ELECTRONOTES 63

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GROUP ANNOUNCEMENTS:

CONTENTS OF EN#63

I think we have a pretty good balance this issue between analog and digital, and also between technical and non-technical. We have in this issue a paper by Douglas Kraul which is an excellent illustration of a microprocessor application which is useful for electronic music. The series on microprocessors by Bill Hemsath will continue next issue. In addition to finishing projects already started, we are studying various systems that are based on noise generators. Specifically we are looking at different types of noise generators and pseudo-random devices, and will be seeing the different ways they can be applied as well as studying the theory. A larger question that we are considering is formulated as follows: In electronic music we use mostly perfectly periodic signal sources (oscillators) or random ones (noise generators). What is there that might be in between, and would it be useful? This is a question that several people have asked me in the past. I believe that the slew-limiting sample-and-hold device discussed in EN#61 is one example. Any and all comments on this sort of thing would be welcome.

NEW MEMBERS AND ADDRESS CHANGES (c): We have quite a list this time due to the fact that we have not printed names for three issues and there have been a lot of reprints requested during renewal time. There are probably a few mistakes in this list as far as the indication of new members (no notation) or changes (noted by "c") goes. Please bear with us. If any names are misprinted, please call them to our attention.

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THE ENS-76 HOME-BUILT SYNTHESIZER SYSTEM - PART 1: -by Bernie Hutchins

We are starting here the presentation of the ENS-76 system. This first installment will give an introduction, and will then give the first two circuits. The new circuits will be a new VCA circuit and a new balanced modulator. Additional installments in the ENS-76 series will appear as circuits are completed.

INTRODUCTION

The ENS-76 system will consist of several different types of modules. Basically these will fall into three categories:

(1) Basic modules as found in most voltage-controlled synthesizers. These will include VCO's, VCA's, VCF's, balanced modulators, envelope generators, noise sources, and sample-and-hold units. Controller setups and interfaces will also be included here. We will try to give here the most reliable circuits we had in the ENS-73 and ENS-74 systems, and add in any recent circuits that seem to fit well. In all cases, we shall try to have at least one module of each type that can be built as simply and inexpensively as possible.

(2) We shall also give some modules that have additional features that are "proven" in the sense that thay have been used before and have been found useful. However, these features are not standard features of all voltage-controlled synthesizers, and may not be needed by all users.

(3) We shall also have a number of experimental modules. These will be tested circuits that are know to work but which have features that have not been musically tested or which are only being tested at this time.

STANDARDS:

Power Supplies: +15 volts [↑]; +5 volts [⇧]; Ground [⏚]; and -15 volts [↓]

Signal Levels: ±5 volts peak-to-peak

Envelope Levels: 0 to +5 volts

Gates: +5 volts = ON

Triggers: short +5 volt pulses

Voltage Control of Pitch Level: 1-volt/octave into 100k input impedance

Input Impedances: greater than or equal to 50k with 100k or greater preferred

Output Impedances: outputs through a 1k resistor or equivalent as standard

Multiplying Modules (VCA, Bal. Mod.): Unity gain at 5 volt levels, linear or exp.

Notation: Standard schematics and symbols. Also, panel controls will be denoted by PC (e.g., PC-4); trim pots as TP (e.g., TP-4).

In general, a good deal of circuit description will be given. In cases where the design principles are available elsewhere (as in MEH), less description will be given. In most cases, we will not be able to give detailed test results along with the circuits. We shall try to do some careful testing of VCO stability and tracking some time before the series ends. All circuits given will be tested to see that they do function even though we may not be able to say that one circuit is better than another and in what ways it is better. At the end of the series, we expect to give out all the trouble shooting information on hand and suggest any individual modifications that may be useful. In particular, we will tell how to modify the circuits to work on ±10 volt signal levels. Anyone needing this information earlier may write.

ENS-76 VOLTAGE-CONTROLLED AMPLIFIER - OPTION 1

As we have often noted in the past, a VCA is basically a 2-Quadrant Multiplier (2QM) while a balanced modulator ("Ring Modulator") is a four-quadrant multiplier (4QM) Previous VCA designs have been quite successful and we have no real reason to change them for the ENS-76. However, we are giving here a very simple design based on the CA3080 and a couple of op-amps - all parts which are readily available. This VCA also serves to introduce the balanced modulator design that follows since the balanced modulator is a simple extension of the VCA technique. Both these designs are based on the ingenious linear current drive for the CA3080 reported by Walter Jung ["Get Gain Control of 80 to 100 db," Electronic Design, June 21, 1974; or "Application of the Two-Quadrant Transconductance Amplifier/Multiplier in Audio Signal Processing," J. Aud. Eng. Soc., Vol. 23, No. 3, April 1975].

LINEAR CURRENT DRIVE FOR THE CA3080:

The CA3080 has a gain that is controlled by the current flowing into pin 5. In normal operation, pin 5 is at a voltage that is approximately one diode drop (0.6 volts) above the negative supply voltage on pin 4. Thus we can supply current to pin 5 by connecting it through a resistor to a voltage that is more positive than the negative supply by an amount exceeding 0.6 volts. For example, when powering the CA3080 from a ±15 supply, current can be supplied from any voltage from -14.4 up to +15. Ground is often used for this purpose in fixed bias setups. This brings up the important point that current supplied in this way is not linear with respect to zero volts, but with respect to -14.4. Thus we can not use the simple resistor to supply current if we want a voltage that is linear with respect to zero volts, and we generally do want a response that is linear with respect to zero (for envelopes that range from 0 to +5 for example where zero corresponds to an OFF condition).

We can drive the CA3080 from a linear voltage-to-current (V/I) converter as suggested by Fig. 1. Satisfactory V/I converters generally use an op-amp and one or more transistors (For example the current source for the ENS-74 keyboard interface, IC-1 and TR-1 in EN#45, page 12, or the current source shown in EN#59, pg. 6).

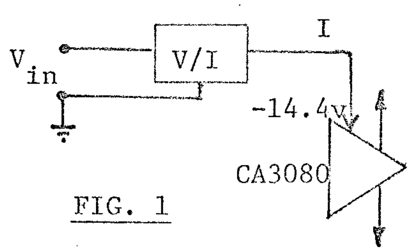

FIG. 1

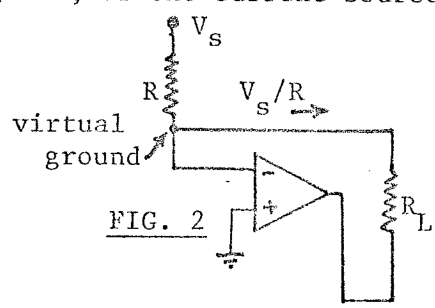

FIG. 2

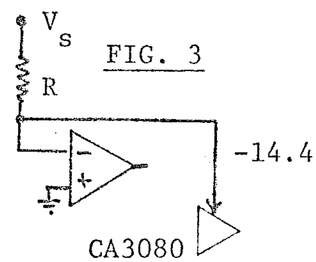

FIG. 3

One very attractive current source is the V/I that is formed from the virtual ground in an op-amp stage with negative feedback. This is suggested by the circuit in Fig. 2. Note that this is nothing more than an inverting amplifier where we have shown the feedback resistor as a load, R_L and put it in a position where to seems to be receiving a voltage-controlled current. The "catch" with this type of circuit is that the operation relies on the fact that the output voltage of the op-amp takes on whatever value is necessary so that enough current is drawn so that the (-) input is at virtual ground (putting the horse back in front of the cart in this case). That is, the virtual ground is a result of the adjustment of the op-amp's output. In short, the loop must be closed. In particular, the circuit in Fig. 3 has no virtual ground. The (-) input in this case is held at about -14.4 by the diode in the CA3080, and a current $(V_s+14.4)/R$ flows instead of V_s/R. We have of course seen a case where the virtual ground type of V/I converter is very useful. This is the case where a reference current is fed to an exponential converter. In such cases, the output of the op-amp feeds back to the (-) input through the attached transistors in the exponential converter. It is this sort of feedback path that we must use here.

Jung's method of driving the CA3080 involves the placement of the CA3080's bias current current-mirror in the feedback loop. This is done by letting the op-amp output supply the negative supply voltage for the CA3080. This is shown in Fig. 4 below:

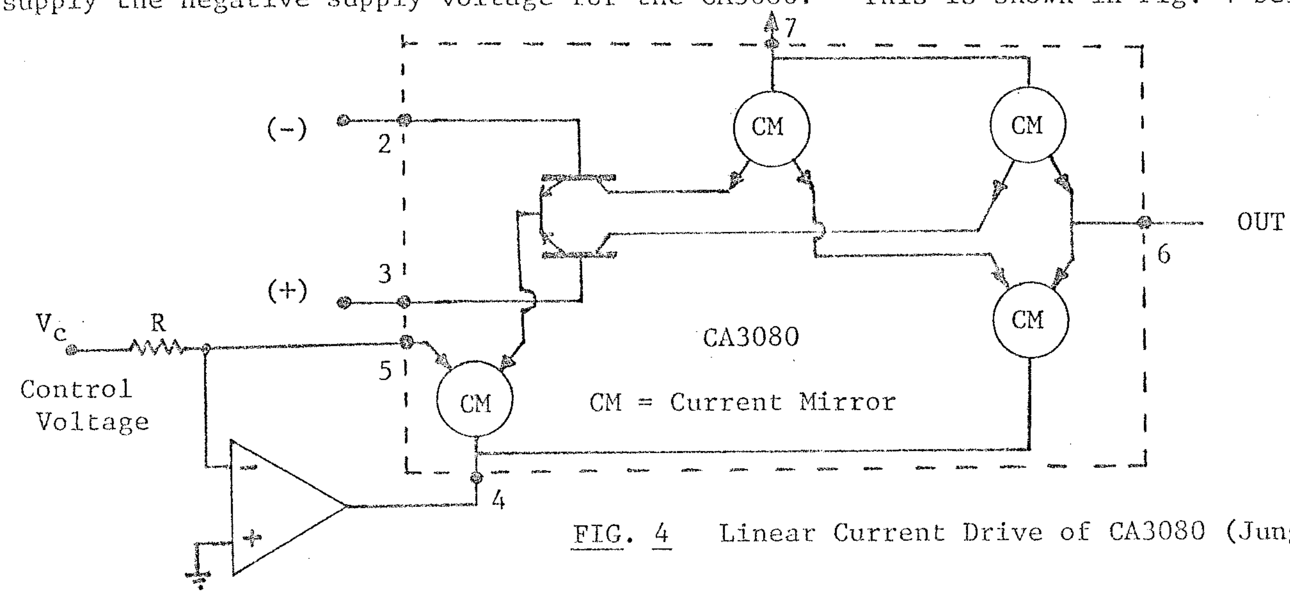

FIG. 4 Linear Current Drive of CA3080 (Jung)

