ELECTRONOTES 66

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GROUP ANNOUNCEMENTS:

CONTENTS OF EN#66

SPECIAL ISSUE ON ENVELOPE GENERATORS - The ENS-76 System Circuits

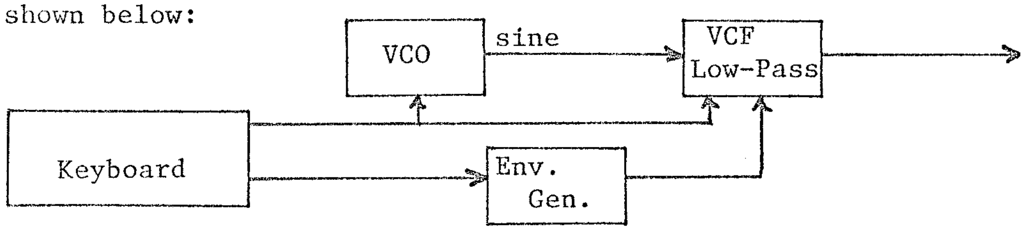
In this issue we are presenting the envelope generators for the ENS-76 series. Several new features are available in these circuits. The most important feature is the development of voltage-control devices for all envelope parameters. While these envelope generators are analog circuits, these devices should prove very useful for persons using sequencer and digital control of analog circuitry as well as persons using only analog circuitry. A total of three envelope generator circuit options are given. The simplest uses only four IC chips while the most complex uses 17 or more.

We are planning to put out the summer edition of the directory of products and services about August 20. Copy should reach us by August 10 at the latest. We will be preparing and mailing 1200 copies this time. Thus we cut back the mailing list by about 20% and the rates will be cut accordingly. Cost of a full page ad will be $46 (copy area 9.5" high by 7" wide). One-Third page will be $20 (copy area 3" high by 7" wide). We will also be offering this time 1/6 page at $12 (copy area 3" high by 3.25" wide), and the $5 listing we used last time will be replaced with 1/12 page (copy area 1.4" high by 3.25" wide) at a cost of $6. We will soon be preparing and mailing a memo on this to those we think would be interested. If you want to be sure you are on the list to receive the memo, drop us a card.

Forum: Sine Waves And VCF's - Do They Mix? -by Myron Mellowitz

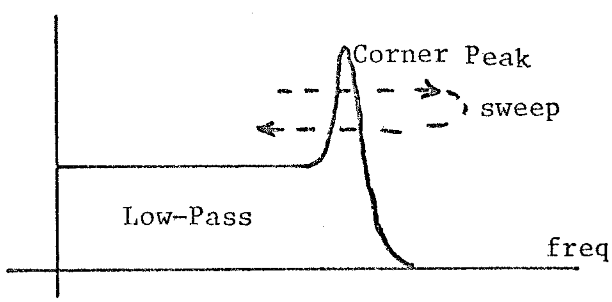
In his review of Larry Fast's Synergy, Craig Anderton appeals for more use of sounds with lower harmonic content: "try not using a VCF for some patches and see what happens." This is certainly a useful suggestion, and one which reminded me of something that happened about five years ago. I have always been interested in the use of sine waves in compositions. Properly used, they don't have to sound "corny" or "sentimental" and can provide a feeling that can't be reached in other ways. Of course, no one would use a VCF with a sine wave! That is, unless he didn't know better or wanted to teach us all something.

I was working with (watching) a composer who was using the sine wave out of a VCO and running it into a VCF. I was about to explain that the VCF wouldn't do anything when I found that the VCA was not connected, and yet he was making notes (or whatever). The patch is shown below:



I then saw that what was happening was that the envelope was forcing the cutoff frequency of the VCF low-pass up and letting the sine wave through, and then falling back cutting it out. I asked him why he did not use the VCA instead and he looked at me as though I was crazy (evidently he was right) and insisted it just wasn't the same thing. He said that the sound was "weak" (I think he used a better word, but I don't recall it) if he only used the VCA. So I proceeded to make a fool of myself by explaining how it was the same thing and that the filter can't do anything to the sine wave but change the amplitude. My explanation was so persuasive that I was astounded that when he demonstrated the difference that the equipment hadn't been listening to me at all and went right ahead and sounded different. The composer hadn't read his manual. He really didn't know what a filter was or what an amplifier was. He just used them and would not think of using a VCA where he always used a VCF (on the sine wave output!). And it did sound different.

Well, I thought a lot about that later (that is, about what went wrong) and decided it had something to do with the fact that the envelope that controlled the filter was in effect "distorted" by the filter rolloff curve. Then still later I remembered phase (we all forget about phase from time to time - at least I know I do) and thought it might have something to do with phase modulation. Yes, the filter is, among other things, a phase modulator. But is that all. I tried it and couldn't get the spectacular difference that I remembered. Then I read about corner peaking of a low-pass filter in EN#41 and I knew that the composer had been using a Moog system with the four-pole lowpass. What if he had been setting the Q way up high? This would give a response like the one shown in the figure below:



After a little experimenting, it was clear that corner peaking was probably what he had been using. I wrote him but he never answered my letter. Surely that sharp corner peak would serve to give a very rapid attack to the amplitude envelope. However, I think it is the very rapid phase changes that occur as the peak sweeps across that gives the sound the extra effect. So by all means use sine waves, but don't forget to try to use your VCF with them.

THE ENS-76 HOME-BUILT SYNTHESIZER SYSTEM - PART 2: -by Bernie Hutchins

In this installment, we will be looking at envelope generator designs. On the one hand, envelope generator circuits tend to be fairly routine. On the other hand, they also tend to be tedious to analyze - there is generally one overall system that has a multitude of possible states and sequences. For these reasons, we want to start right out here with a short description of what is to follow. This will serve to point out the new features of these circuits in a way that does not involve a detailed analysis.

The first thing we will do is present the first circuit (Option 1) which is actually the circuit from EN#50 with a small amount of reworking. The new feature is a switching arrangement that makes it easier to use as an AD type generator.

Then we will add on a delay unit to Option 1 to form Option 2. This is basically the delay circuit from EN#51 with a few rearrangements of gates and buffers. We have also cleaned up the switching sequence to prevent glitches that may be a problem in some cases.

The third thing we do is to describe an option that can be added to either of the first two circuits (and probably to others) that gives an instant response feature to the sustain control. Consider that when you set the sustain level you are usually varying a sustain level voltage and that the output of the envelope generator varies with the time constant of the decay circuit. A small bother, but here is a way of avoiding it if you want to. With this option, you get instantaneous response.

Next, we will be looking at methods of voltage-controlling the parameters of the envelope generator. Since we have never covered this before, we will look at this in some detail. Basically, we just use our old friend the CA3080. It turns out as well that voltage-control of time constants makes it possible for us to produce several types of envelopes that were not possible before. For example, we can use linear attacks or even "concave exponential" attacks instead of the usual "convex exponential."

Finally we will be looking at Option 3 which is a voltage-controlled option. This is quite a complex circuit which includes nearly all the features that we have developed. In many ways, it might be considered over-optioned. However, the builder with the ability to take on such a complex circuit should have no problem designing out the features he does not need. Another point along these same lines is that conceptually Option 3 is not much more complex than Option 1. A pot that appeared in Option 1 for example is a voltage-variable resistor in Option 3, but the function of both devices is essentially the same.

ENS-76 ENVELOPE GENERATOR - OPTION ONE

Option 1 in the envelope generator series is shown in Fig. 2. It is essentially the "four-chip" ADSR (Attack-Decay-Sustain-Release) generator that was first described in EN#50. The ADSR envelope waveform is indicated in Fig. 1 below for reader's who may be unfamiliar with this envelope which has become fairly standard.

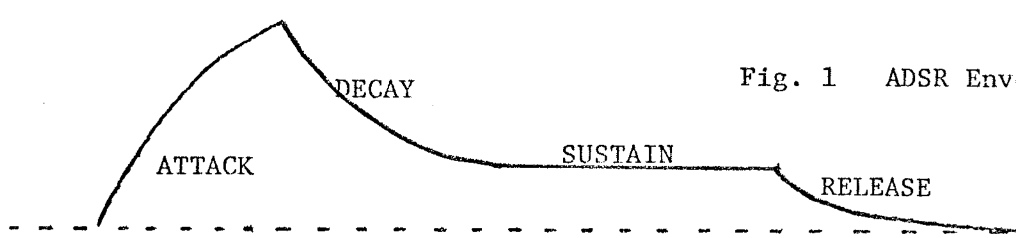
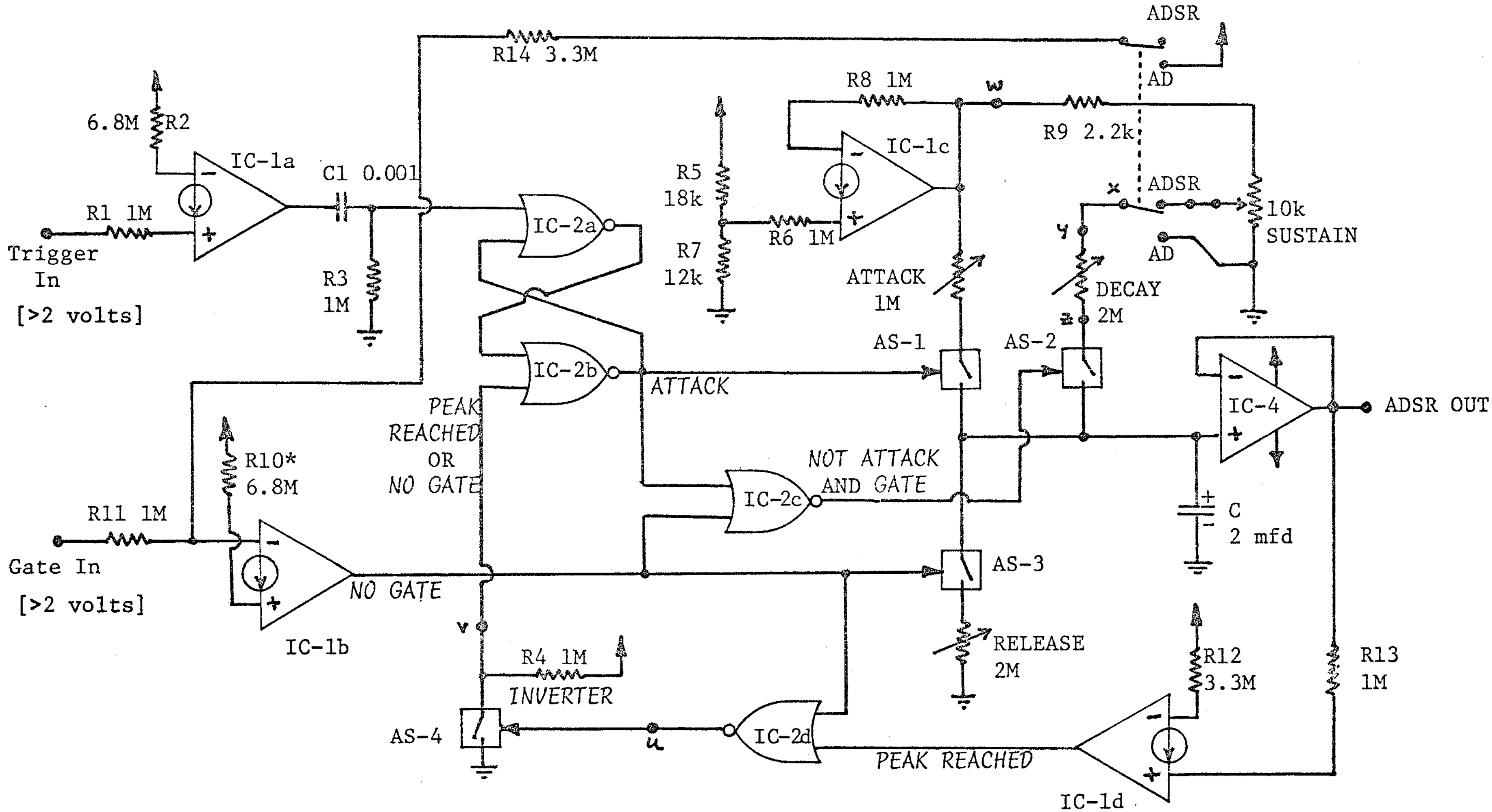


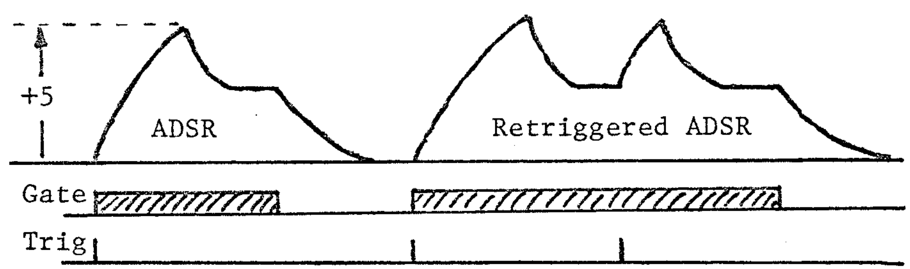
Fig. 1 ADSR Envelope

FIG. 2



*This resistor is mislabeled in some copies of EN#50 and in MEH Chapter 5e (7) as 6.8 rather than 6.8M. Please make corrections.

