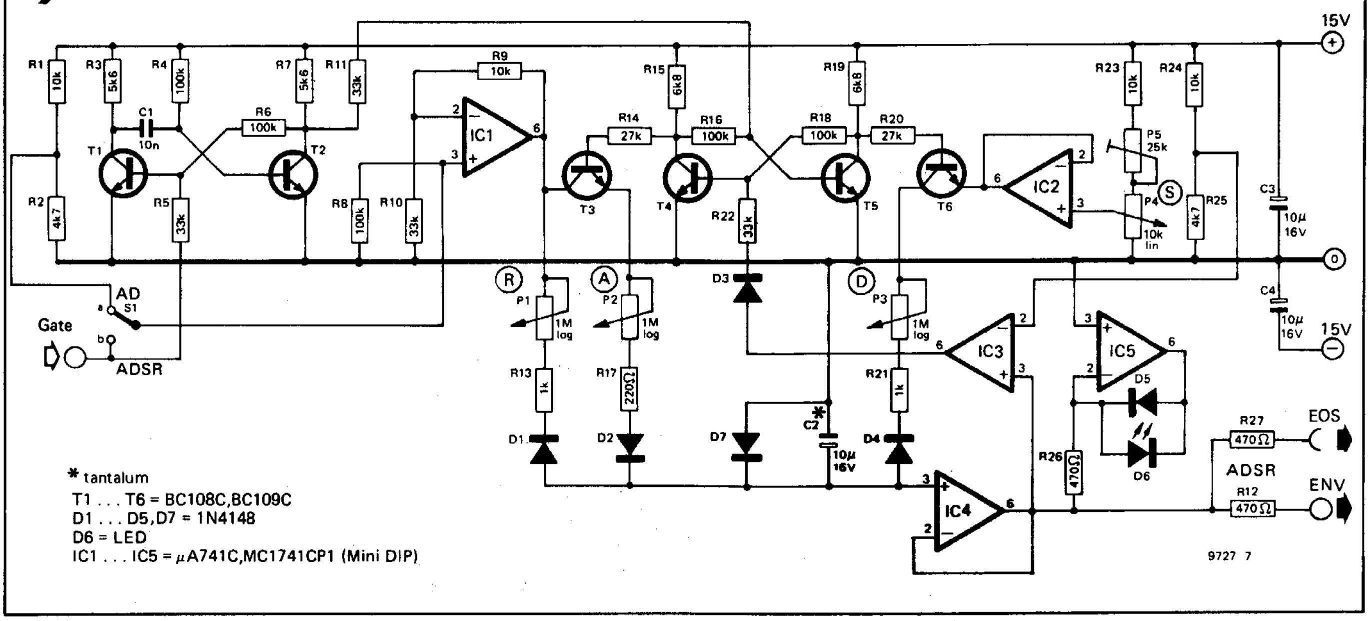

duces a short pulse to set flip-flop T4/T5 (T5 turned on and T4 turned off). The collector voltage of T4 thus rises, turning on T3 and allowing C2 to charge from the output of IC1 through T3, P2, R17 and D2. This is the attack period.

The voltage on C2 is fed to voltage-follower buffer IC4, which is connected to the outputs EOS and ENV and also to the non-inverting input of IC3. This IC functions as a comparator, with its inverting input held at about 4.7 V by R24 and R25. When the voltage on C2, and hence at the output of IC4, exceeds this value, the output of IC3 swings positive, resetting flip-flop T4/T5, turning off T3 and terminating the attack period. T6 is turned on, initiating the decay period when C2 discharges through D4, R21, P3 and T6 into the output of IC2 until the sustain level, set at the output of voltage follower IC2 by P4, is reached.

The output of the envelope shaper then remains at the sustain level until the key is released, when the output of IC1 goes to zero volts and C2 discharges through D1, R13 and P1 (release period).

Diode D7 protects C2 in the event of the output of IC1 going negative for any reason, when the voltage across C2 is clamped to a maximum of −0.7 V.

A LED indicator constructed around IC5 allows visual monitoring of the envelope contour. The brightness of the LED follows the envelope voltage.

Two outputs are provided from the envelope shaper; an external output to a front panel socket (EOS), and an internally wired output (ENV).

The full ADSR envelope contour is, of course, produced only if the key is depressed for a period longer than the attack plus decay time, and if the sustain level is greater than 0%. If the key is released before the sustain level is reached then the release period is initiated prematurely, and either AR or ADR curves may be produced. If the sustain level is 0% then only AD or ADR curves may be produced, depending on when the key is released. If the sustain level is 100% then, of course, only AR or ASR curves may be produced, depending on when the key is released, since the decay period is inhibited.