Pin 4 of the CA3080 (the output of the op-amp) thus assumes whatever voltage that is necessary to draw the current V_c/R through pin 5 of the CA3080 and into the current mirror. This will be on the order of -0.6 volts. The op-amp thus works as a negative supply of about -0.6 volts for the CA3080. This negative supply value can be increased by inserting diodes (or zener diodes) in the line to pin 5. One such diode, as will be seen in the examples below will give a negative supply value on pin 4 of about -1 volt. What are the restrictions of this method? First, the input voltages to pins 2 and 3 of the CA3080 must not exceed the supply limits (+15 and -1 in this case). Note that for the VCA designs we are considering below that the differential input should not exceed ±10 mv due to the two-transistor differential amplifier stage. This is done so that the device works in a linear mode. Thus, we will always use an attenuator on the inputs to the CA3080 and the differential input and absolute input voltages relative to ground will be well within the supply limits. The second restriction is that the output will not drive current into a voltage exceeding the supply limits. Thus, in the VCA example it will be necessary to drive the output into an op-amp summing node as a current-to-voltage converter. This is a good choice of output stage anyway, and the inversion due to this type of current-to-voltage converter is easily taken care of by using a different input to the CA3080. Thus we see that neither limitation poses a problem here. Note however that the limitations may become apparent in other designs. If we tried to drive the basic oscillator stage of the VCO in EN#46, it won't work. This is because the input voltages are quite large since we want to saturate the input stage (CA3080 as a current switch) and the output drives the gate of a FET which must reach -5 volts. The solution in this case would be a zener diode of about 8 volts in the line to pin 5 of the CA3080. This would mean that the op-amp would be supplying a negative supply voltage to the CA3080 which would be something like -9 volts.

The discussion above relates directly to the actual VCA circuit shown in Fig. 5. For a first analysis consider R6, R7, TP-1, and PC-1 to be out of the circuit. IC-1 then forms a linear V/I converter stage which drives IC-2. Don't be confused by diode D1 as it only keeps negative envelope voltages out so that the output of IC-1 is never very far from its desired operating point. Also, diode D2 is not essential to the analysis - it just gives the negative supply to the CA3080 a slightly lower value as discussed above. IC-3 is the inverting I/V converter and note that the (-) input of the CA3080 has been used to compensate for the inversion. We have shown the (+) input to the CA3080 grounded. It could be used as another input if desired (with the 100k - 220 ohm attenuator). Others may want to use the (+) input to trim out the offset voltage of the CA3080 if the lowest distortion performance is desired. This could be done as it is in the balanced modulator circuit that follows.

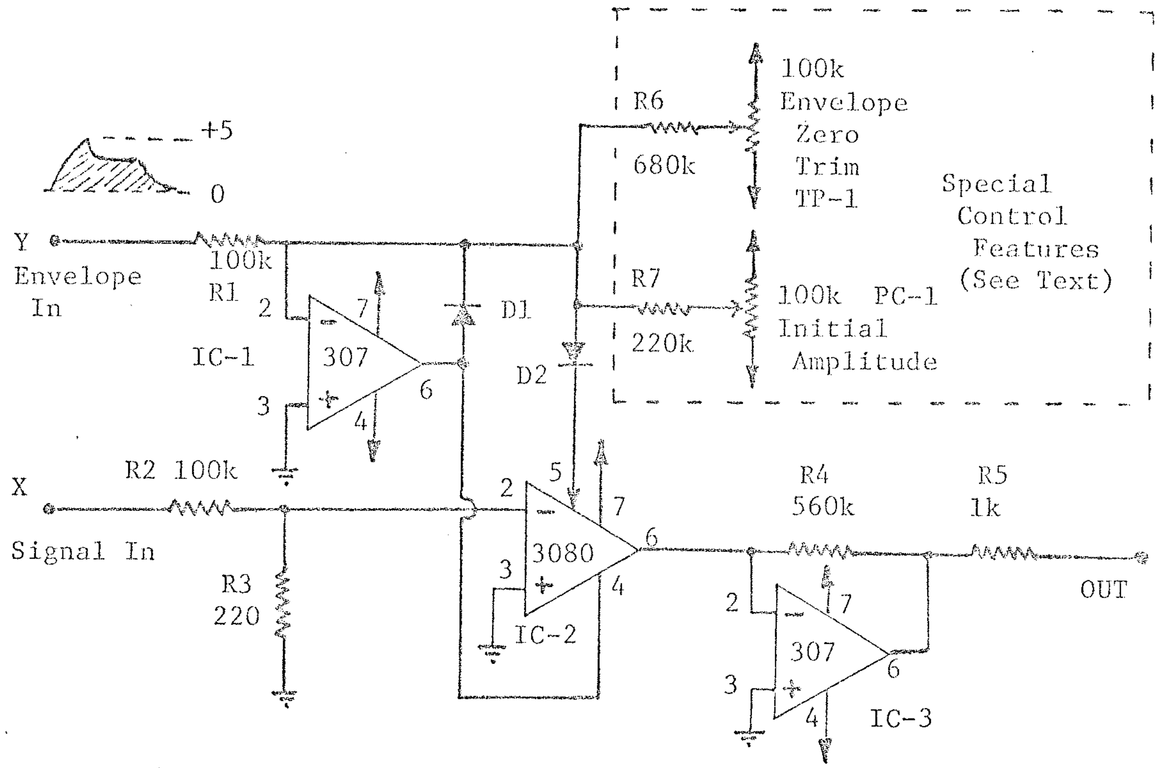

FIG. 5 ENS-76 VCA Option 1

At full envelope voltage (+5), the current through R1, D2, and into pin 5 of IC-2 is 5/100k = 0.05 ma. At max. input signal level ($\pm$5 volts), the signal on pin 2 of IC-2 is ($\pm 5 \cdot 220$)/100220 or about $\pm$11 mV which is in a range where the differential input of IC-2 is still sufficiently linear. The basic equation of the CA3080 tells us that the maximum output current will be:

$$I_{out}(max) = 19.2[V_{in}(max)][I_{bias}(max)]$$

$$= 19.2[0.011][0.05 \text{ ma}] = 0.01056 \text{ ma}$$

We want this current to be forced through R4 to give a 5 volt level out. Thus:

$$R4 = 5/0.01056 = 473k$$

We actually found that a larger resistor (560k) was needed in our design to give unity gain. In practice you may want to adjust R4 a little if an accurate unity gain is required. This can be done with a trim pot, or you can just make R4 a series of two resistors - one to get it close to unity gain, and a second to take up the slack. This is a procedure that is often useful when you need only a few percent accuracy and would rather spend a little time and an extra fixed resistor rather than investing in a trim pot.

So far, we have shown that the circuit is a two quadrant multiplier where the X input is bipolar and the Y input is unipolar (only accepting + voltages). The output is:

$$V_{out} = XY/5$$

This is a very basic VCA. However, for an actual module you may want to add some extra controls. If you want a manual control, add R7 and PC-1 as shown, but make R7 = 300k. This gives the manual equivalent of a 0 to 5 volt envelope. We also know that it is common practice to "bury" the envelope a little so that a normal exponential decay is truncated (see Fig. 6 over). To add this feature simply make R7 = 220k. Then select a marker point on the dial for PC-1 at a point approximately 2/7 rotation. This will

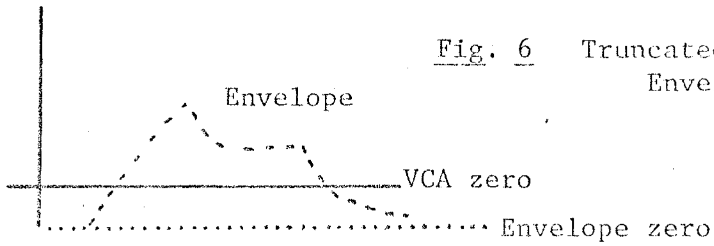

Fig. 6 Truncated Exponential Envelope

be envelope zero. Now set TP-1 to its +15 volt position and apply a signal to X. The signal should come through. Now adjust TP-1 toward -15 until the signal just stops coming through. You can now use PC-1 to bury the envelope by up to -2 volts, and still use the control as a 0 to +5 manual envelope. The only problem is that the exact zero point is only realized by setting PC-1 at its 2/7 rotation position. This is not difficult to do manually however if there is a signal trying to get through. For an actual synthesizer module, the full circuit as shown in Fig. 5 is recommended.

If you do not elect to use PC-1, you may still want to use TP-1 with R6 increased to about 4.7 meg. This will permit fine adjustment of the zero. Or you may just want to use a 22 meg resistor connected between -15 and the (-) input of IC-1. This will assure that the VCA is held off in the absense of an envelope (held off by about -60 mV). Finally, note note that the VCA is often the final output point from a synthesizer to an amplifier and speakers. If you intend to use it this way, the output pot shown in Fig. 7 may prove useful. This will allow you to adjust the level going out with a synthesizer panel control. As shown, if the pot is put in the top position you have the regular 1k output impedance since the op-amp easily drives the 100k pot resistance. In a lower position a signal level appropriate to the amplifier and speakers can be set. Other arrangements of an output pot are possible and may be used.