OUTPUT ENVELOPES AND TIMING



Integrated Circuits:
- IC-1a,b,c,d LM3900
- IC-2a,b,c,d 74C02 CMOS
- IC-3 (AS-1, AS-2, AS-3, AS-4) 4016 CMOS
- IC-4 307 (or 741)

Note: All IC's except IC-4 powered between +15 and ground. IC-4 between ±15.

The basic theory of the ADSR envelope generator can be found in several places including Dave Rossum's description in EN#22 and in Chapter 5e of the Musical Engineer's Handbook. For this reason we will not go into a lot of description here. We will look at two models of the ADSR which will be useful when we get to voltage-controlled designs. First we should observe that a waveform of the type shown in Fig. 1 can be produced by a simple RC charging circuit with certain sequencing circuits that determine the charging (or discharging) voltages and time constants. This idea is illustrated by the diagram in Fig. 3.

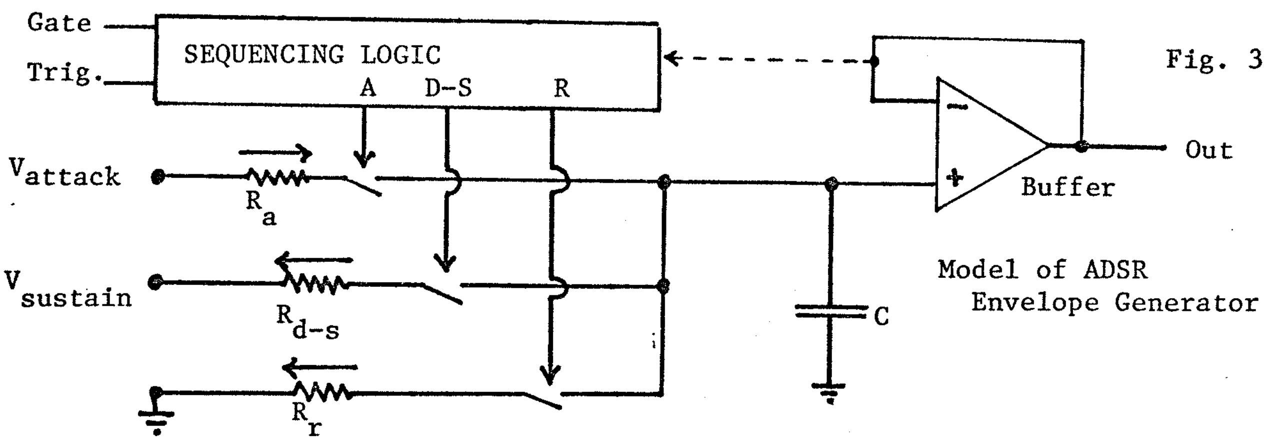


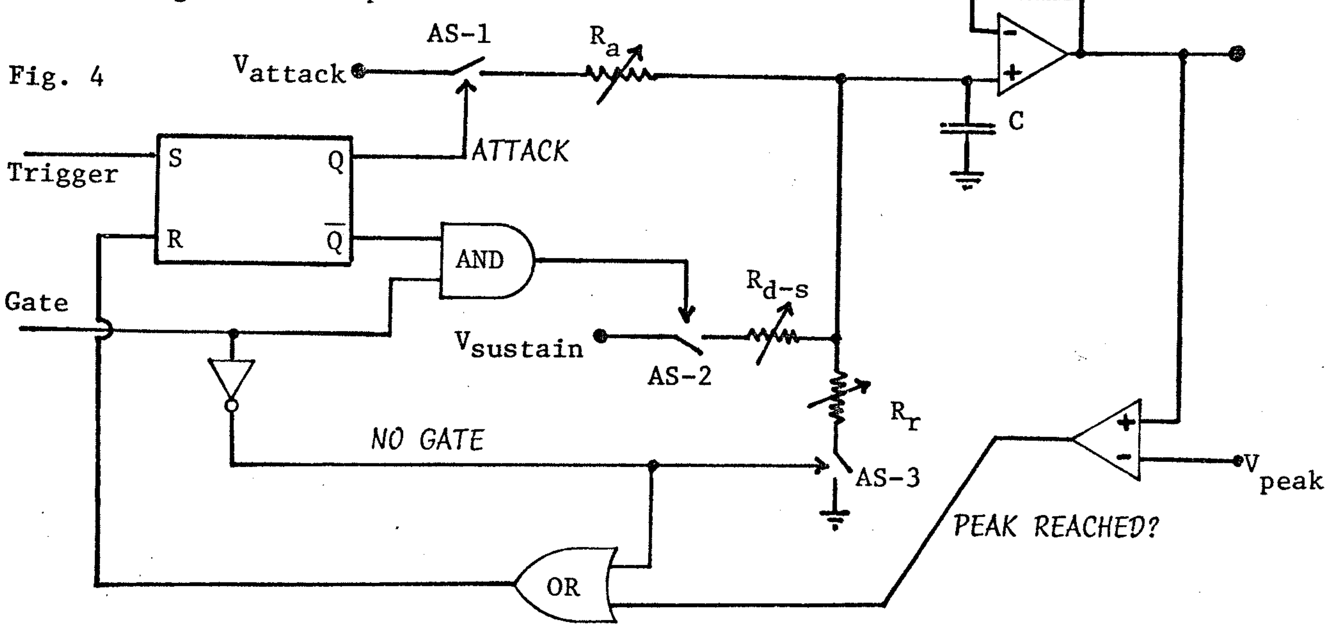
Fig. 3

Model of ADSR
Envelope Generator

In the above model, we show three principal sections. First there is a capacitor with an attached buffer. Secondly, there is some sequencing logic which controls appropriate analog switches. Finally, there are certain reference voltages (V_{attack}, $V_{sustain}$, ground) which are available through corresponding resistances.

One form of the sequencing logic is shown by the setup of Fig. 4. This is the usual combinational logic for an ADSR system that is controlled by gate and trigger commands from a controlling device (e.g., a keyboard). The reader can easily observe how the logic is used. For example, the decay-sustain mode is determined when a GATE is present AND when the attack mode is not in effect. A full description of this logic scheme is found in the references given above. The circuit in Fig. 2 is an implementation of the logic of Fig. 4. For a full description of the operation of the circuit in Fig. 2, see the original description in EN#50.

Fig. 4



The one difference between the circuit in Fig. 2, and the earlier EN#50 circuit is that this circuit has a switch that is useful for using the AD mode only. It is well known that an ADSR envelope generator can be used as an AR (Attack-Release) generator by just setting the sustain level to the maximum (peak) value. Also, the ADSR can be used as an AD (Attack-Decay) generator (no sustain; thus independant of gate) by setting the sustain level to zero. However, note that while an ADSR used in this manner produces an AD envelope that is independent of the gate as far as its timing is concerned, there must be a gate present for the AD to occur. With the addition of the ADSR-AD switch shown in Fig. 2, two things occur. First, enough current is dumped into the gate comparator (IC-1b) through R14 to keep this comparator low (actually the no-gate condition, but the comparator looks for no-gate rather than gate). In other words, it makes the envelope generator think it always has a gate. The other half of the switch can be seen to set the sustain voltage to zero whenever the AD mode is employed. The way this switch might be useful is illustrated by the following example. Suppose we are using a delay unit giving 10 seconds delay. If the switch is in the ADSR mode with S= 0 volts, we make AD type envelopes. Now suppose we press a key down and hold it. Ten seconds later a note sounds under the AD envelope. If however we release the key after three seconds, no note will sound. With the switch in the AD position however, it is not necessary to hold a key down. We can tap a key, walk across the room, and the AD envelope will still occur after ten seconds. There are other examples that could be given where this switch can be very useful.

ENS-76 ENVELOPE GENERATOR - OPTION TWO

In Option 2 (Fig 5, next page) we add a delay unit on to the Option 1 circuit. To do this we use the basic circuit from EN#51. For a full description of the circuit and timing diagrams, see the EN#51 presentation. The original circuit was used directly connected to digital logic levels from a keyboard interface. In this reworked version we have removed the buffers from the input of the ADSR and put them on the inputs of the delay unit instead (which makes more sense in the general case). Thus, the LM3900 CDA's that served in Option 1 are moved to the delay unit while one of the inverters (part of the 74C02 quad NOR gate), IC-5d moves down to give the "NO GATE" signal to the ADSR. In this way, option 2 requires only 6 IC's total. The delay unit is operated on +15 volts so the 74C02 CMOS chip is used rather than the optional 7402 TTL chip in the earlier design. However, since the inputs are buffered and respond to any signals that exceed about +2 volts, this circuit is easily driven by TTL levels or by CMOS. The maximum delay with this circuit as drawn is about 4 seconds. This can easily be increased by increasing the DELAY TIME pot to about 10M, or by increasing C6.