Figure 4. The attack-decay-sustain-release contour is the most complex envelope shape provided by the Formant envelope shaper. When applied to the VCF it is useful for imitating brass instruments, where the harmonic content of the note rises initially to a large value, then reduces to a lower level during the steady-state part of the note.

Figure 5. By varying the sustain level the envelope contour can be changed from an AD contour at 0% sustain, through various ADSR contours to an ASR contour at 100% sustain. T is the time for which the key remains depressed.

Figure 6. This simplified diagram illustrates the basic principle of the envelope shaper. C charges through D2 and P2 during the attack period. It then discharges through D4 and P3 to the (adjustable) sustain level; finally, it discharges through D1 and P1 during the release period. P1, P2 and P3 can be used to vary the release, attack and decay times.

Figure 7. Complete circuit of the Formant envelope shaper.

Triggered AD mode

It is sometimes useful to be able to produce AD envelope contours that are unaffected be releasing the key, that is to say, once the key is depressed, a fixed attack-decay sequence is initiated, which is completed whether the key is released or not. This triggered AD contour is obtained by setting S1 to position 'a' and selecting 0% sustain level. The input of IC1 is now connected to the junction of R1 and R2, so its output is permanently at about +6 V, irrespective of the gate input.

When a key is depressed, the gate signal triggers the monostable, setting the flip-flop and turning on T3. At the end of the attack period, comparator IC3 resets the flip-flop, turning on T6 and initiating the decay period. C2 will now discharge through D4, R21, P3 and T6 to the 0% level (sustain is set at 0%).

Even if the key is released before this sequence is complete, the release period is inhibited since the output of IC1 is permanently at +6 V, so C2 cannot discharge through D1, R13 and P1.

Construction

There are no special requirements with regard to resistor tolerances in the envelope shaper circuit, and ordinary, good-quality 5% carbon film components are quite adequate; C2 should be a tantalum electrolytic capacitor for low leakage, and C1 the usual

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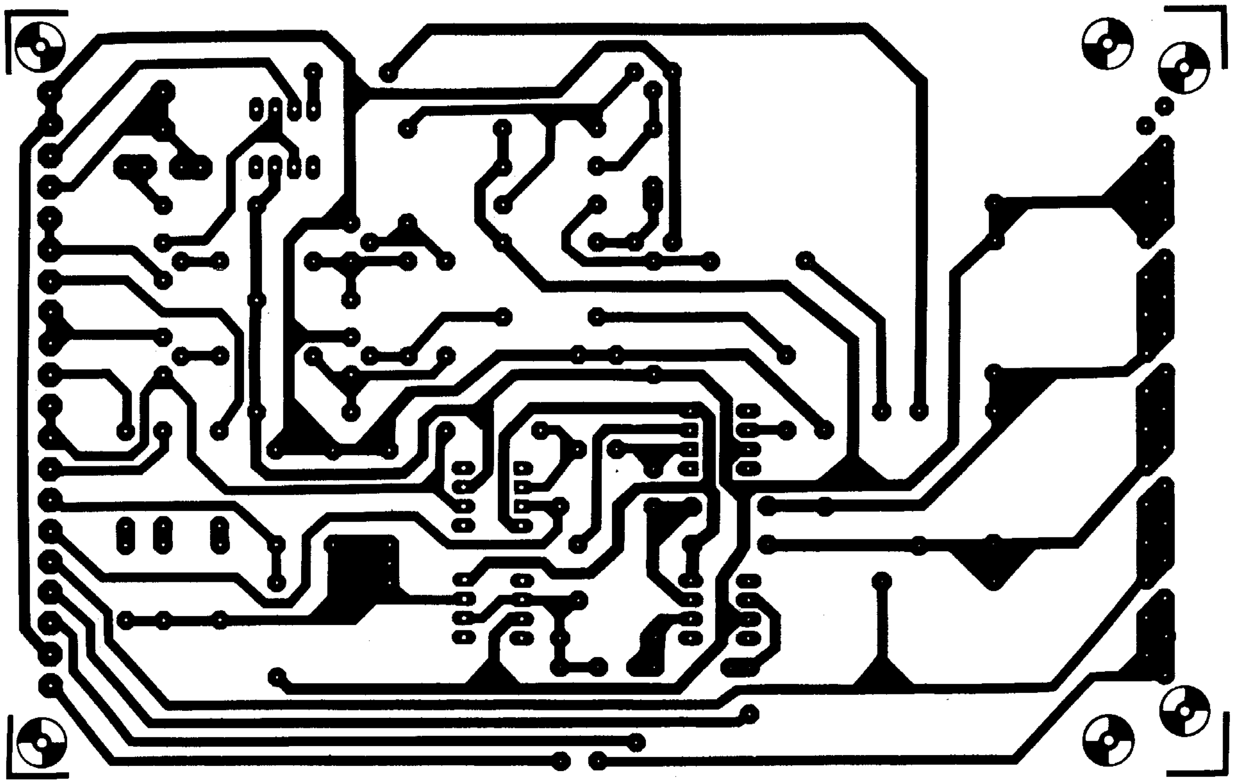