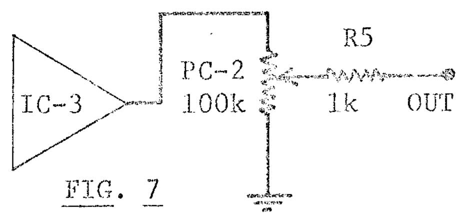

FIG. 7

ENS-76 BALANCED MODULATOR - OPTION 1

All of our balanced modulators ("Ring" modulators) to date have been based on the type 595 4-quadrant multiplier IC's. These have been satisfactory, although not outstanding (due to insufficient carrier rejection). Also, these have been a little difficult to balance. The new circuit given here may have some performance advantages (the one we built has better carrier rejection than the older 595 design). However, we have another important reason for changing the design - the 595 is getting hard to find. A year or so ago these were available from a number of sources for a price in the range of \$2 to \$4. Currently, we don't know where to get these except from a regular distributer. This means that the builder has to pay a price in a range where he has to seriously consider one of the newer and better 4QM IC's available. The use of one of these newer 4QM's as the heart of a balanced modulator design is an attractive design option. Here however, we are interested in a design that will cost only a few dollars for the IC's. The circuit is shown in Fig. 8.

The present design is basically an extension of the VCA design described above. We have simply connected two 2QM's in parallel. One of the 2QM's is formed by IC-1 and IC-4 while the other is formed from IC-3 and IC-5. The outputs of the CA3080's are currents so we can sum them by just shorting them together. This summed current is applied to I/V converter IC-6. IC-2 is a simple inverter for the Y input (unipolar) of the lower 2QM. Since Y is unipolar (must be positive in this case), only one of the 2QM's is on at any one time. If the Y input is positive, IC-4 supplies current while IC-5 supplies none. The use of the (-) input of IC-4 and the inversion due to IC-6 result in a polarity of the output of IC-6 which is the same as the polarity of the X input. If on the other hand, Y is negative, then IC-4 is cut off while IC-5 is supplying current. Since the X input is applied to the (+) input of IC-5, and IC-6 is inverting, the output of IC-6 is inverted with respect to the polarity of the X input. This is how a four-quadrant multiplier is achieved.

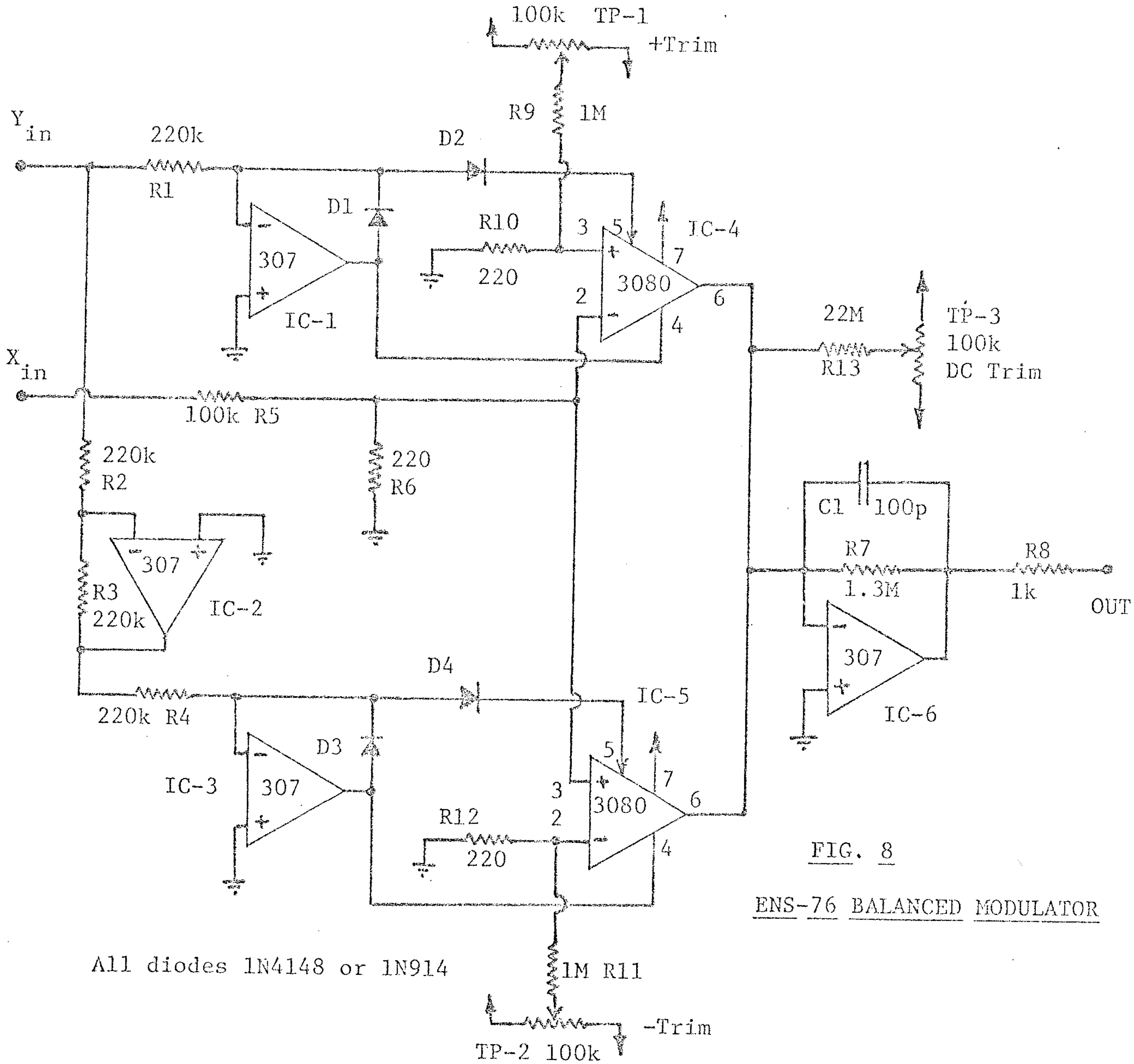

FIG. 8

ENS-76 BALANCED MODULATOR

From this point on, the rest of the circuit should be self-explanitory if the earlier VCA circuit was understood. A few final points on the design should be made. We used 220k resistors on the Y input so that the actual input impedance would be 100k or greater. This means that R7 had to be approximately twice the corresponding value in the VCA case. (We actually have a 1M and a 270k in series for R7). For best results R1, R2, R3, and R4 should be matched to 1%. The capacitor C1 is needed to remove a glitch that occurs at the zero crossings of the Y_{in} voltage. If it is desired that the circuit operate above 10 kHz, better performance will be obtained by using type 556 op amps (MC1456 or equivalent) instead of type 307's. Type 556 op-amps can also be used in the VCA circuit. It is (as always) good practice to add power supply bypass capacitors of about 0.02 mfd at various points in the circuit. In particular, these are useful on the supply lines to IC-1 and IC-3.

BALANCING THE BALANCED MODULATOR

Balancing the 4QM in Fig. 8 is not difficult. A number of techniques can be used. We suggest DC balancing using a digital voltmeter or a sensitive DC scope. Note that a very accurate DC zero can be obtained by using the scope on a sensitive range and using ground as the zero reference. First you set the level as near zero as possible. Then you short the output point to ground and see if the scope trace deflects. When you can't see it move as the ground is made, you have an accurate zero. Balance as follows:

First with no inputs connected, adjust TP-3 so that the output voltage is zero. Then apply +5 volts to the Y input. If you don't have a +5 source handy, use a +15 source and a 220k series resistor. This puts about +5 volts at the input. This +5 volt signal turns IC-4 on full. Now adjust TP-1 for a zero at the output of IC-6. Next apply -5 volts to the Y input (or -15 through 220k as before). ,This turns IC-5 on full. Now adjust TP-2 for a zero at the output of IC-6. Recheck the whole procedure.

Now as a check for balance and proper operation, connect +5 to both the X and the Y inputs. Note that if you use the +15 source and the 220k series resistor, you should use two resistors, one for each input. Better still, use a 100k resistor to +15 with the two inputs shorted. The output voltage should be roughly +5 (in the range +4 to +6 say). Now connect -5 volts to both inputs (or -15 through series resistors as with the +15 source). The output should be the same as with +5 on both inputs. Finally, try the combinations of +5 on one input and -5 on the other. This should give the same magnitude as before (the roughly 5 volt level), but the output will be negative. All these values should be within about 10% of each other in magnitude. Average them. If the average is not 5, then you can adjust R7 accordingly. Do not be concerned if the agreement is not better than about 10% unless you are testing with precision resistors and precision voltage sources. It is the DC balance that was done initially that is important, not the exact agreement of the voltage products. Once all this checks out, and you adjust R7 so that you have a 5 volt output for 5 volt inputs, the device should be suitable for most musical applications.

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PRECISE MATCHING OF RESISTORS USING SYNTHESIZER OSCILLATORS:

-by Carl Fravel, Gentle Electric, 119 Brainerd Rd Suite 15, Allston, MA 02134

Circuits for electronic music applications frequently call for resistors that are precisely matched, although the exact value of the resistance is not so critical. The resistor value may only be specified to 5% or 10%, whereas matching between resistors may need to be within a small fraction of a percent. The traditional procedures for matching require an expensive meter or precise circuitry which may not be readily available. However, the standard 1 volt per octave VCO found in many synthesizers is sensitive enough to be used for fine discrimination over a fairly large range of resistance. This is possible because the ear is very sensitive to small changes of pitch. The general technique is indicated in Fig. 1.

V_O is a voltage derived from some synthesizer output such as a keyboard or a sustaining envelope generator. Since it is desirable for V_O to be fairly large, you might wish to use a mixer to add several voltages together to get 10 to 15 volts.