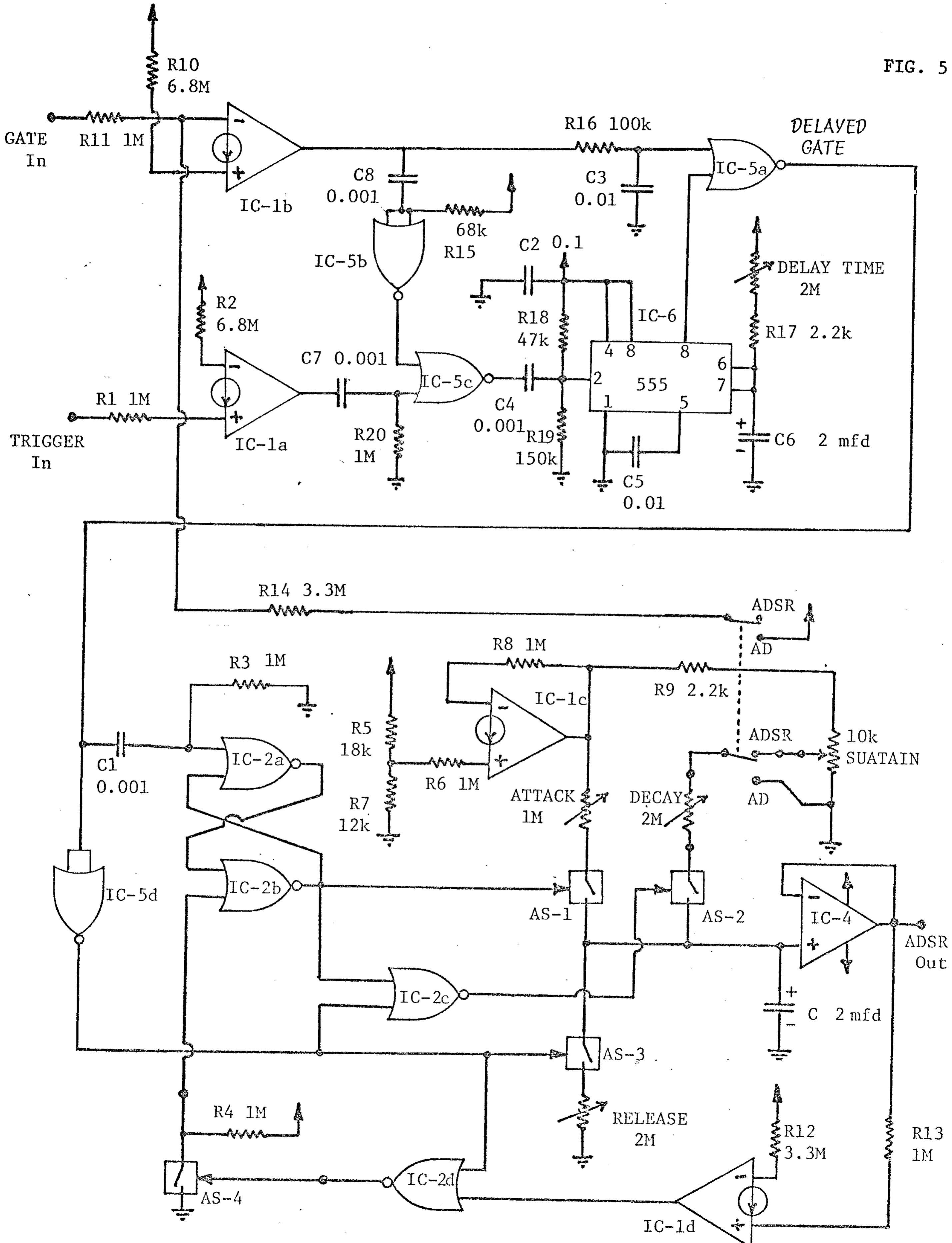
In addition to the rearrangement of buffers and gates, we have added two devices intended to reduce erratic triggering. The first of these is the 0.1 mfd capacitor C2 which bypasses the power supply on IC-6. The inclusion of such capacitors is more or less standard practice when type 555 timers are used, and this one should not be omitted. The second thing is the RC combination R16-C3 which gives about a 1 ms delay to the undelayed gate signal. This assures that no "glitch" will occur if it takes a little time for the delaying process to set up (through IC-5b, IC-5c, and IC-6). A glitch coming through could trigger some envelope generators, including this one in the AD mode. [Actually we tried it without the R16-C3 network and there was no problem, but it is probably safest to leave it in.]

ADDING "INSTANT SUSTAIN LEVEL ADJUSTMENT"

When we first started making ADSR envelope generators, we used a method in which an AD envelope was added to an AR type. This worked well, but had the drawback that it was necessary to use a dual pot so that both attack sections were adjusted the same. Such an ADSR generator can be found in the ENS-74 system, EN#45 (15). The ADSR circuits as in Options 1 and 2 of this issue are probably easier to build. In going over to these

ENS-76 ENVELOPE GENERATOR OPTION TWO

FIG. 5



new designs, there were two features of the earlier design that we missed. The first was the fact that the AD section of the new circuits was not independent of the existence of a gate signal. This has been corrected by the addition of the ADSR-AD switch. The second thing was that the sustain level of the new circuit had a time delayed response as the control was adjusted. This was not present in the ENS-74 design, and it is our purpose here to show how the time delayed response can be removed from the newest designs.

This time delayed response can be understood by studying the circuit in Fig. 6.

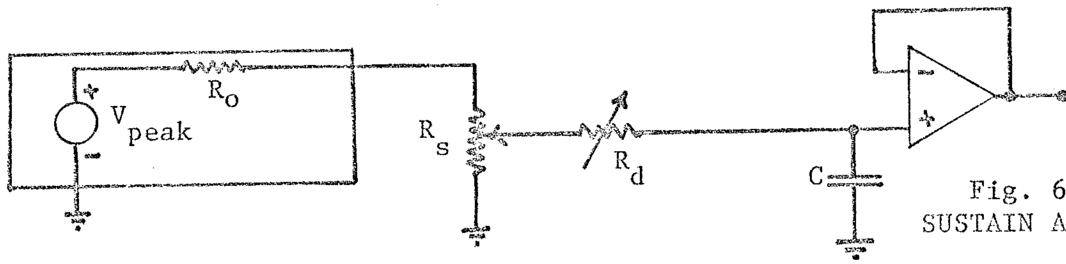


Fig. 6
SUSTAIN ADJUSTMENT

We can make the following assumptions about the above model. First, the output impedance of the source of the voltage V_{peak} (or V_{attack}) is generally fairly small (about 200 ohms in the case of the LM3900 source in Fig. 2). Secondly, we know that the time constant of the R_s pot and the capacitor C is approximately $(R_s/2) \cdot C$ or less, and this is most likely only a few milliseconds (10 ms in the case of Fig. 2). Thus, the only noticeable time delay is likely to result from a high resistance setting of the R_d pot. In the circuit of Fig. 2 for example, R_d may be 2M and C is 2 mfd, so a 4 second time constant results. What does this mean? Well, suppose you want to set the sustain level of the ADSR generator. You press down a key on the keyboard and wait for the envelope generator to cycle through attack and decay. When the sustain level settles down, it may well not be the one you want. You then turn the R_s pot up or down. Instead of responding instantaneously, there is a delay as the voltage on the capacitor can change only as current moves through R_d. In fact, it take one time constant for the output to respond by about 2/3 of the difference. It may thus take several time constants for the new sustain level to be established with enough accuracy. The process of course does converge, and if necessary the R_d pot could be set to zero during the adjustment, but most users would agree that everything else being equal, it is desirable to have the sustain control have no time delayed response at all.

Thus we will discuss the necessary circuitry here. The builder must decide if the additional circuitry can be justified. Two points against should be brought out. First, if the user is using mainly short decay times (short notes), then the time constants are small and probably little problem. Secondly, the user often has to evaluate the sustain setting "on the fly" anyway, and does not just stall the generator in sustain and adjust the control.

Assuming you do want this feature, there are several ways to go about it. Obviously you want to short out R_d during the time the control is being adjusted. One way would be to use a metal knob on a plastic shaft for the R_s pot, and rig up touch control circuitry. Thus, when the knob was touched, an analog switch could be closed to short out R_d. Another approach, which we shall use here, is to use a differentiator on the pot wiper voltage to determine when the pot is being adjusted, and then use this information to close an analog switch. A circuit which we have tested and found successful is shown in Fig. 7. In this scheme, IC-1 buffers the pot voltage in the event that the impedance is too high (don't use it if you don't need it). IC-2 forms a high gain differentiator and IC-3 forms a full-wave rectifier (non-precision). When the pot is adjusted (rotated), the change in wiper voltage forces the output of the differentiator into (+ or -) saturation. This is rectified by IC-3 and then turns on the analog switch, shorting out R_d. If the pot is adjusted very slowly, there is not enough output from the differentiator to trigger the analog switch, but by the same token the change is small and the proper sustain level converges rapidly. Naturally, this works best when the pot is adjusted in small rapid motions.

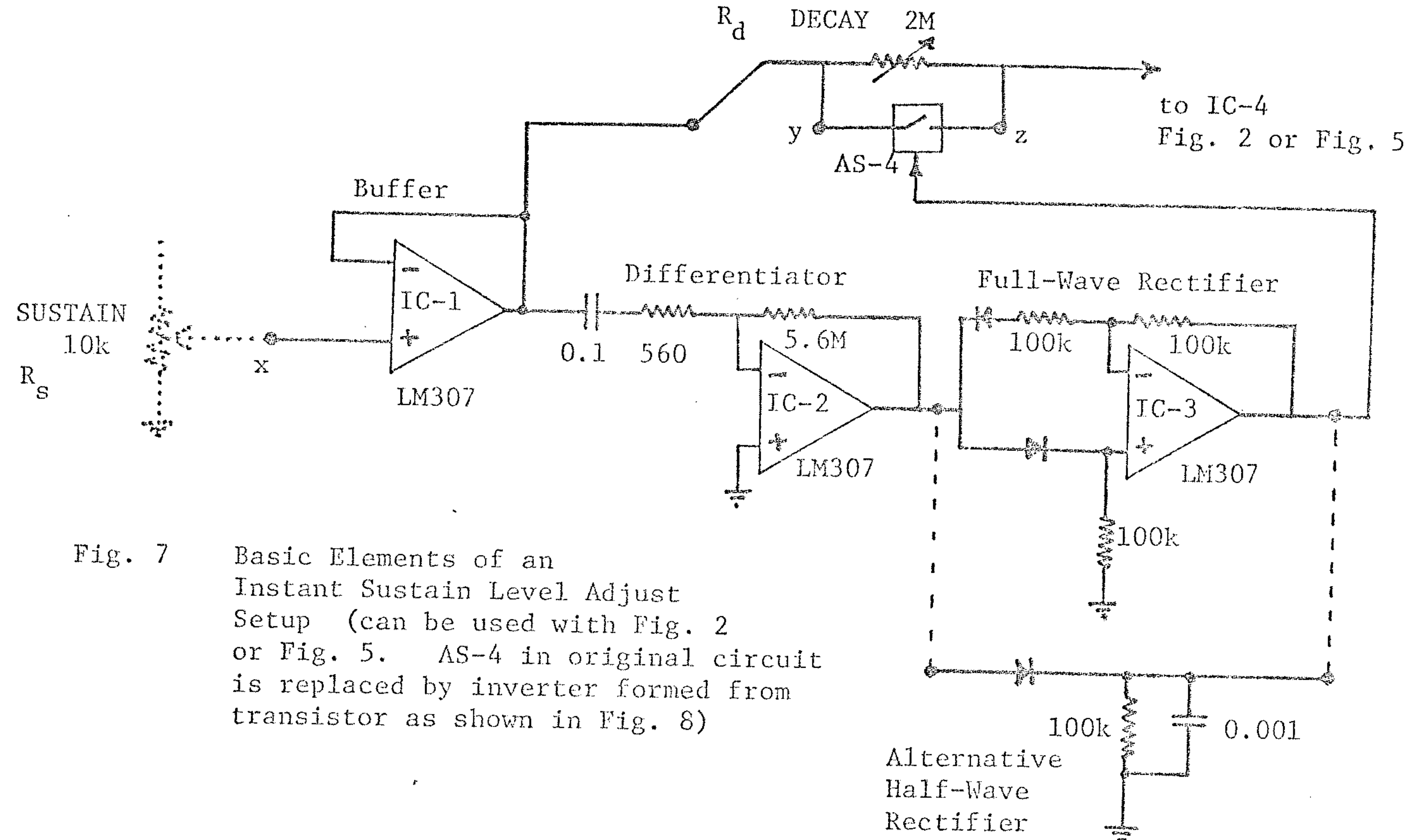


Fig. 7 Basic Elements of an Instant Sustain Level Adjust Setup (can be used with Fig. 2 or Fig. 5. AS-4 in original circuit is replaced by inverter formed from transistor as shown in Fig. 8)

When this circuit was first breadboarded, it worked just great. A second setup did not work so well, and we had to increase the gain of the differentiator to get it to work satisfactorily. After a little checking, it was found that the difference was due to the fact that the sustain pot in the breadboard was wire-wound while the one in the second setup was carbon. It seems that the wire-wound pot "bounces" quite a bit and one need not rely on just the dv/dt due to the pot rotation. In fact, the wire-wound pot seems to bounce so much that you get saturated noise at the output of the differentiator that is the same with either direction of rotation. In fact, there was so much output that we could just use the half-wave rectifier shown in the lower portion of Fig. 7. Extending this idea even further, it is possible to add instant sustain level adjust to either of the options given earlier in this issue without using any more IC's. To do this, we free up one analog switch and one of the LM3900 CDA's. This is done by using a transistor inverter in place of AS-4 and a 6 volt Zener diode in place of IC-1c. The circuit is shown in Fig. 8 below:

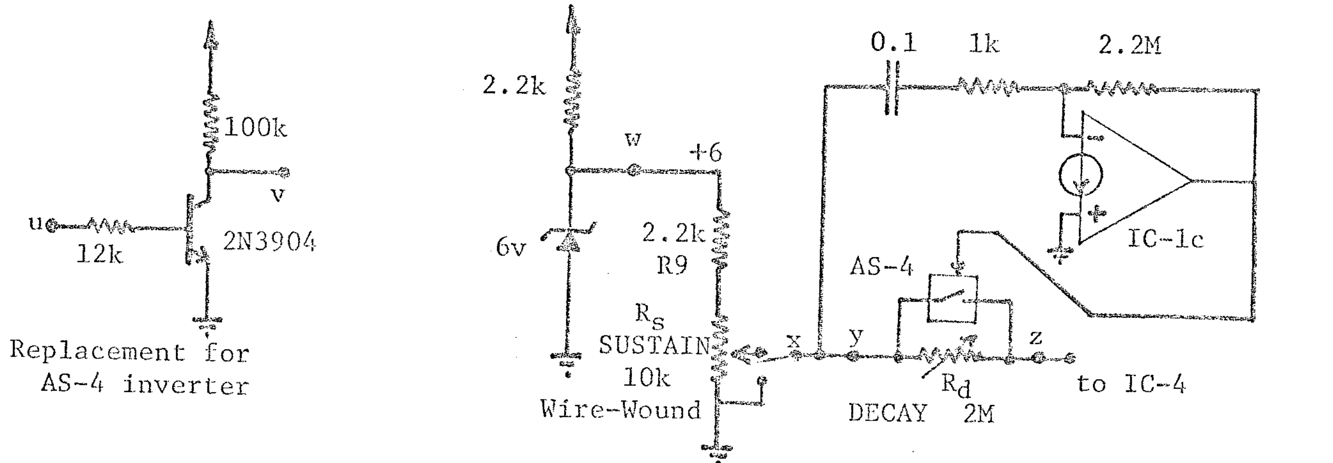


Fig. 8. Alterations to Fig. 2 or Fig. 5 for Instant Sustain Adjust Feature.

With the arrangement of Fig. 8, a system is achieved that works very well and does not require additional IC's. The output of IC-1c is "hash" that appears whenever the pot wiper is moved. This "hash" varies between +15 and ground, but is high enough for enough of the time to turn on AS-4 part time and thus short R_d. This is so simple to include, it should be made a part of either option as long as there is no problem getting the wire-wound pot required for R_s.

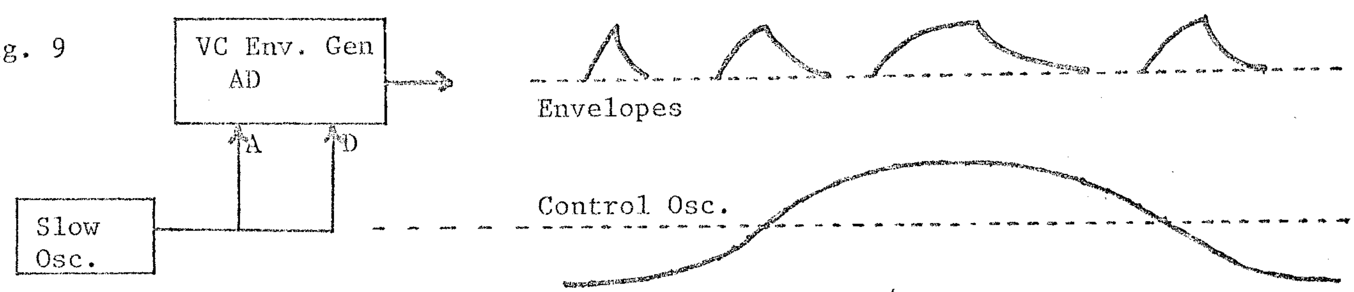
VOLTAGE-CONTROL OF ENVELOPE GENERATOR PARAMETERS

In this section we want to discuss the why's and how's of voltage-controlling envelope parameters. We shall begin by discussing why. Next we will list the parameters that we might want to voltage-control, and then give possible strategies for voltage-control. Finally, we will outline the actual voltage-control devices that we shall eventually employ in Option 3.

WHY VOLTAGE-CONTROL?

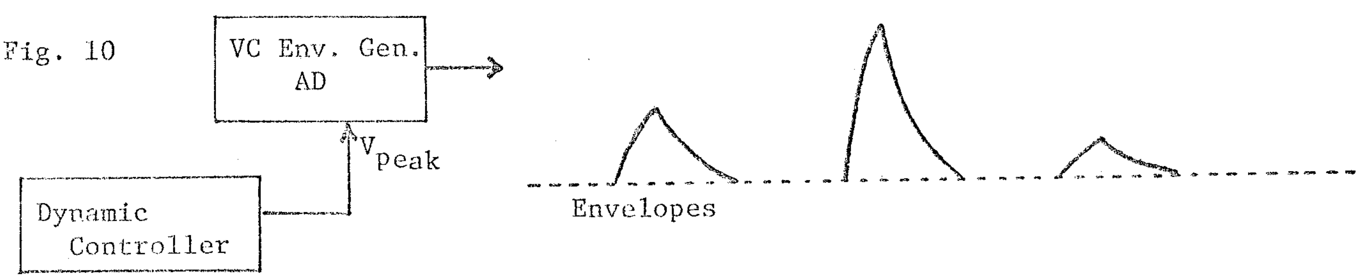
As with many things, the reason why is answered by showing what the device does or can do. First however, we should mention that in certain computer-controlled applications it is virtually essential that envelope peramenters be voltage-controlled since computers are good at setting voltages but no good at all reaching out and turning knobs. We then want to see what we could do with a voltage-controlled envelope generator in a conventional voltage-controlled synthesizer. Suppose for example that we had VC of attack and decay times of an AD generator. We could then voltage-control the length of notes in response to a slow oscillator as shown in Fig. 9.

Fig. 9



As a second example, we can consider the voltage-control of the peak voltage of the envelope as shown in Fig. 10.

Fig. 10



We have shown in Fig. 10 how the peak voltage can be controlled by some sort of dynamic controller. This might be for example a keyboard which puts out a voltage proportional to the force with which a key is hit. In the above example, this would mean that the attack would peak at a voltage that was proportional to keyboard force.

It is possible to go on with more examples. The reader will probably look at examples of his own and conclude that voltage-control is useful. It is in fact probably most useful with sequencer-oriented systems, and less useful for keyboard live performance systems. In any event, most medium and large size studios can justify at least one voltage-controlled envelope generator.

VOLTAGE-CONTROLLABLE PARAMETERS AND CONTROL STRATEGIES

Below we list the parameters that we can voltage control and a possible strategy of control. These strategies are aimed at adding voltage-control to the first two option given so far:

PARAMETER	CONTROL STRATEGY
Delay Time	Voltage-Controlled Monostable
Attack Time	Voltage-Controlled Resistor (Charging Type)
Peak Voltage	This is already a voltage.
Decay Time	Voltage-Controlled Resistor (Discharge Type)
Sustain Level	This is already a voltage.
Release Time	Voltage-Controlled Resistor (Discharge Type)

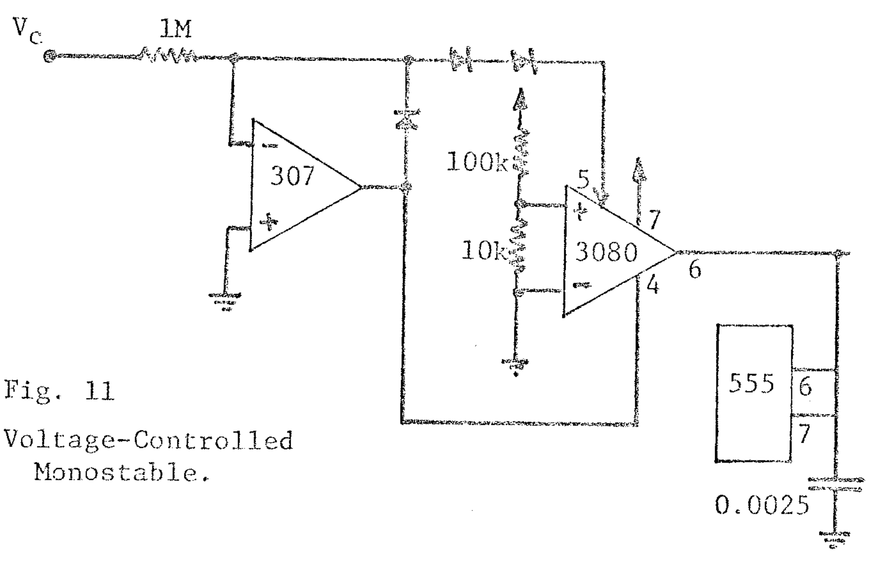
In addition to obtaining satisfactory voltage-control, we will be interested in seeing if there are any interesting new features that we can add as a result of voltage control devices we have installed.

VOLTAGE-CONTROL DEVICES

We can easily see from the listing above that the easiest parameters to voltage-control are the peak voltage and the sustain level. Since these levels are already voltages by their very nature, we have only to provide appropriate input devices for the desired control. We can consider this problem well in hand.

The second easiest control problem is the voltage-control of the delay time. As indicated above, our strategy is to use a voltage-controlled monostable. That is, we are going to voltage control our 555 timer which generates the delay time. This is a logical first step, and one which will lead us to many points that will be of interest later when we get to voltage-controlled resistors.

We can start by trying the voltage-controlled monostable described in EN#54 (20). This method employs the CA3080 as a current source for the capacitor on the 555 timer. The CA3080 is in turn controlled linearly in a manner described for the VCA circuits in the first part of the ENS-76 presentation. A typical setup is shown in Fig. 11 below:



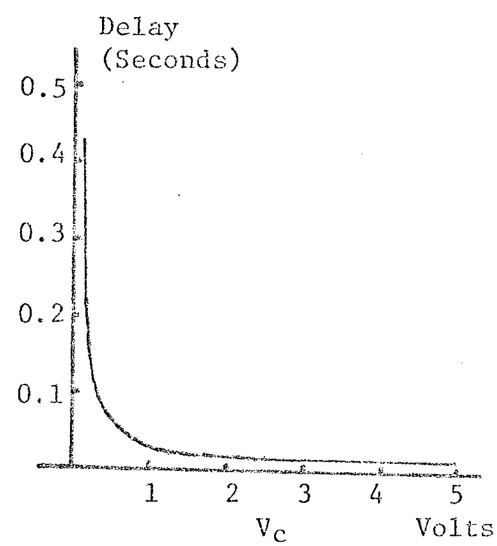


Fig. 11

Voltage-Controlled Monostable.

There are several points to notice about the graph in Fig. 11. First of all, it does show linear control! A plot of 1/(delay) vs. V_c gives a straight line. We have given the graph as shown since it is a better illustration of what the user would have to work with. On the high voltage side (V_c=+5) the delay is 7 ms. This is really short enough to be negligable, but we don't want to make it much longer and still expect to experience what seems to be zero delay. On the low side, the device fails (i.e., the monostable does not come down at all) when we try to exceed delays of about 425 ms. This is less than a 100:1 range, but even with out best efforts we don't expect much more with a linear control circuit. We could of course get longer delays be using a larger capacitor on the 555 timer, but we have to rule out range switching because we want to rely on voltage-control only. Thus we see that the circuit is not well suited for our purposes since it is of limited range and the control curve is a little "touchy" to say the least. In fact, it is probably correct to say that in many ways our perception of time intervals is logarithmic rather than linear. Thus we look for a circuit with more range and with a control range that is easier to adjust. The exponential circuit below serves well (Fig. 12).