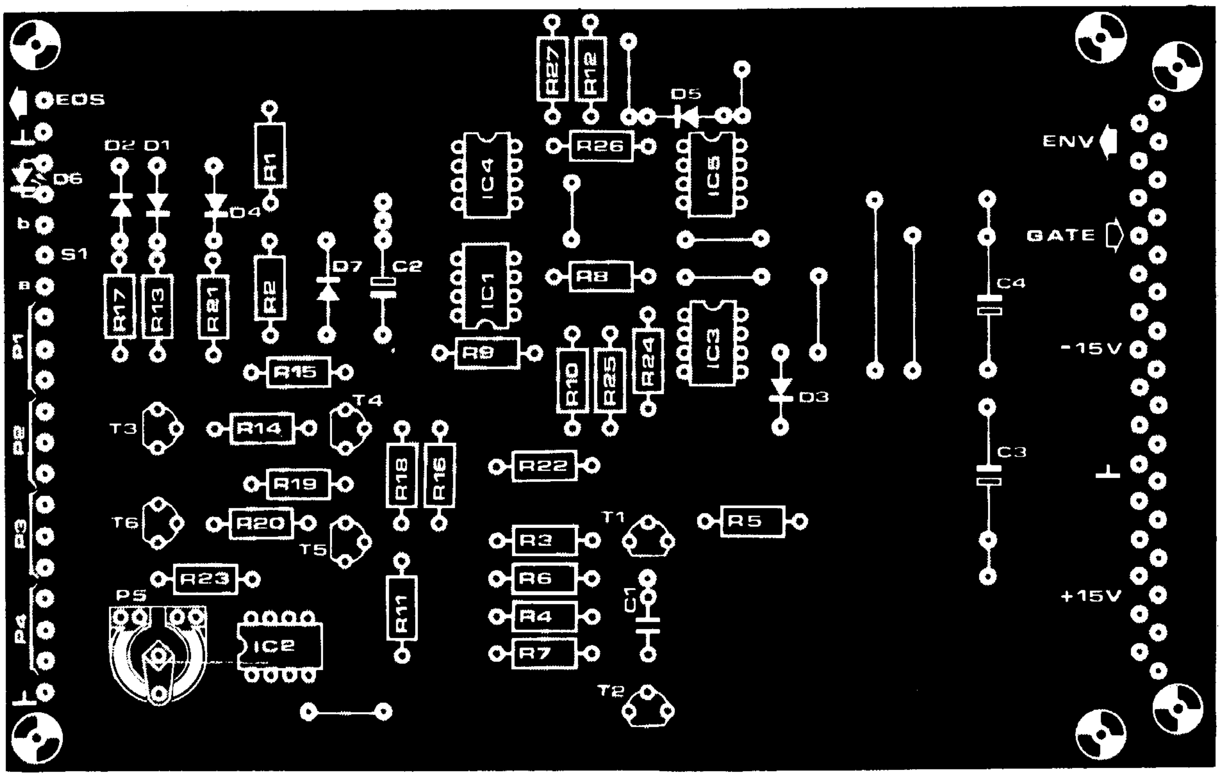
EOS
D6
b
S1
a
D2 D1
D4
R1
R17
R13
R21
R2
D7
C2
R15
P1
P2
P3
P4
T3
R14
T4
R19
T6
R20
T5
R23
P5
IC2
R18
R16
R11
R27
R12
R26
IC4
IC1
R8
R9
R10
R25
R24
D5
IC5
IC3
D3
R22
R3
R6
R4
R7
T1
C1
T2
R5
C4
C3
ENV
GATE
-15V
+15V

Parts list for figures 7 and 8

Resistors:
R1,R9,R23 = 10 k
R2,R25 = 4k7
R3,R7 = 5k6
R4,R6,R8,R16,R18 = 100 k
R5,R10,R11,R22 = 33 k
R12,R26,R27 = 470 Ω
R13,R21 = 1 k
R14,R20 = 27 k
R15,R19 = 6k8
R17 = 220 Ω