The resistor divider R_1, R' gives a voltage V_c which is used to control the frequency of the VCO. This VCO and another oscillator are tuned to zero beat at some frequency F_1. Then other resistors are substituted for R_1 until one is found (R_2) which causes the new VCO frequency to

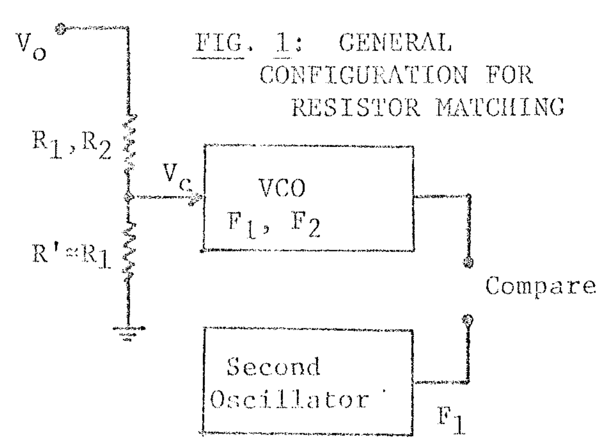


FIG. 1: GENERAL CONFIGURATION FOR RESISTOR MATCHING

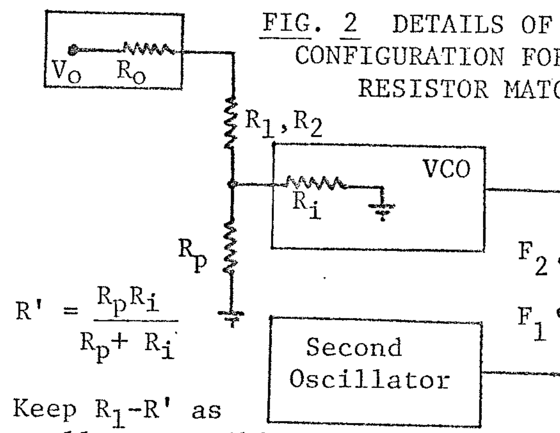
be sufficiently close to the second oscillator frequency (F_1). R' is chosen to be roughly equal to R_1.

Comparison of oscillator frequencies for different values of the test resistor can be done in several ways. In the setup of Fig. 1, the difference between oscillator frequencies is the same as the beat rate that occurs when the two signals are mixed. A second method uses only one oscillator and a good ear to detect pitch changes. This method is especially useful for rough sorting of candidates for a match, and these can be more precisely matched by the beating method.

For resistances larger than the output resistance of V_o and less than the input resistance of the VCO, resistors are matched to better than 0.1% if V_o = 10 volts, F_1 = 1 KHz, and the difference frequency is 1 Hz. The results can be quantified by the selection of the frequency F_1 at which matching will be done to within 1 Hz.

There are two considerations for selecting F_1. One is the precision with which R_1 and R_2 are to be matched - the higher the frequency, the more accurate the match is when $F_2 = F_1 \pm 1$ Hz. The second consideration (See Fig. 2) relates to the fact that V_o will not have a zero output resistance (R_o) and the VCO will not have infinite input resistance (R_i). The most accurate matching is done when $R_o \ll R_1 \ll R_i$. When R_1 is too small or too large, the frequency F_1 must be higher to get the desired resolution. Note that R_p is selected so that R' (that is, R_p parallel R_i) is as nearly equal to R_1 as possible. The accompanying graphs assume that R_p is treated in this manner. The matching procedure is then as follows:

FIG. 2 DETAILS OF CONFIGURATION FOR RESISTOR MATCHING



$$R' = \frac{R_p R_i}{R_p + R_i}$$

Keep $R_1 - R'$ as small as possible

For $R_1 \geqslant R_i$, do not use R_p

To determine the appropriate frequency F_1, use formula (1) and the two graphs. Let n be the precision of the match (i.e., for 1% n=0.01). Then ΔV_c(the maximum allowable change in V_c) is given by:

$$\Delta V_c = V_o n/D \qquad (1)$$

where D is found from Graph 1. Now look up F_1 on Graph 2. Note that Graph 1 has values for R_1 given in terms of the synthesizer's input and output resistances (R_i and R_o). The parenthesized resistances are typical values. If your synthesizer varies from these, adjust the graph between R_o and R_i.

As an example, say you wish to match a pair of resistors of nominal value 330k to within 0.5%. In this case, n = 0.005 and (if the VCO input resistance is 100k) D = 5, from Graph 1. We will use 10 volts for V_o. We now calculate ΔV_c:

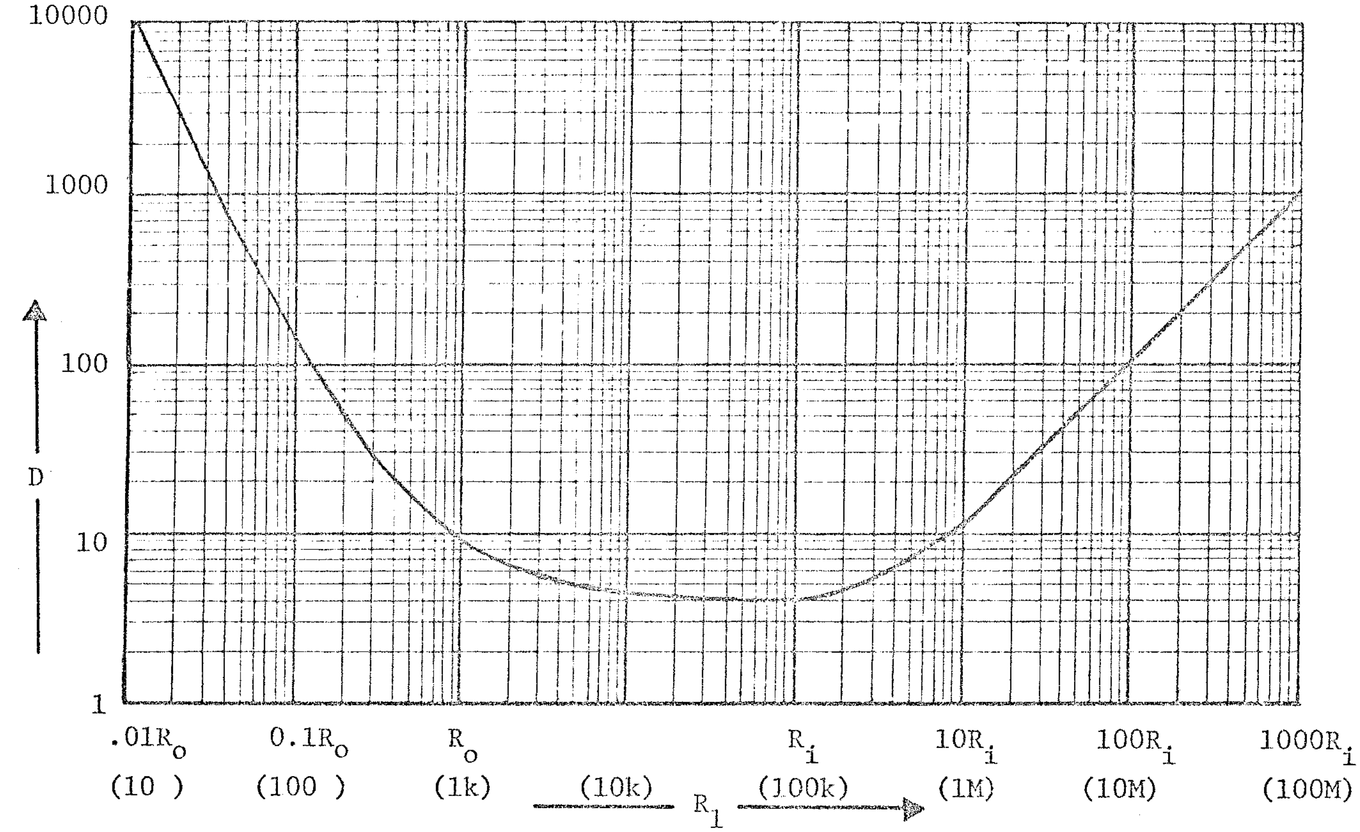
$$\Delta V_c = V_o n/D = (10)(0.005)/5 = 0.01 \text{ volts}$$

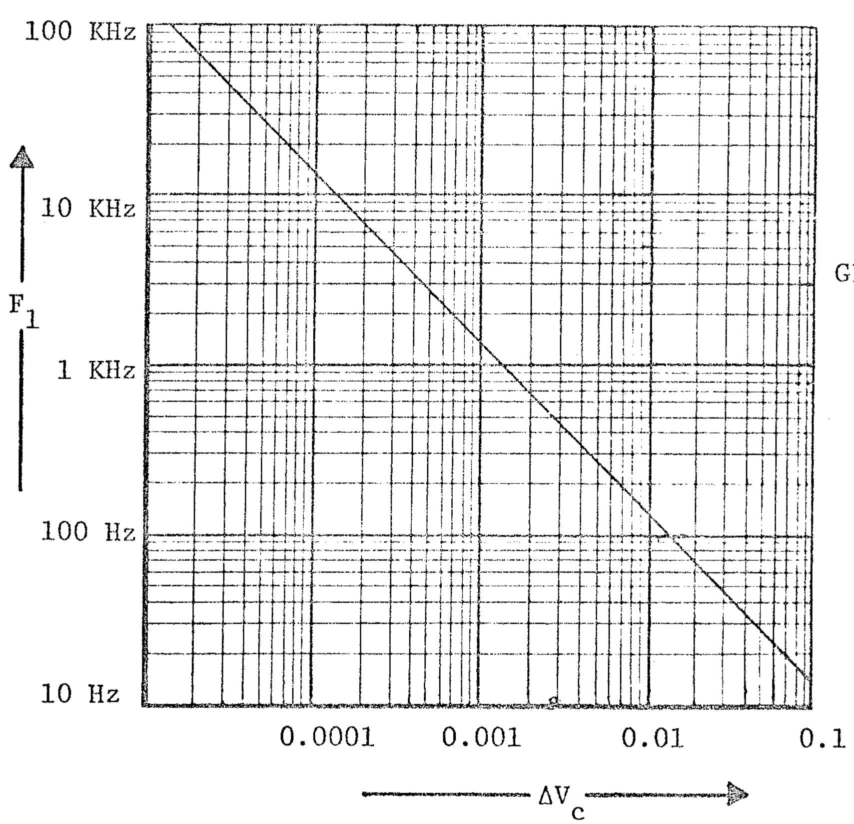
We then find from Graph 2 that F_1 = 144 Hz. Now select R_p so that (R_p parallel R_i) is as near to R_1 as possible. In this case, no R_p should be used at all, since R_i is already less than R_1. Now, arbitrarily select a 330k resistor as R_1 and use it in the matching circuit (Fig. 2). Tune both oscillators to F_1 = 144 Hz. If the frequency must be estimated, stay on the high side. Most important is that the oscillators be tuned to a zero beat frequency. Now substitute other 330k resistors for R_1 until one is found (R_2) which gives a VCO frequency that beats against the second oscillator once per second or less. If your oscillators tend to drift, recheck with the original R_1. R_1 and R_2 are matched to 0.5%.