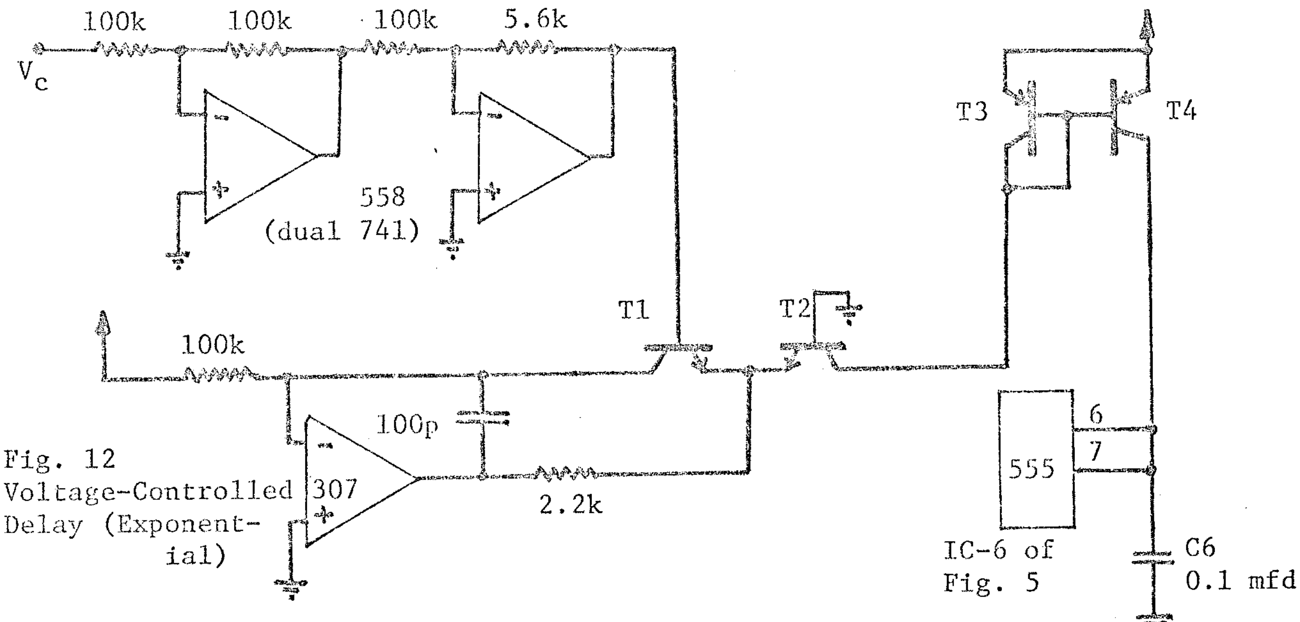
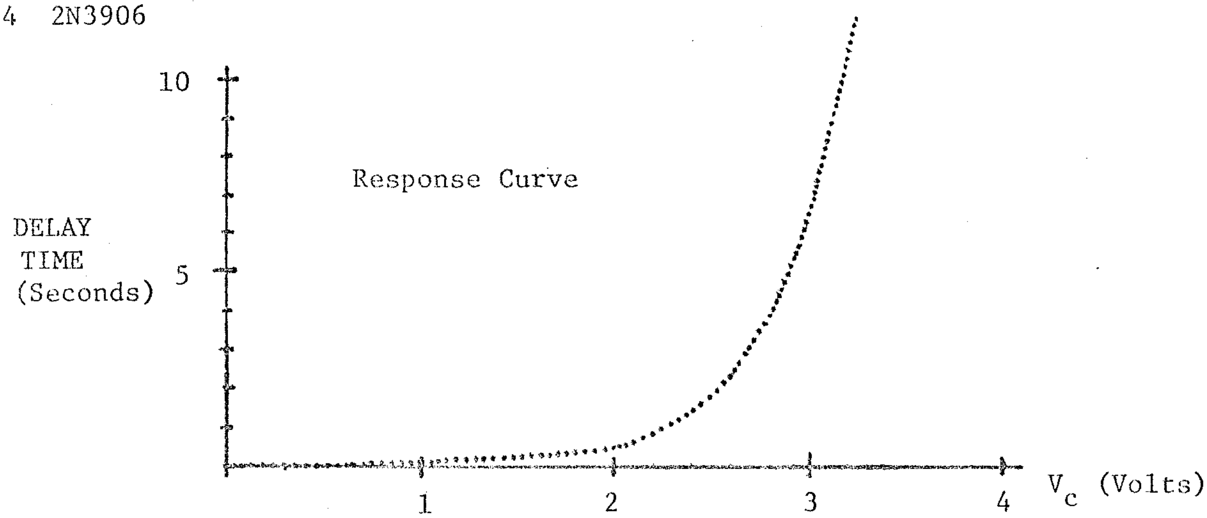


Fig. 12
Voltage-Controlled Delay (Exponential)

T1, T2 2N3904
T3, T4 2N3906



As can be seen from the curve, the response is exponential and over a wide range. The shortest time (V_c=0) is about 5 ms. From there the delay increases by about one decade per volt and delay times of several minutes are achievable. The transistor pairs can be but need not be matched monolithic devices. T1 and T2 are the familiar exponential converter while T3 and T4 are a current mirror.

IMPLEMENTATION OF VOLTAGE-CONTROLLED RESISTORS (VCR's) FOR CONTROL OF ATTACK, DECAY, AND RELEASE TIMES

Perhaps someday we will be able to go out and buy the voltage-controlled resistors we need, but for now we have to be content with making things like CA3080's look like VCR's. The use of the CA3080 as a VCR has been discussed before [Gordon Wilcox in EN#40 (7), and additional remarks in EN#58 (14)]. The basic setup for the VCR as given in EN#58 is shown below in Fig. 13.

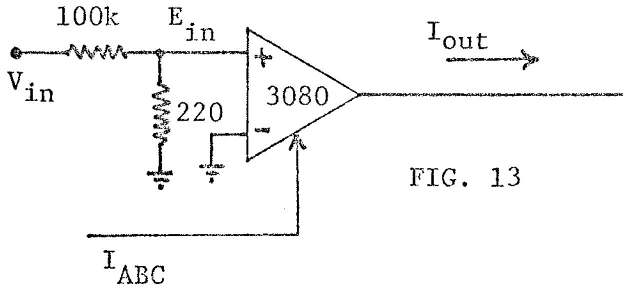


FIG. 13

$$I_{out} = 19.2\cdot I_{ABC}\cdot E_{in}$$

$$R_{eq} = V_{in}/I_{out} = \frac{23.7}{I_{ABC}(\text{amps})}$$

Actually, the above is no big deal - it just says that the CA3080 is what it is: a transconductor. The circuit supplies a current that is proportional to a voltage, and this is just Ohm's Law. However, it is not a resistor. The voltage V_{in} is not loaded down by a resistor R_{eq}, but by about 100k at all times. It is on the output of the CA3080 that things look like a resistor, since a current is being delivered that might have come from a resistor R_{eq} connected to V_{in}. Thus while this VCR implementation is useful in many cases, it is not general.

The kind of application we have in mind is most simply seen by considering the VCR for the Release part of the envelope. This is a case where the resistor must act like a load on the voltage applied to it. This can be seen in Fig. 14a. A little thought will show that we can reverse the + and - inputs in Fig. 13, and then connect the output of the CA3080 back to the point where voltage is applied. This is the method suggested by Gordon Wilcox, and is illustrated in Fig. 14b. This method is fine in many cases where the 100k attenuator on the inputs of the CA3080 does not load down the capacitor too much. However, in this case we know that this will in general discharge the capacitor very rapidly (we are accustomed to using several megohms for long decays). So we need a buffer for the capacitor voltage. But we already have the buffer sitting there! All we have to do is use it as in Fig. 14c.

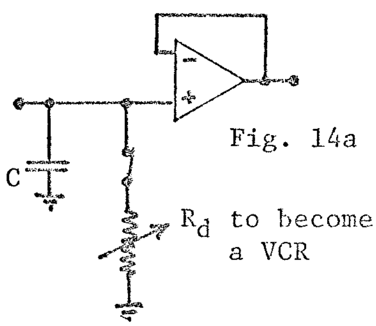


Fig. 14a

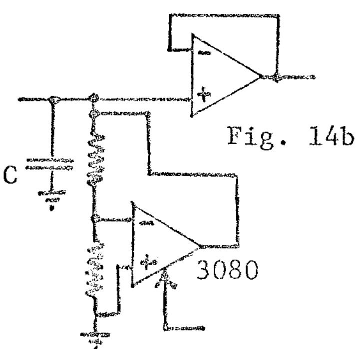
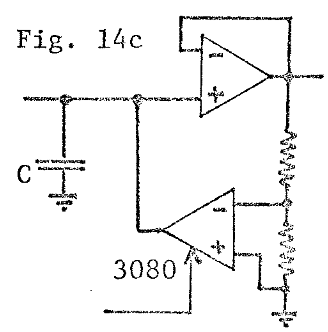


Fig. 14b

Fig. 14c



The above is a good example of a VCR implementation procedure. You start with something that should work, and then keep moving things around until it does. What remains to be done is to implement the control current driver for the CA3080. To do this, we will borrow what we learned from the delay section, and jump right to an exponential control scheme. Also, bear in mind that we will find it easiest to remember which way to turn controls if we associate higher voltages with longer times (as was done in the delay section, which required an extra inverter). With the VCR's we have the happy situation where things just happen to work out right. We can use a PNP exponential source and drop the current right into the bias terminal of the CA3080.

Now, the PNP source gives less current as the control voltage rises. This means that the CA3080 VCR's will be higher resistances for higher voltages. Higher resistances are (happily) what we need for longer time constants. The implementation of the driver stage is shown in Fig. 15 below.

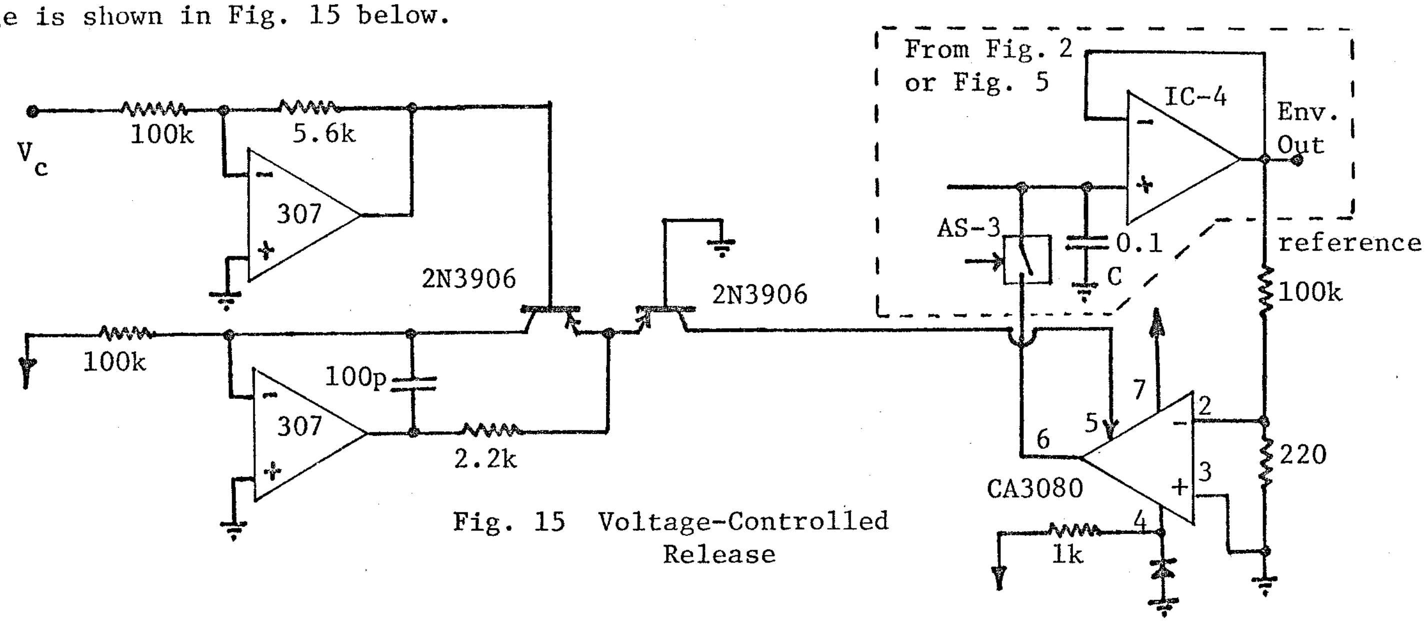


Fig. 15 Voltage-Controlled Release

The circuit gives release times ranging from a few milliseconds (V_c=0) up to about 10 seconds (V_c=5). Note that we have changed the value of the envelope generator capacitor from 2 mfd (Fig. 2 and Fig. 5) to 0.1 mfd for this voltage-controlled circuit. Note that the CA3080 is being run an a negative supply voltage of about -0.7 volts. It was found during testing that the -15 volt supply did not work. Apparently the fact that current was being drawn through an analog switch (operating on 0 to +15 volts) to a current mirror connected to -15 (in the CA3080) "confused" the analog switch chip so that the ADSR logic did not work. It will be seen presently that this supply is handy when we try to generate linear decays.