Potentiometers:
P1,P2,P3 = 1 M log.
P4 = 10 k lin.
P5 = 25 k preset

Semiconductors:
T1 . . . T6 = BC108C, BC109C or equivalent
D1 . . . D5,D7 = 1N4148, 1N914
D6 = LED (TIL209 or similar)
IC1 . . . IC5 = μA 741C, MC1741 CP1 (MINI DIP)

Capacitors:
C1 = 10 n
C2 = 10 μ/16 V tantalum
C3,C4 = 10 μ/16 V

Miscellaneous:
31-way Euro connector (DIN41617)
1 x 3.5 mm jack socket
4 x 13 . . . 15 mm collet knobs with pointer

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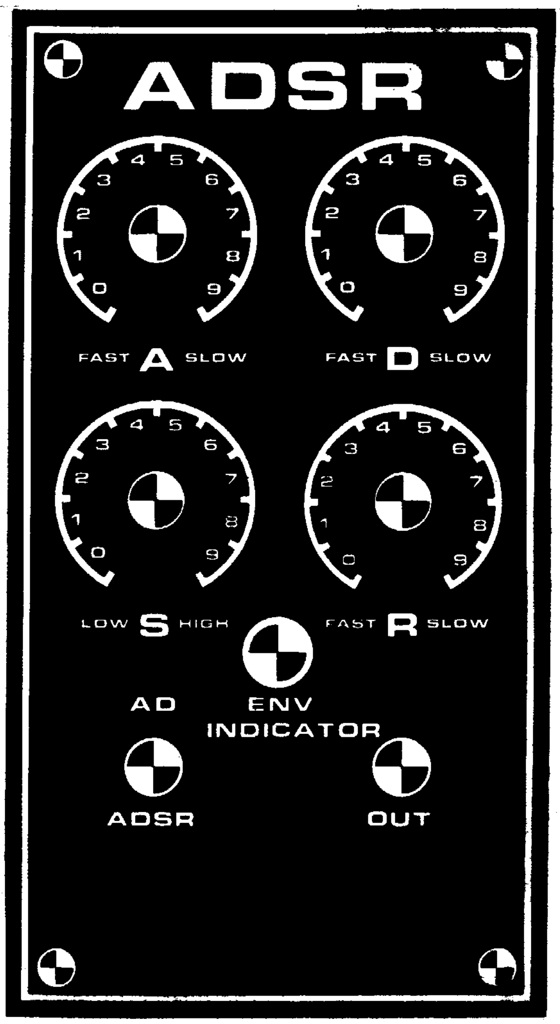

polyester or polycarbonate type. It is a good idea to test T3 and T6 for leakage, using the method detailed in chapter 5.
A printed circuit board and component layout for the envelope shaper are given in figure 8, and a front panel layout is shown in figure 9. Connections to the front panel are fairly simple, the only front panel-mounted components being the four potentiometers for attack time, decay time, release time and sustain level, switch S1, the external output socket and the envelope indicator LED.

Testing and adjustment

To test the envelope shaper a gate pulse must be available from the 'GATE' output of the interface receiver board. The EOS output of the envelope shaper is monitored on an oscilloscope with the Y sensitivity set to about 1 V/div and the timebase set to about 10 ms/div.
For the first test, the sustain level is set to zero, S1 is set to the 'AD' position and the attack and decay potentiometers are set to 'fast'. The release potentiometer has no effect during this test. If a key is depressed at short intervals then a short AD envelope curve will be seen, which rises and falls between about 0.5 V and 5 V. The output of IC3 can also be monitored, to check that it swings briefly between −15 V and +15 V when the peak of the attack curve is reached.
The only adjustment required to the envelope shaper is to set the 100% sustain level, using P5, to correspond with the voltage on C2 at the end of the attack period. If it is too low, then there will always be a decay, even at 100% sustain level; if it is too high then the calibration of P4 will be inaccurate, since 100% sustain will be reached before maximum rotation of the potentiometer.
To make the adjustment, the sustain level is set to 100% and medium attack and decay times are selected. Preset P5 is then adjusted until there is just no decay after the attack period (i.e. the attack period blends into the sustain level with no dip). The adjustment can be checked by turning P4 slightly to the left, when a slight dip after the peak of the attack period should be noted. As P4 is turned further anticlockwise then the decay down to the sustain level will become greater and greater, until finally, at 0% sustain level, pure AD curves will be produced.
The envelope shaper is now ready for use.

Figure 8. Printed circuit board and component layout for the envelope shaper (EPS 9725-1).

Figure 9. Front panel layout for the envelope shaper module.