A caution: It should be kept in mind that resistors are temperature sensitive (a typical value is -0.02%/°C) so that a 10°C change in temperature (easily introduced by holding in one's hand) could produce in excess of a 0.1% change in resistance.

The interested reader will find an explanation of the way the two graphs were derived in Appendix 1.

GRAPH 1





GRAPH 2

APPENDIX 1:

Graph 1 is derived from the complete fromula for ΔV_c, as follows:

$$\Delta V_c = V_o \left[\frac{R'}{R_o + R_1 + R'} - \frac{R'}{R_o + R_1(1+n) + R'} \right] = \frac{V_o R' R_1 n}{(R_o+R_1+R')[R_o+R_1(1+n)+R']}$$

Assuming $n<<1$

$$\Delta V_c \simeq \frac{V_o R' R_1 n}{(R_o+R_1+R')^2}$$

For $R' = R_1 << R_o$,

$$\Delta V_c \simeq \frac{V_o R_1^2 n}{R_o^2} \qquad \text{Therefore} \qquad D \simeq \left(\frac{R_o}{R_1}\right)^2$$

For $R_o << R_1 = R'$,

$$\Delta V_c \simeq \frac{V_o R_1^2 n}{(2R_1)^2} = \frac{V_o n}{4} \qquad \text{Therefore} \qquad D \simeq 4$$

For $R_o << R' << R_1$,

$$\Delta V_c \simeq \frac{V_o R_i R_1 n}{R_1^2} = \frac{V_o R_i n}{R_1} \qquad \text{Therefore} \qquad D \simeq (R_1/R_i)$$

Graph 2 is derived from the definition of 1 volt per octave:

$$\frac{F_1 + 1 \text{ Hz}}{F_2} = 2^{\Delta V_c}$$

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ANALOG INTERFACES FOR MICROPROCESSOR SYSTEMS: -by Douglas Kraul

The mocroprocessor is a technical innovation of such magnitude that before long it will touch every facet of electronics. Electronic Music is no exception. The superior musical Engineer will prepare himself (herself) to make effective use of this device.

The microprocessor does not, however, solve one of the problems with digital circuitry in general: the continuous-to-discrete/discrete-to-continuous conversion problem, known better as A/D, D/A conversion. There are some principles here which the microprocessor does make possible.

D/A conversion (Digital-to-Analog) represents no new problems, or solutions, for the microprocessor system. A/D conversion (Analog-to-Digital) is another matter. To the newcomer, it is mysterious. However, let's remove ourselves a bit and examine it from a more elementary point of view.

Let us say that there is a number which is between one and ten, and it is to be guessed. An approach to take would be to randomly say numbers in that range until it is guessed. Obviously this is a very inefficient method. A better, more systematic method would be to start at one and keep guessing one more until an answer is found. This is a practical method, and useful, especially for small ranges of numbers, but increase the range to one hundred and the method proves quite time-inefficient. Now the clever person would ask questions such as "greater than five", "less than three", and by this process quickly narrow the possibilities. This method eliminates one half the remaining possibilities with each guess. So in the one to ten example four guesses are needed, as compared to the five on the average needed for successive guessing. Not a spectacular saving. However, in the one to one hundred example only seven guesses are needed, as opposed to an average of fifty. Clearly a significant savings.

This method of A/D conversion is called successive approximation. It presents the microprocessor user with a method of conversion which is well suited to the microprocessor. A method for doing the successive approximation might be flow-charted as indicated in Fig. 1. Computer people like to call these special methods "algorithms."

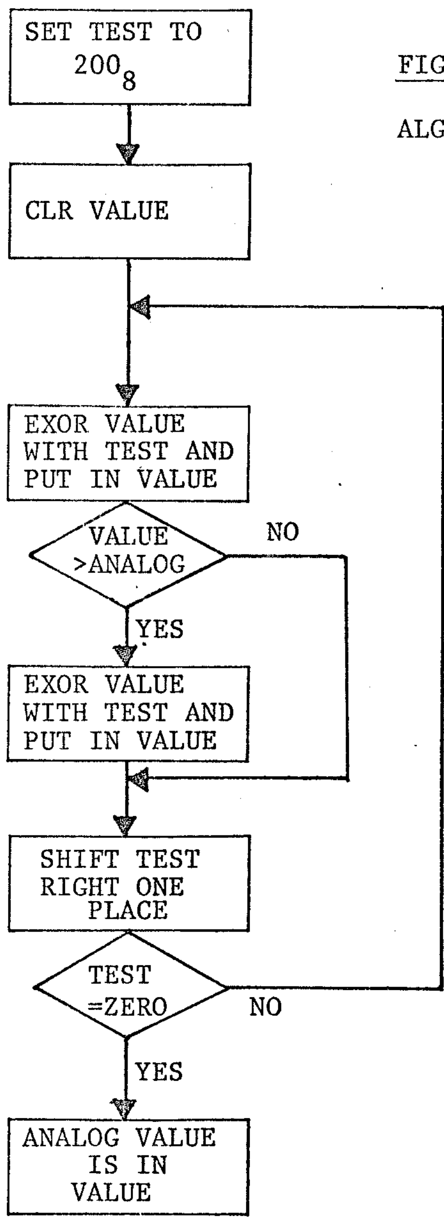
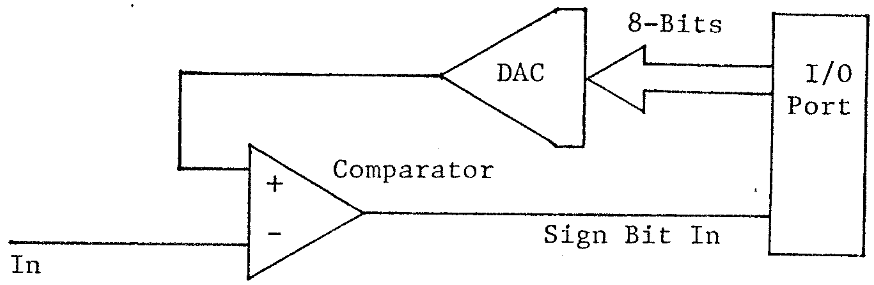


FIG. 1

ALGORITHM FOR SUCCESSIVE APPROXIMATION

The algorithm sets a bit in the value register. If that bit causes the values to be greater than the analog value then the bit is cleared and the next lower bit is tried, this repeating until all eight bits are tested. Now one might ask how the microprocessor physically uses this to convert analog voltages to binary numbers. One possible setup is shown in Fig. 2.

FIG. 2



Here the microprocessor outputs the value being tried to the DAC (Digital-to-Analog Converter) where it is compared to the analog voltage being converted. The comparator is then used as a sign bit into the computer. This is wise because the sign bit is easy to test.

One immediate consequence of this is that we have used a general purpose DAC. Now there is nothing wrong with our using this DAC to provide an analog output from the microprocessor, as long as a conversion is not taking place. Not very often you say. True. However, the digital world gives us a solution which not only allows time-sharing the DAC between D/A and A/D converters, but also between many outputs. How? Through time-multiplexing. Imagine a number of sample-and-holds which have sample inputs which are each assigned one number so that when that number appears the device samples, but holds all other times. Also imagine all inputs connected to our one hard working D/A. Each sample-and-hold can be given a voltage from the D/A provided that we update the sample-and-holds at different times. The results are as many independent voltages from the microprocessor as we have sample-and-holds.

This method does have limitations. If each output is required to change rapidly then the practical number of channels is limited. But for Electronic Music work these signals can be control voltages, and thus not very fast moving.

Another limitation one might think of is the cost of each sample-and-hold. These do not need to be the types which are familiar to us all. A general purpose sample-and-hold needs to be fast as well as provide a long hold time; conflicting requirements that lead to expensive, complicated designs. But in this application the sample-and-holds will be likely to be updated as least once every so often. Call this longest update interval the refresh period. Now as long as we can guarantee that the time between updates will be less than this refresh period, then we can design hold time for this period. If we choose this time wisely the sample-and-hold can be fast and simple.

One last consequence of the above is that if we can multiplex the output, why not the input. We merely use a number to enable a voltage to the converter. All this suggests the 8-In/8-Out analog-digital interface structure shown in Fig. 3. By using suggested components an inexpensive, flexible interface can be designed for the microprocessor. The observant musical engineer will see the implication of applications to polyphonic controller's, recording sequences, multiple envelope generators, etc.

Briefly, two I/O ports are used; one for data and one for control. The control port addresses the correct channel and strobes the sample-and-hold. The least significant bit was chosen to strobe because it can easily be toggled using an increment/decrement pair.