Now we reach an interesting point. We implemented a VCR, and we get as expected, the characteristic "exponentially decaying" release (See Fig. 1). What if we used as a reference voltage for the VCR not the envelope itself (as in Fig. 15 above), but a constant voltage? In this case, the current drawn into pin 6 of the CA3080 would be a constant, and the change in voltage would be linear in time. Since we are using a -0.7 volt supply for the CA3080, and there is a similar drop across the current mirror at the output of the CA3080, the linear downramp must end at zero. [Note that in the exponential release, the envelope stops at zero because this is the voltage at which the differential input to the CA3080 becomes zero. In the linear case, this would not have stopped for the same reason since the differential is a constant.] One further point about the linear downramp. If we have some idea that we may want to put a switch on the final design to switch from exponential to linear, we would like to have the decay times about the same (at least subjectively) in both cases. If we connect the reference to the peak voltage for example, the decay time in the linear mode will be much too fast relative to the exponential (which gets slower and slower as it approaches zero, and never really reaches zero in theory). Thus, we have to slow down the linear downramp. This is basically just a matter of putting a resistor in series with the 100k to further reduce the differential input voltage to the CA3080 when we connect this to some constant of about the peak voltage.

Now that we have two types of release waveform, why not try for three? The ones we have are linear and "concave" exponential. The "convex" exponential is possible by supplying a voltage that is the same as the peak minus the envelope, and using this as the reference for the VCR. The basic setup for this and the corresponding waveforms are shown in Fig. 16. Note that linear decay and release waveforms have been available in other circuits before, but the "convex" exponential is new.

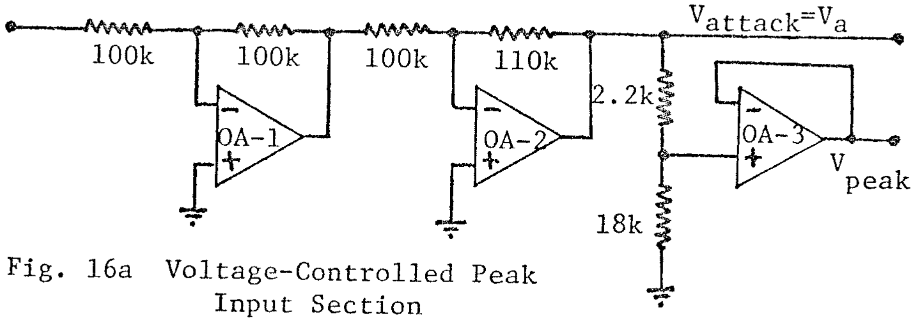


Fig. 16a Voltage-Controlled Peak Input Section

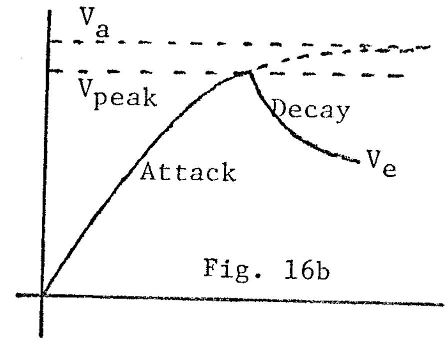


Fig. 16b

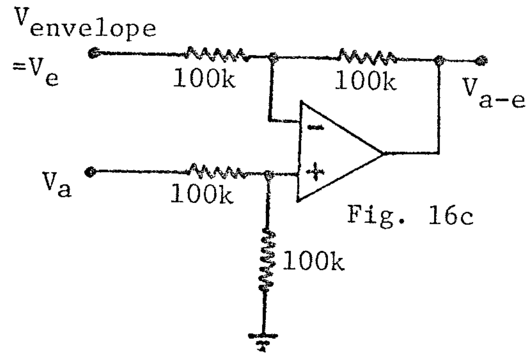


Fig. 16c

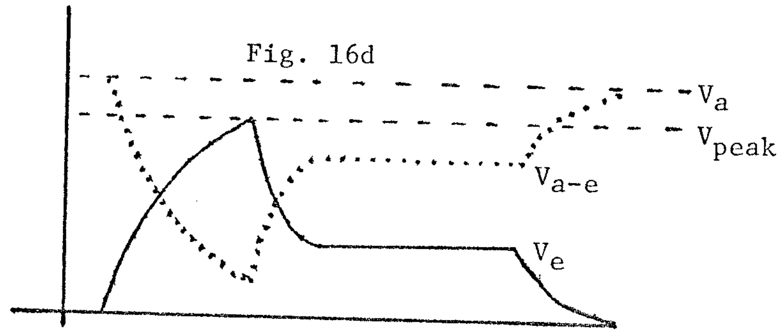


Fig. 16d

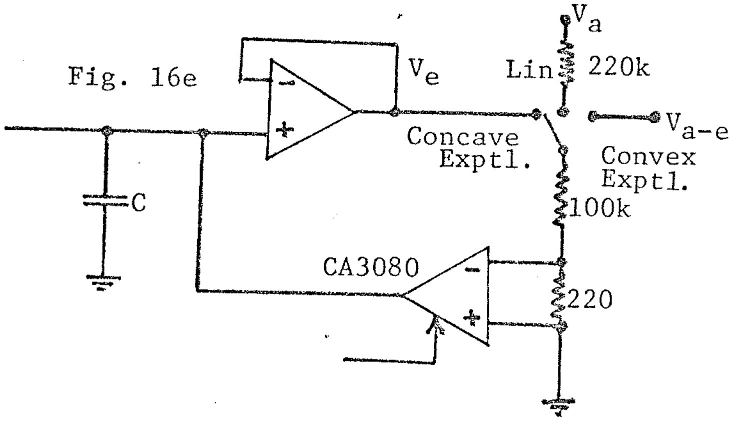


Fig. 16e

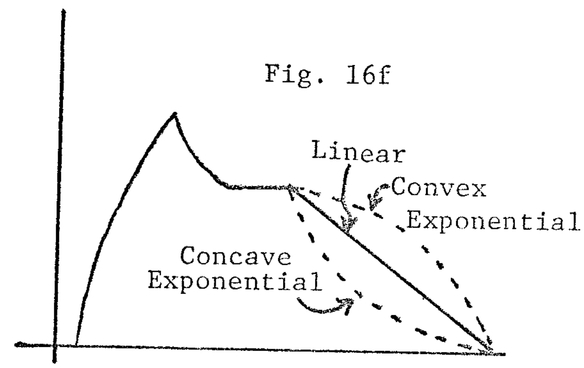


Fig. 16f

Fig. 16a shows the input section for the voltage-controlled peak. OA-1 and OA-2 form a non-inverting summer for the peak control voltage. The summer has a gain of 1.1 and a corresponding 10% cut is provided by the voltage divider on the output of OA-2. [Buffer OA-3 may not be needed in all cases. In the actual circuit (Option 3) the buffer is not needed since V_{peak} is obtained by using a larger resistor on the input of CDA comparator IC-15d]. Thus in providing the VC peak voltage in Fig. 16a, we have also made available a slightly higher voltage V_a. This higher voltage is needed so that the capacitor in the ADSR section charges toward a voltage higher than the peak. If it just charged toward V_{peak}, we would get a very flat top (theoretically, the exponential never reaches the peak) and response would not be well defined. Fig. 16b shows how this relationship between V_a and V_{peak} is used in the ADSR.

Fig. 16c shows the circuit for taking the difference between the attack and the actual envelope. Fig. 16d shows the corresponding waveforms. Note that even with sustain at the peak level, the V_{a-e} waveform does not reach zero. This assures that the convex exponential will always start down (theoretically the convex exponential never starts!). Thus we can use the switching arrangement in Fig. 16e to provide the release envelopes shown in Fig. 16f.

Next we look at the implementation of a VCR for the Decay→Sustain part of the ADSR. This is quite similar to the release, except instead of grounding the (+) input, we connect it to the sustain voltage level (through the appropriate attenuator). The circuit is shown in Fig. 17. Note that in this case the only thing that will stop the generator at the sustain level is the fact that at the sustain level the differential input voltage to the CA3080 becomes zero. There is no hard limiting factor such as there is in the case of attack (attack ends when peak is reached - switch opens) or in the case of release (can't have an envelope voltage below zero). Thus we can only have the concave exponential decay in this case unless some sort of logic state is established so that the sustain level is determined independent of a zero differential input voltage to the CA3080. The CA3080 in Fig. 17 is controlled in the same way it was in Fig. 15. Note that there is no reason why we can't set a sustain level above the peak. This permits a two phase attack to be achieved as shown in Fig. 17a. In this case however, it may not be possible to use a convex exponential release (see Fig. 16d)

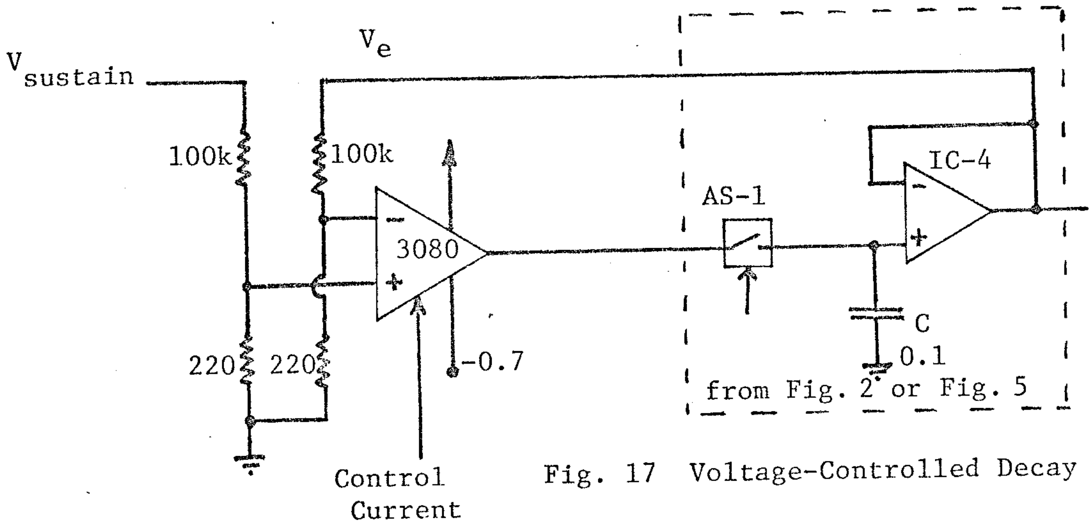
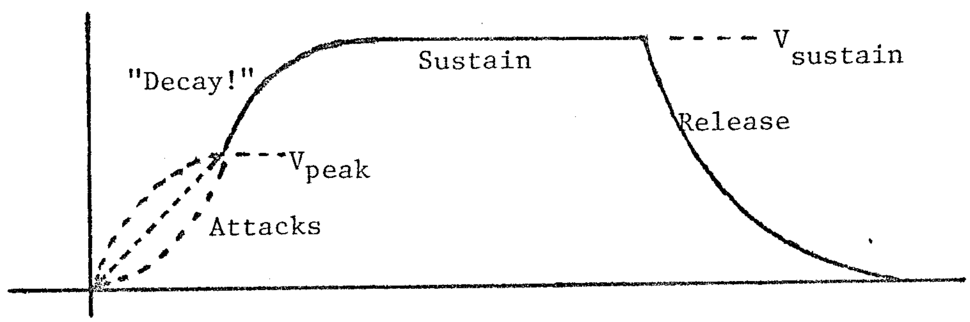


Fig. 17 Voltage-Controlled Decay Section

Fig. 17a

Two-Phase Attack



The attack section is similar to the sustain-decay section except we are charging so we reverse the + and - inputs to the CA3080, and reference the + input to V_{attack}. The circuit is shown in Fig. 18. Since attack ends by a logic decision ($V_e = V_{peak}$), we can use different types of attack waveforms [convex exponential (which is the normal one for attack - see Fig. 1), linear, and concave exponential]. Note that the attack VCR effectively simulates a "floating" resistor. One end of the resistor is connected to a charging voltage while the other end is connected to a capacitor being charged.

ENS-76 ENVELOPE GENERATOR - OPTION THREE

The ENS-76 Envelope Generator, Option 3 is shown in Fig. 19 on pages 18 and 19. The actual circuit is less complex than it might appear at first glance. If you understand everything we have been discussing up to this point, there is very little new in

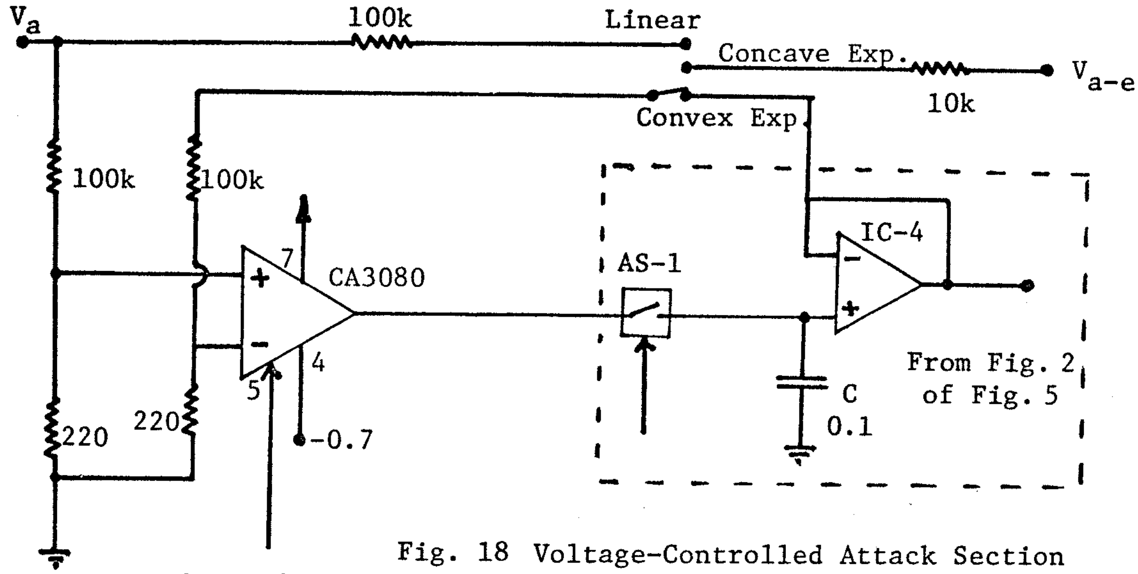
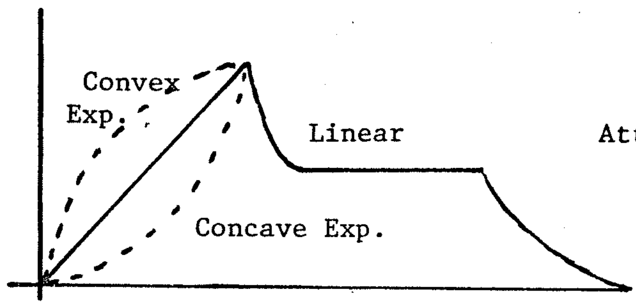


Fig. 18 Voltage-Controlled Attack Section



Attack Waveforms

the final circuit. This is basically the Option 2 circuit with voltage-control provisions added for Delay Time, Attack Time, Peak Voltage, Decay Time, Sustain Level, and Release Time. These have been added by means of techniques that have been discussed up to this point.

The control range has been set to accept control voltages of zero to +5 volts into a summing node through 100k. An initial setting of these values can be obtained by setting the manual controls which are 100k pots which supply zero to +15 through 300k. A second input is provided for each of the six sections and the actual remote control voltage enters through these.

Note that the op-amps used in the circuit are not too critical (except for IC-20 which should be a 307, 556, or better), and it is often convenient to use the type 558 (dual 741) as the sections tend to require op-amps in pairs. The generator can be built with 17 chips if this is done. We used ordinary unmatched 2N3904's and 2N3906's for the transistors. These seemed to work fine. If you touch one transistor with your finger while leaving the other untouched, the heat can cause a 10% drift in the controlled parameter. This may not be any problem, but for best results, glue the two transistors of each pair together with epoxy glue.

If you do build this, it is probably a good idea to start with fixed resistors (2.2 meg is good) for each of the VCR's and then verify proper operation of the ADSR logic. You can get the necessary attack voltage (+6 volts say) and sustain voltage (+3 volts say) by using voltage dividers between +15 and ground with the total series resistance of the voltage divider on the order of 10k. Once the generator is found to cycle properly, replace these dividers with the Peak voltage controls and the Sustain level controls. Finally connect up the VCR's one at a time making sure each one functions properly.

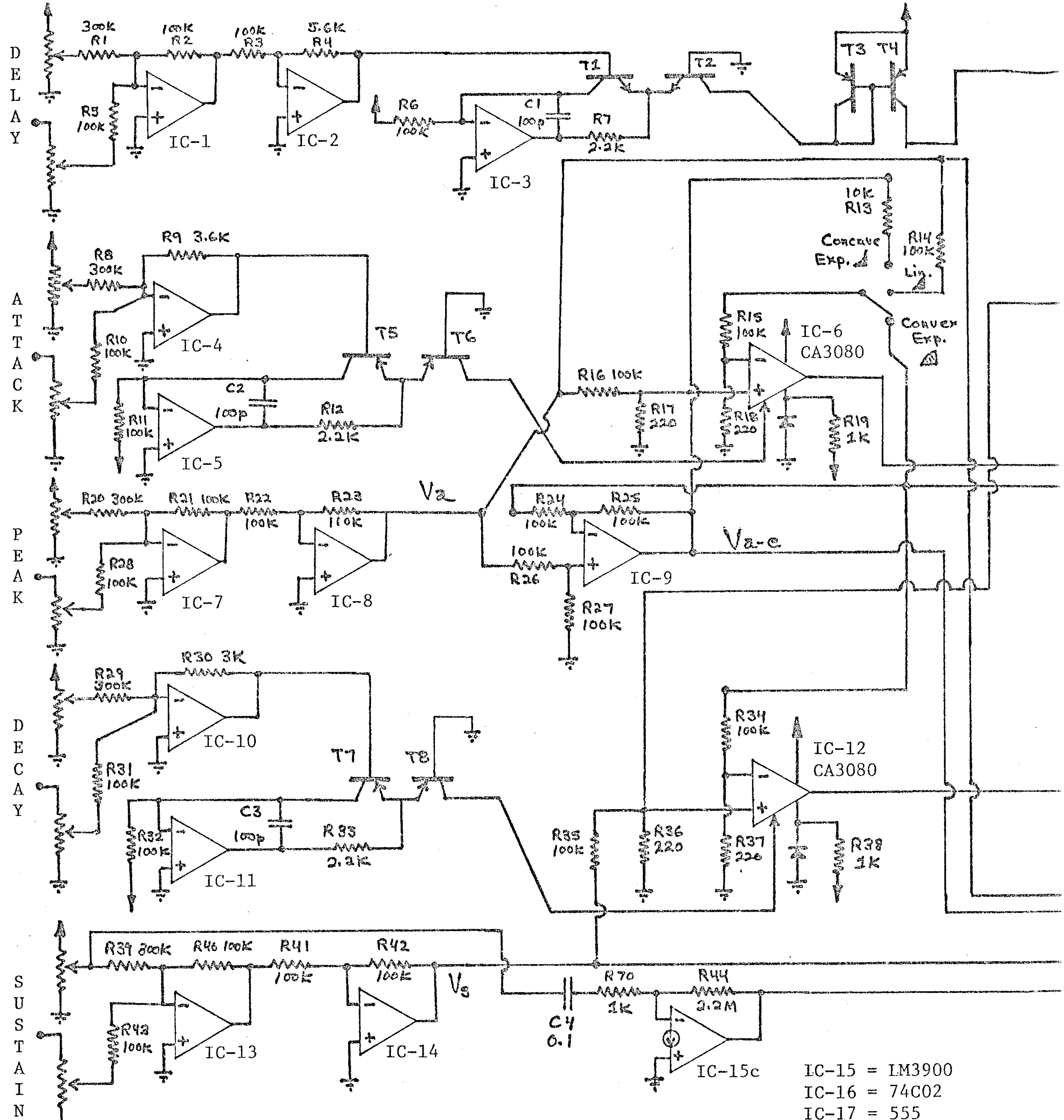
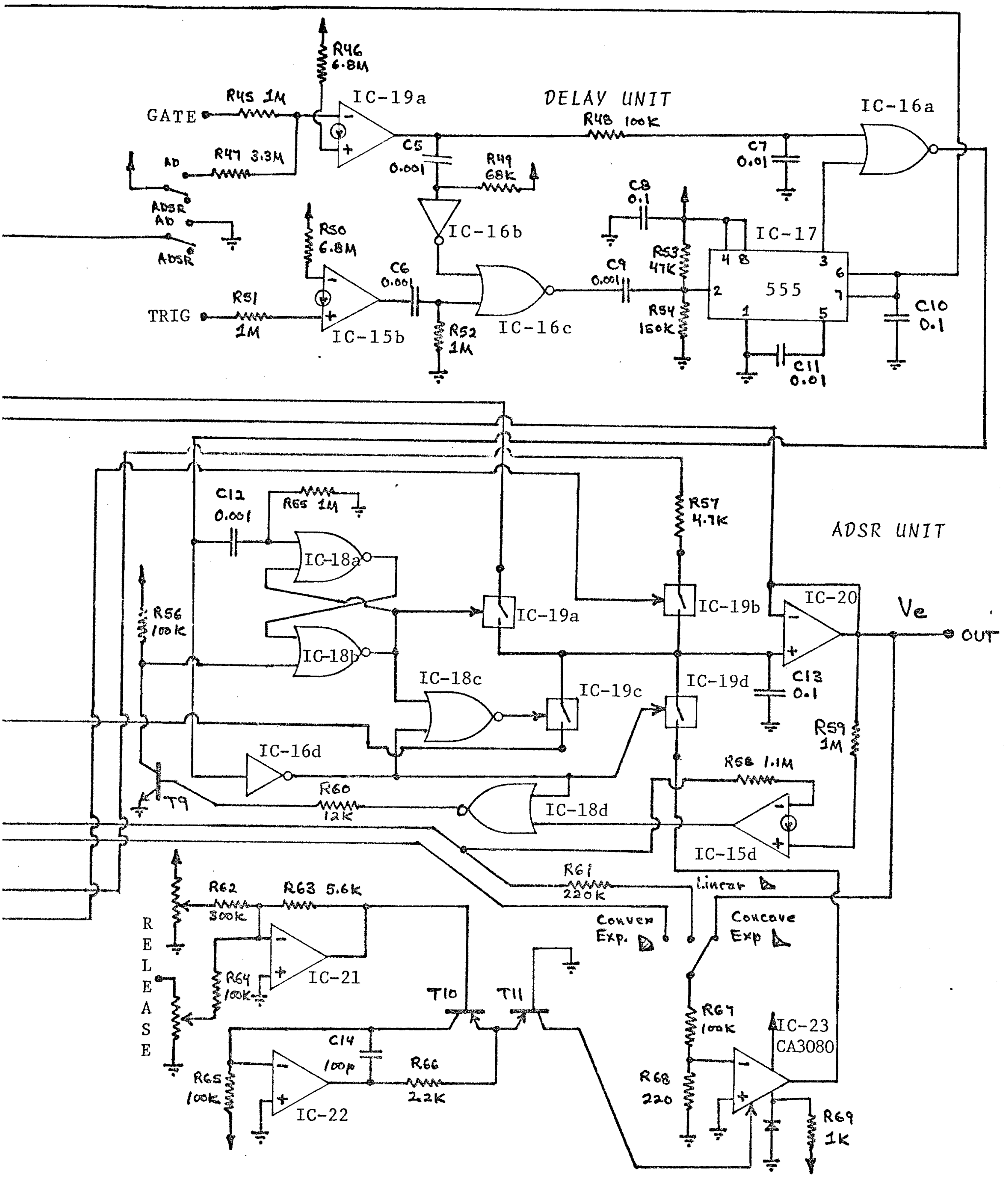