It is hoped that this has eliminated the anxieties of interfacing a microprocessor to the analog world. The methods here, while not complete, provide a solid basis for fruitful innovation in the area of computer controlled analog systems. It is hoped that the methods answer some pending questions.

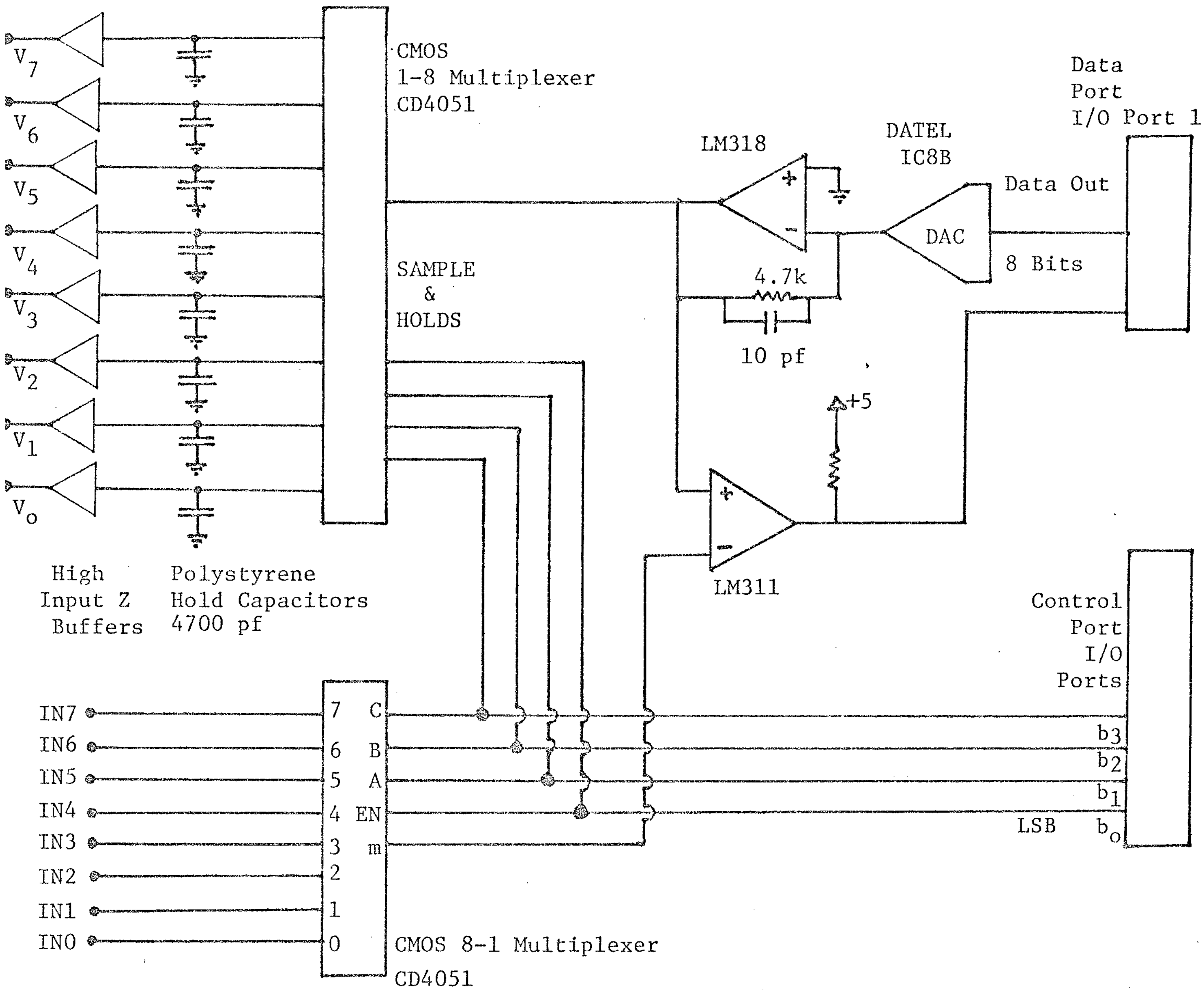


FIG. 3 EIGHT CHANNEL ANALOG-DIGITAL INTERFACE

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REVIEWS OF RECORDED MUSIC: -by Craig Anderton

EDITOR'S NOTES: We have not carried any musical reviews for some time now. We have had several good reasons for not doing so. However, we do feel that musical engineers can benefit from reviews of recorded music if they are properly presented. Thus we are going to try some reviews and will be anxious to hear from out readers as to whether or not we should continue these.

The central figure in these new reviews will be Craig Anderton who will be providing material on a regular basis this year. Craig's activities in both music and engineering are most likely well known to our readers, and Craig has experience writing reviews on a wide range of music. We feel that he will offer us some thoughtful comments on the types of music that will be of interest to musical engineers. He will be starting off this first series with a few comments on what he will be doing this year. We will welcome any and all comments. ----

INTRODUCTIONS

As I will be reviewing recordings of interest to Electronotes members on a regular basis over the months ahead, I thought you might like to know my outlook on the subject of reviewing.

First of all, I feel that my paritcular views on whether or not I like a piece of music are irrelevant to most readers; I'm pretty sure we all agree that liking music is a matter of taste. But appreciating and understanding music is an altogether different subject---one which is a better goal for a review.

My personal tastes in music are quite varied. I'm not too sure why I ended up this way, but during the course of an evening I can easily start off with a little Bach, edge into some Miles Davis, play the Who, listen to something I cut in the studio for my own amusement, finish up with Morton Subotnick or ethnic music...anything is possible. My musical idols are John Coltrane and J.S. Bach. So now you know where I stand, or more likely, have no idea at all of where I stand. To tell you the truth, neither do I; what makes me like certain things, and you other things, I can't explain. But I'm sure of one thing: if YOU think a piece of music is valid, it's valid, whether I like it or not...and I'm not any better, or any worse, for not liking it. Music is universal, and it belongs to everyone according to their taste. Although I don't get emotionally involved over most top 40 music, it brings tears of joy to the eyes of some people. Fine---I'm glad that everyone's need for music gets satisfied somewhere along the way.

You might ask how could I write a review with an attitude like that. Well, I'm going to write a different kind of review, one that's as objective as possible. We'll be talking about why the electronics are effective in some places, where they sound out of place, how they blend into a piece, what kind of emotional impact they convey...and anything else of interest regarding the musician/electronic interface. For example, if I were to talk about Keith Emerson, I'd be more concerned with whether he gets unusual patches, whether he adds any different techniques to playing the synthesizer, how much control he has over his instrument, and so on, rather than any other aspects of his playing. In this manner, I hope to avoid the trap of giving reviews that tell you more about the reviewer than the piece of music under scrutiny.

REVIEW: THE OCEAN RECORDS STORY

For this review, I've chosen to talk more about the company releasing the music than the music itself, for reasons that will become obvious as the review progresses.

Ocean Records is a small outfit that is offering an issue of "Composer's Cassettes" on a one-per-month basis, sent via the mails. (As far as I know, their recordings are not available over the counter. The address is Ocean Records, Box 1726, Los Gatos, CA 95030). I received a mail solicitation from them in November, and figured I'd sign up...might as well see what's going on out there.

The first tape arrived on schedule, and I immediately put it on my cassette deck. It was a piece of live electronic music, recorded several years ago by Allen Strange plus friends. The first event I heard on the tape was a voice telling me that this tape is Dolbyized, and if my machine wasn't Dolbyized, that I should compensate with the tone controls. Great, except that the voice became a tape loop, then some echo got added in, and before long, I was listening to a bona-fide 60s electronic music cliche.

Then came the music. Now I know music is very personal, and I'm sure that some people liked this tape, but it just wasn't my style. It seemed very self-conscious (a common problem with much abstract music), the performance was amateurish to my ears; all in all, the tape seemed to typify an aesthetic approach that had spent itself many years before. But that wasn't enough: the cassette was dubbed at a pitifully low level---the meter needle barely made it off its pointer, and turning my amp up full blast merely attained audibility (and I'm NOT a loud music freak). That was the final straw: I wrote an angry letter to Ocean Records. partially because I was angry but also because I felt that if these people were a rip-off operation, I should spread the word before other people got taken.

I got back a hand-typed letter that expressed what seemed like obvious distress on their part that I had been dissatisfied, and an offer to personally redub the tape if I wished. They also said they would return my money in full if I felt I had been cheated...but they added to please wait until the next release before making up my mind. That was a hopeful sign that these people at least believed in what they were doing.

The next tape was by a fellow named Ragnar Grippe. I put this tape on, and there was an immediate improvement. First of all, there was no problem with the signal level, and the quality of the music, while not earth-shaking, was much improved. The pieces were mostly music concrete/aleatory sounds, but done with a sincerity, earnestness, and humor that I found irresistable. I started feeling better about Ocean Records.

The next month featured a cassette of Gamelan music---side 1 done more or less Western style, and with side 2 done more traditionally. This cassette was also pleasing to my ear, both in terms of musical and recording quality. This was the latest cassette I received, and I'll be interested to see what they come up with this month.

The cost of a year's cassettes is $25, which breaks down to a little over $2 per cassette. I think this is an exceptionally reasonable price; aside from the disastrous first cassette, the quality has been commendable (especially compared to cassettes issued by the "Big 3" record companies), and they have shown a willingness to correct a cassette that's improperly dubbed if you get a lemon.

But there is another aspect to Ocean Records: they actively solicit tapes from composers everywhere for inclusion in their series. In this respect, they are aiming for a "by the people - for the people" approach that looks promising. This seemed to be what Bernie was trying to do with the club tape idea a few years back; but some things are better left to those who have the time to do them. I feel that you won't necessarily enjoy every cassette of the series (I certainly haven't!), but they do carry different ideas (ideas that non subscription-supported recording companies would probably never touch), and different musical inspirations, into one's life.

Many times, I get fatigued hearing the same types of approaches to melody and rhythm used over and over again, and yearn for something different.

Ocean Records indeed offers something different every month, and as such, I feel they're worthy of my support, and yours too if you can cover the $25. Who knows? Maybe Ocean Records will become part of the record biz in the same manner that educational TV has worked its way into the world of television.

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BACK TO BASICS 2, TRIGGERING THE 555 AS A MONOSTABLE:

-by Bernie Hutchins

The 555 timer IC is useful as a monostable for times ranging from a few microseconds to a few seconds. For shorter times, the TTL type 74121 is recommended. The 555 is quite simple to use. However, there are a few problems that come up in practice which are not clearly described in the manufacturer's notes on the circuit. One major problem comes about when the power supply is not properly bypassed. In such a case, it is common for a 555 somewhere in the circuit to put a glitch on the supply line and thereby strike up a conversation with other 555's in the same area. It is therefore suggested here that whenever a 555 is used that a capacitor of about 0.1 mfd be placed on the power supply line at each chip. The basic monostable setup is shown in Fig. 1. We have shown a bypass capacitor of 0.1 mfd on pin 8, but it can equally well go on pin 4.

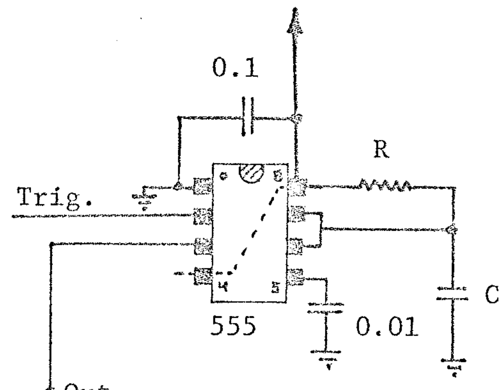


FIG. 1

Now, this prevents triggering that is not wanted, and we can turn to the problem of getting wanted triggers in. The manufacturer's literature says that when a negative going pulse arrives at pin 2, pin 3 goes high for a time of about 1.1 RC and then falls back to zero. This does not mean however that the trigger is "edge sensitive." A flip-flop for example is often edge sensitive - it triggers when its clock goes from high to low, and it does not matter what happens after that until the clock line again undergoes a high to low transition. In the case of the 555, the situation shown in Fig. 2 must be avoided. The trigger line must go from the upper power supply level (V_S) to $V_S/3$ (or lower) and return to V_S before the high time of pin 3 (1.1 RC) expires. The correct triggering waveforms are shown in Fig. 3. Thus, we can see that the important thing is to keep the trigger high at all times except when an actual trigger pulse is coming in, and then the trigger should be no longer in duration than is needed.

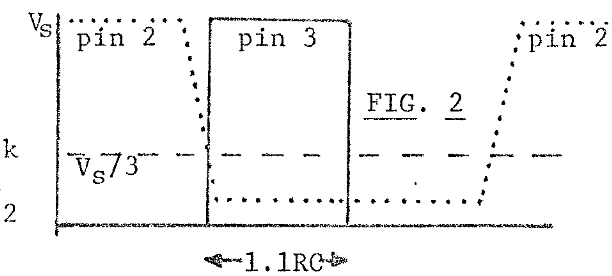


FIG. 2

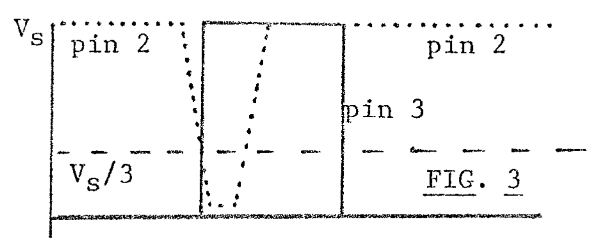


FIG. 3

A differentiator circuit (referenced to V_S) is useful for producing the required pulse to trigger the 555. The suggested circuit is shown in Fig. 4. This is particularly well suited to the case where the output of one 555 drives another. By adjusting the value of C_i (and sometimes R_i), it is usually possible to obtain the necessary trigger pulse. Bear in mind that a short ON time for pin 3 will usually require smaller R_iC_i time constants.

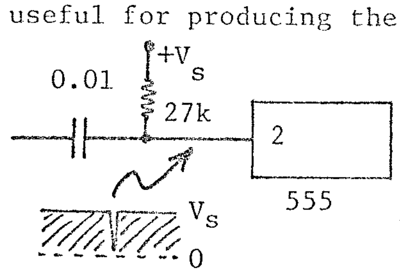


FIG. 4

The differentiator referenced to V_s (Fig. 4) can often be used. In addition to other 555 timers, this configuration can be driven from op-amps and CMOS. The case where the 555 is to be driven from TTL requires a little special attention however. Here it is assumed that both the 555 and the TTL are supplied by the usual $V_s = +5$. The actual voltage swing of the TTL outputs (assumed to be the "totem pole" outputs) may be less than three volts. Even with careful waveshaping by selection of C_i and R_i it may be difficult to shape the trigger pulse so that the circuit in Fig. 4 gives a trigger that falls below $V_s/3$. In such cases, there are two choices. First, as long as we are using TTL, we can add a pull-up resistor of about 4.7k to the TTL output thus strengthening the magnitude of the high to low transition. This is fine where it can be done. In other cases, we may have to work with the weak negative transition directly. In such cases, we can change the reference voltage on pin 2 by using a voltage divider. This is shown in Fig. 5. The voltage set on pin 2 should be low enough to cause reliable triggering, but not so low that triggering problems will result. With the two 100k resistors as shown, the standby voltage on pin 2 is $V_s/2$ so that a negative spike of $V_s/6$ is enough to lower the voltage on pin 2 to the DC value of $V_s/3$ which is required for triggering. This is illustrated in Fig. 6. Note however that a noise spike of magnitude $V_s/6$ could also cause triggering in the same manner.

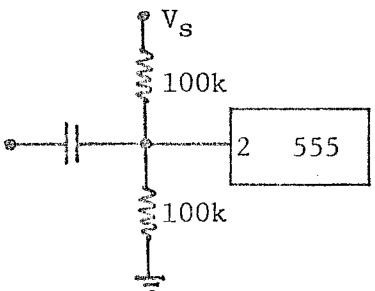
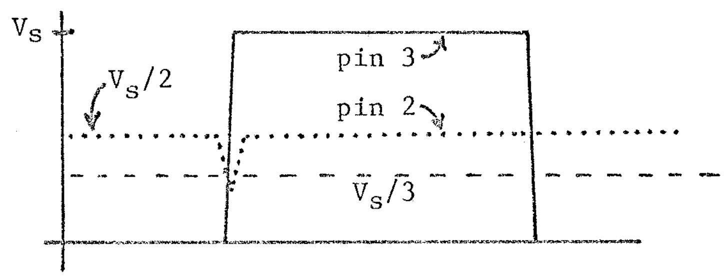


FIG. 5



In summary, the following general rules should be followed when using the 555 as a monostable:

(1) Bypass the power supply terminals with 0.1 mfd at each chip.

(2) Always use a differentiator or other very short pulse.

(3) If the differentiator in Fig. 4 does not work, decrease the value of C_i by a factor of 2 and repeat until proper triggering occurs or until C_i is below 500 pf.

(4) If triggering is still not correct, try first to strengthen the driving signal (as with the TTL pull-up).

(5) If necessary, the next step is to begin pulling down the standby DC level of pin 2 (for example, Fig. 5). Pull it down only as much as is needed, keeping the total series resistance of the voltage divider in the range of 100k - 300k. The suggested value of C_i in these steps would be about 0.001 mfd.

(6) If pin 2 has been pulled down much below $(2/3)V_s$, it may be necessary to add additional noise proofing to prevent noise triggering. If pin 2 is pulled down only a little (DC on pin 2 is $2/3\,V_s$ or higher), this pull down method on pin 2 usually works well and is usually simpler than adjusting C_i to properly shape the pulse.

(7) If the circuit is being used in a production model, it is a good idea to try 555's from several different manufacturers in the same test circuit. All 555's are not the same so it is important to test the circuit with a device from the manufacturer you will be using in production.

NEWS AND NOTES FOR MARCH:

SEQUE AND PAN: About ten readers wrote to comment on the origin of the terms "seque" and "pan." Pan is the simplest to discuss so we will start with that, and try to collect together the various suggestions. Pan is definitely related to the term "panorama" and probably originated in the movie industry in direct analogy with the term pan which is used with reference to the horizontal motion of the camera field. There may also have been a commercial product called a "panoramic potentiometer" which was later shortened to just "pan pot." In any event, the term pan is useful since the pan pot spreads sound around in the same way a camera pans. and this makes it easy to remember.

Some readers thought we misspelled "seque" and that it should have been "segue." While Electronotes is not particularly well known for flawless spelling, this is not an error. The spelling "seque" appears in Bill Hartmann's original manuscript (as published in EN#60), and also in a number of earlier books on electronic music (e.g., Allen Strange's 1972 book Electronic Music). The other spelling, "segue" is apparently Italian from the Latin "sequi." The "segue" spelling and corresponding pronunciation were apparently used in radio work where it referred to the fade in of one type of program material while another was being faded out (just as the electronic music "seque" pot works). Others suggested that the "seque" term is a corruption of "seek" and is used because it is mnemonic. It was also suggested that the term came from "sequence" since the pot sequences different sound events. Well, we told you that it was simpler to explain "pan." As for us, we are going to continue to use "seque" and remember what it does since it sounds like "seek." Thanks to all who wrote.

NEW SYNTHESIZER: A new synthesizer is available from Process Electronic Corporation, Box 7, Centerville, PA 16404, or 180 Marlborough St., Boston, MA 02116. This is a modular system, the "OZNI Mark I" available at $3250. A Mark IA is available at $1995 as well as a series of separate modules.