FIG. 19

IC-15 = LM3900
IC-16 = 74C02
IC-17 = 555
IC-18 = 74C02
IC-19 = 4016

Notes: All PNP = 2N3906, etc.
All NPN = 2N3904, etc.
All diodes = 1N914, 1N4148, etc.
All unmarked op-amps, 741, 307, ½558, etc.
All pots = 100k (or any value 10k to 250k)



ENS-76 ENVELOPE GENERATOR OPTION THREE

The Option 3 circuit has been tested for proper operation and for a reasonable range of the controlled parameters. The range of the parameters in the VC mode exceeds the corresponding manual range in the Option 2 circuit. None the less, there is probably room for improvement, and different circuits may need slightly different values for certain resistors. In particular, as we have noted, it seem reasonable that when we change from one envelope waveform to another that the subjective feeling for time is as much the same as possible. We could if we wished determine experimentally (and in some cases, theoretically) exactly how these parameters should be trimmed up to achieve this. In the design as shown we opted for ballpark values that seemed to assure reliable operation.

A few final points. It is a good idea to bypass the power supply with about 0.01 mfd on each of the logic chips and on the LM3900. As always, handle the CMOS (IC-16, IC-18, and IC-19) with a little care. Finally, we list below the power requirements for the IC's in the event this is not clear from previous examples:

IC's using ±15 volt supplies:	IC- 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 13, 14, 20, 21, and 22.
IC's using +15 and ground:	IC- 15, 16, 17, 18, and 19
IC's using +15 and -0.7 (by means of the diodes):	IC- 6, 12, and 23

BRIEF NOTES ON TROUBLESHOOTING ENVELOPE GENERATORS

Envelope generator circuits tend to either work or not work - there is no marginal case to worry about. When they don't work, it is usually because the logic gets stuck. For this reason, you have a good chance that things will work right the first time if you do a careful job of construction. However, if things don't work the first time, you had better understand how the circuit is supposed to work so you can see what state it is stuck in. Once this is determined, it should be simple to find out why it is not advancing to the next state. For example, if you find it is stuck at the peak voltage, it may be that the inverter in the reset line is not functioning. Or, it might be that noise on the trigger line is causing rapid retriggering and holding the generator at the peak.

Don't forget to take advantage of the input buffers during testing. You can use any sort of waveform and get a trigger whenever the waveform crosses +2 volts and goes above. You get a gate whenever the input is above +2 volts which remains until the input falls below +2. This makes it possible to connect up oscillators operating at a frequency like 1/10 Hz and have two hands free for testing as the envelope generator cycles automatically every 10 seconds.

With the VC generator (Option 3) as we have previously suggested, it is best to start with fixed devices and add in the VC features one at a time. Also, you may want to defeat the "Instant Sustain Adjust Feature" (IC-15c and IC-19b) if you are having any problems with the sustain level. For example, if you are being held at the sustain level, IC-19b may be closing erratically in response to noise in the circuit.

SOME NOTES ON "FUNNY" ENVELOPE WAVEFORMS

As can be seen from Fig. 1, the standard ADSR is the simplest waveform you can get by just charging and discharging a capacitor. These valtage waveforms are the "natural modes" of the resistor-capacitor combination. As they are the natural modes of electrical components, so are they the natural modes of some mechanical devices, including many musical instruments and many musical-like sounds that we hear. For example, the simple AD waveform in Fig. 20a is somewhat characteristic of percussive sounds and of many sounds we hear every day like the neighbor's dog knocking over your garbage can. The point is that this sort of waveform seems quite "natural" to us while other envelopes may seem unnatural in the sense that when we hear them we can't imagine what sort of worldly device might have produced the sound. It is a fimiliar demonstration to play a tape of piano music backward. The resulting envelope is a long attack and a very rapid decay which is not recognized as a piano, and may be mistaken for something more like a pipe organ. This sort of waveform is shown in Fig. 20b. We could always approximate this sort of waveform with our convex exponential attacks, but to do it properly, we need a concave exponential attack. With the envelope generator Option 3 we can do this sort of thing. We can make the reverse of the normal AD by setting the attack for concave, the release for convex, and lightly tapping the keys of the controlling keyboard. This waveform is shown in Fig. 20c. Two other envelopes of interest are shown in Fig. 20d and 20e which use concave and convex exponentials respectively for both the attack and the decay. Also, by setting a sustain level above the peak, it is possible to obtain an attack with an inflection point as shown in Fig. 20f.

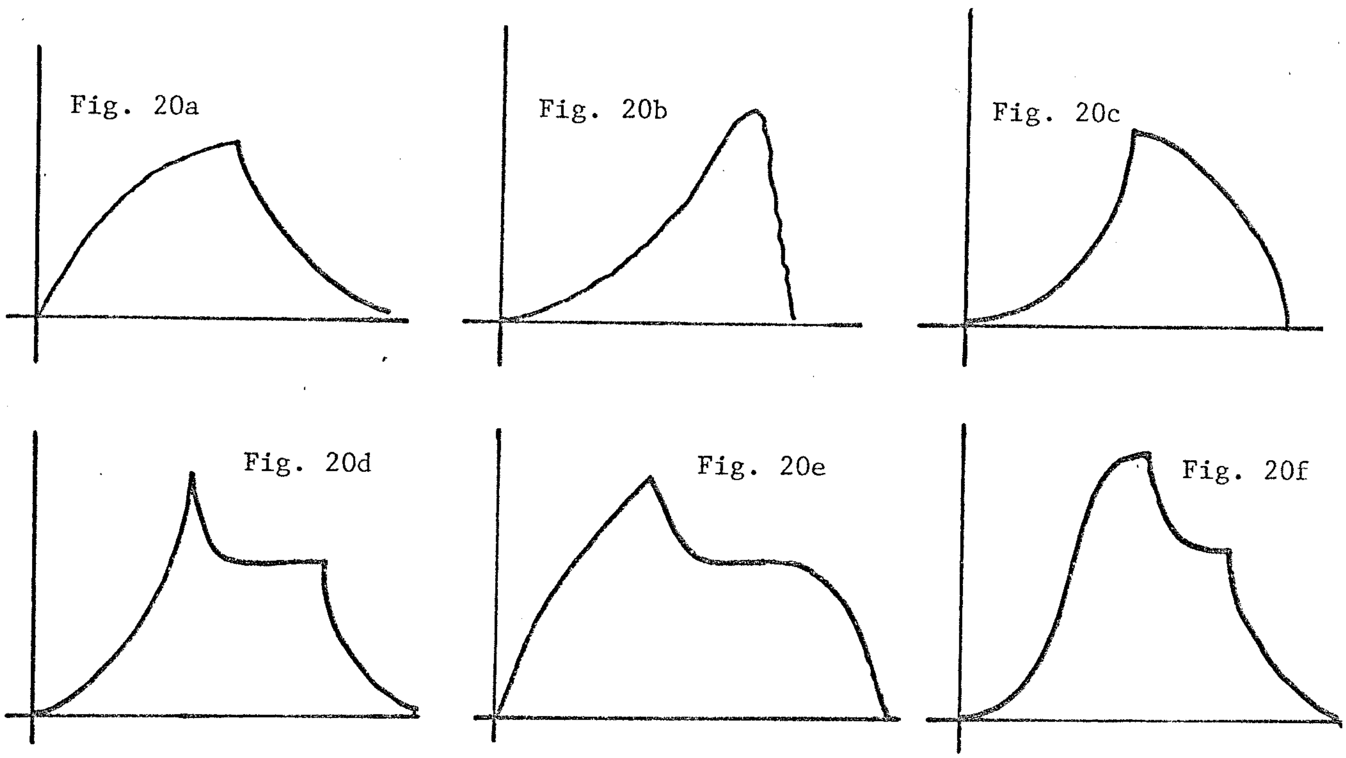
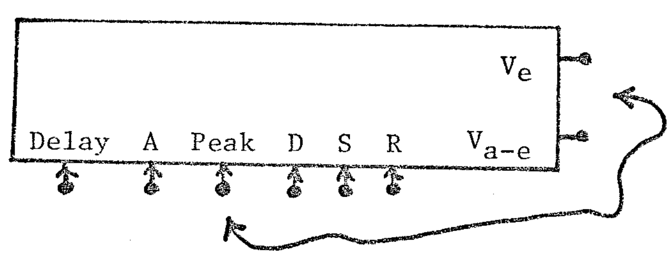


Fig. 20a Fig. 20b Fig. 20c

Fig. 20d Fig. 20e Fig. 20f

As a rule, whenever you develope some sort of voltage controlled device, it is a good idea to plug various outputs back to the control inputs to see what happens. Quite often, something of interest results. In the case of envelopes, linear waveforms can be changed to exponential waveforms [See "On Changing Linear Waveforms and Envelopes to Exponential" by B. Hutchins, EN#26]. The feedback method is similar to what we have been doing internally when we adjust the reference voltages to the VCR's in the Option 3 circuit. If we hook up the feedback in the Option 3 circuit with the convention that higher voltages represent longer time constants, it is clear that we will be able to make only certain types of variations. For this reason, we want to also make available an inverted version of the envelope (or just bring out the V_{a-e} envelope from the Option 3 circuit). With this combination, many feedback paths are possible. The possibilities are suggested by the diagram in Fig. 21.

Fig. 21



As an example, suppose we feed back the envelope itself to the voltage-control input for attack. This means that as the envelope rises, it starts to go slower and slower. This will tend to square up the corner of the attack. If on the other hand the V_{a-e} voltage were fed back, the normally exponential attack would tend to become more of a straight line. It is of course possible also to control a voltage-controlled envelope generator with another envelope generator, and this could also provide many more complex envelopes.

We should also mention that there is another factor that tends to complicate the picture when the envelope generator is controlling a VCA. Many VCA's have both a linear and an exponential response. Naturally if we control the VCA using the exponential mode the amplitude is going to rise faster than it does in the linear mode, and this is equivalent to having a different envelope waveform applied to a linear VCA control.

Eventually you get to the question as to whether or not a variety of envelopes are needed for a given musical application. This is of course a matter of personal opinion, but we can say a few things. First, different envelopes seem less apparent during amplitude attacks. It is possible to tell convex and concave exponentials apart, but linear is not much different from either one. It is possible to clearly tell concave exponential, linear, and convex exponential releases apart. As mentioned above, only the concave exponential release sounds "natural" while the others are certainly interesting. We must also consider that devices other than VCA's are controlled by envelope generators. It is common practice to control a VCF with an ADSR generator and thereby alter the relative harmonic content of a waveform. It is difficult to say anything simple and exact about harmonic changes, but we do know that during the attack phase of a musical tone it is often the case that very complex harmonic changes take place rapidly. There is no reason to suppose that these changes can be approximated by a VCF controlled by an ADSR envelope generator. Here is where complex envelope waveshapes may prove to be very useful. We should further note that it is not just the shape of the envelope contour that is important, but the duration. Many very short envelopes (10 ms to 100 ms) will sound essentially the same. Envelopes that last for one to several seconds are those during which a different contour is most likely to be detected. Envelopes with very long duration tend to loose their identity - not just as different contours, but as any sort of unified envelope. Apparently with long envelopes there is less apparent change of a parameter, and the change could be manual, while shorter envelopes give the impression of something that exceeds the capability of manual control.

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