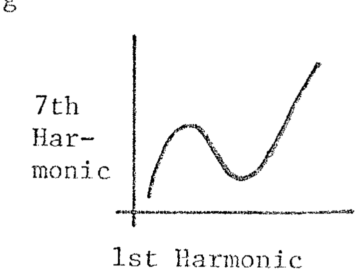
ELECTRONIC MUSIC ACTIVITIES: Dondisound, 12 St John St., Red Hook, NY 12571 will be offering programs of study in recording engineering and synthesizer techniques starting April 20, with additional courses to be given in August.

Carl Fravel has formed a company called Gentle Electric located at 119 Brainerd Rd., S15, Allston, MA 01234 (617) 731-4844. Carl will be handling a wide range of musical engineering activities.

LITERATURE: We have learned that a new publication on electronic music is being issued. It is called Synapse and is located at PO Box 359, N. Hollywood, CA 91603. We shall pass along more information on this as it becomes available.

Persons interested in the history of the synthesizer industry will want to take a look at the article "David Friend of ARP Instruments" by Hans Klein that appears in the March/April 1976 issue of Contemporary Keyboard.

A very interesting paper with what we feel may be important implications for electronic music synthesis is "Analysis and Synthesis of Cornet Tones Using Nonlinear Interharmonic Relationships," as given by James Beauchamp in JAES, Vol 23, No. 10, 1975. The paper presents experimental data which reveals an interesting fact: For a given pitch, there is a one-to-one relationship between the level of the fundamental frequency and the level of a given overtone. The same is of course true, for example, of a sawtooth, where the relationship is linear (Fourier series - ratio of coefficients). For the cornet tones, the relationship is non-linear. The shape at the right might be an example of such a relationship.



Persons interested in the technical details of magnetic recording will find the paper "Tutorial Review of Magnetic Recording" of interest. The paper is authored by J. C. Mallinson and appears in Proc. IEEE, Vol. 64, No. 2, Feb. 1976. This is a 13 page paper which should give plenty of information. If not, one can always resort to the approximately 200 references listed.

More on the pitch-to-voltage conversion problem can be found in "Real-Time Digital Hardware Pitch Detector," by J. J. Dubnowski, R. W. Schafer, and L. R. Rabiner in IEEE Trans on Acoustics, Speech, and Signal Processing, ASSP-24, No. 1, Feb. 1976. This method starts with center clipping (as in the EN#53, 54, and 55 circuits) and follows this with a digital autocorrelator. This is probably a little too complicated for musical use at the moment, but the paper is well worth reading as a piece of an overall puzzle. This paper is mainly concerned with applications to speech. Another paper concerned with speech is "Epoch Extraction of Voiced Speech," by T. V. Ananthapadmanabha and B. Yegnanarayana in ASSP-23, No. 6, Dec. 1975. This general scheme has a pitch extraction approach which is quite different. It is too involved to discuss in this short review, but interested persons may want to consider whether this might work for music as well, or at least for certain types of instruments. However, this method too is very far from a simple black box at the present time. We are considering the formation of an informal "subgroup" concerned with pitch extraction as applied to musical instruments. Interested persons may write to us here at Electronotes. If anything developes, we will report it later.

An application note on analog delay lines is available as "Principles of Analog Discrete-Time Signal Processing Devices," App. Note #102 from Reticon Corporation, 910 Benicia Ave., Sunnyvale, CA 94086

SURPLUS? We note that the surplus market is quite good at the moment and there is generally a good product available at a fair price. There have been some changes in the semiconductor business in the last year or so that should be noted. A few years back you would get mostly relabeled IC's - ones which had the manufacturer's name taken off and only the type number reprinted. These may well have been factory seconds - material that did not quite measure up to prime, so it was sold as surplus on the condition that the original labels be removed. Most of it worked quite well. In fact, some batches of "741's" were something better, perhaps 307's. At the present time it seems that the prices of prime material has fallen so rapidly that it is easier for dealers to just buy in large quantities and sell at or below the usual surplus prices. Thus, we see that most of the material is new and fully labeled.

We get a fair number of questions on the 556 type op-amp. This is a little difficult to find, and it is often confused with the type 556 timer which is a dual version of the 555 timer. When we specify the 556, we mean the 2.5v/microsecond op-amp. This is made by Motorola and Signetics, and perhaps others. The Motorola numbers are: MC1556, MC1456, and MC1456C. The Signetics numbers are: S5556 and N5556. The MC1456 is available from International Electronics Unlimited, PO Box 1708, Monterey, CA 93940 at a cost of $1.59. These have appeared briefly at times for a price of about $1.00, but have been listed only for a short time by several dealers. Please inform us if you know of any such sources and we will pass them along. We plan to use more and more of these 556's as time goes on.

GENERAL: In EN#61, we asked some questions at the bottom of page 8. These concerned the probabilities of finding certain number sequences in random number tables. So far, no one has sent in answers. Perhaps it has been assumed that we know the correct answers. In fact, we are not sure. We do not believe that the simplest answer that everyone first guesses is correct. Someone out there surely knows how to handle this sort of problem. In a larger sense, we plan to do some material that involves some calculations of probability and distributions and that sort of thing, and if anyone has had a lot of experience with this sort of thing, we could use a little help.

And/Or	1525 10th Ave., Seattle, WA 98122
Kevin Austin	Metamusic, 2216 Oxford, Montreal, Quebec, Canada H4A 2X8
Robert Austin	8517-28th NW, Seattle, WA 98117 (c)
D. Mitchell Balog	1001 59th Ave So., St. Petersburg, FL 33705 (c)
Brad Bennett	1063 Darwick Ct., St. Louis, MO 63132 (c)
Don Bennett	517 Sunnyland Ave., Pittsburgh, PA 15227
A. F. Berger, Jr.	800 Horsepen Rd., Richmond, VA 23229
Bob Bielecki	RD#1, Fort Edward, NY 12828
Henry Birdseye	316 Jefferson NE, Albuquerque, NM 87106 (c)
George Blanz	1127 E. Ann St. #36, Ann Arbor, MI 48104
Vernon D. Bostian	302 E. Indian School Rd, Phoenix, AZ 85012
Bruce R. Bouchard	810 Pinecrest Apt 801, Ottawa, Ont. Canada K2B 5W6
Richard Bozek	12907 Shady Oak Blvd., Garfield Hts, Ohio 44125
Fred Brome	29 Fowler St., Jamestown, RI 02835
Roger Brooks	2890 Virginia St., Apt 635B, Coconut Grove, FL 33133
Bruce A. Brown	#3, Dept M1, 9651 Maureen Dr., Garden Grove, CA 92641 (c)
Martin Brunet	Pasaje Oller-17, Manresa (Barcelona), Spain
Timothy D. E. Burnham	207 E. Columbia St., Falls Church, VA 22046 (c)
Patrick Buryk	69 North St., Madison, NJ 07940 (c)
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David Cockerell	c/o IRCAM, 33 Rue Saint Merri, 75004 Paris, France (c)
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Len Kaplan	65 Burnham Dr., Fords, NJ 08863

(list to be continued)

CLASSIFIEDS:

91L02 RAM UPDATE: Final "worse case" price is $2.00. If we hit 5000 chips, everyone will get a refund up to $0.25/chip. 16 pin solder tail DIPS - 16¢. Send certified check or MO to S. Edelman, 204 Dryden Rd., Ithaca, NY 14850. Include 5% shipping. Include postcard so that I can acknowledge order and shipping date. (607)-272-2339 till 1200PM EST.

WANTED: Unused Tel Labs Q81 1000 ohm resistors, any quantity 10 to 100. State price. Ron Tipton, Box 45, Prairie Grove, AR 72753

FOR SALE: Large Moog with 2 keyboards, 1 ribbon controller and custom cabinet. $4,950. Woodland Sound Studios, Nashville, TN 615 227-5027

FOR SALE: Attention musicians - exclusively customized Eμ Synthesizer built for live performance. Complete with five octave kbd and Oberheim DS-2 digital sequencer. Ron Costa, 140-2B Casals Place, Bronx, NY 10475. (212) 379-0292, 7750

FOR SALE: TMS2501NC - $8.00, TMS3002LR - $1.50, TMS3003LR - $1.50, TMS3113NC - $1.50, 7491 - 2/1.00, MC1414L - 2/$1.00, 710 - 3/$1.00, 741 - 4/$1.00. I will pay packing and shipping. Min order $8. Also have some computer peripherals - send SASE for more info on these. John Marshall, Box 242, Renton, WA 98055

FOR SALE: Heathkit 180 mHz freq. counter model IB-1103, assembled and guarenteed. Jay Busch, 1430 Sunnycrest Rd., Apt 6, Syracuse, NY 13206.

FOR SALE: Revox G36, excellent condition, two track stereo, with two ten inch metal reels, $250. Buchla-like CBS Musical Instruments series 100: Power supply, dual sine-saw generator, octave formant filter, dual mixer, and white sound generator. Cabinet and patch cords included $335. Christopher Jones, 545 Broadway, New York, NY 10012

FOR SALE: 2N5172, MPS3392, MPS3563 @10¢; SPF729 @ 7¢; 1N4154 (PRV 25V) signal @ 3¢; 115 ohm 1/4 watt 1% resistors @ 12¢; in sets matched to 0.2% @ 20¢; $5 minimum on above. 1 only - 6 octave Hammond keyboard, 13 bus expandable to 20, 6th octave is preset convertable to regular play, excellent condition, $100 + shipping. Mark Goldstein, PO Box 825, Tempe, AZ 85281.

TECHNICAL SERVICES: Design, construction, synthesizer modifications & repair, private lessons, technical correspondence, PC layout & fabrication, kit assembly. Specializing in custom controllers and instrument interfaces. P/V converter available. Send 25¢ and legal size SASE for more information to: Carl Fravel, Gentle Electric, 119 Brainerd Rd., S15, Allston, MA 02134 (617) 731-4844

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