# ELECTRONOTES 129

NEWSLETTER OF THE MUSICAL ENGINEERING GROUP
1 PHEASANT LANE
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## GROUP ANNOUNCEMENTS:

### CONTENTS OF EN#129

The main feature of this issue is a new voltage-controlled oscillator. This is a circuit that offers through-zero modulation capability in what is still a relatively simple circuit. If you have been thinking you could use an extra VCO, try this one. Those great dynamic percussive sounds are well worth the effort.

## NEWS AND NOTES:

We want here to mention briefly three new books, which we hope to review in more detail later. The first of these is a new edition of Craig Anderton's Electronic Projects for Musicians, and is available from Guitar Player Books, Music Sales Corporation, 33 W. 60th St., New York, NY 10023. The price tag on this is $14.95. The book also includes a sound sheet recording of the effects that can be achieved with the projects. The Complete Guide to Synthesizers by Devarahi has been published by Prentice-Hall, Englewood Cliffs, NJ 07632. This is a 214 page book covering synthesizer theory and applications. A book by Barry Schrader, Introduction to Electro-Acoustic Music, has been published by Prentice-Hall. It is a 223 page book with little in the way of theory, but a great deal about music, musicians, and the details of some individual compositions. As we say, more on these later, but you might want to keep an eye out for them now.

A variety of electronic music and computer music services are available from ESSP (Electronic Synthesizer Sound Projects) which is located at The Sound House, PO Box 37b, E. Molesey, Surrey, KT8 9JB, England. It is not totally clear what these services are or the cost, but they include library and publication lists and some promotional services.

We have heard from Hans Weigand Habermehl at Wartweg 12, D-6300, Giessen 1, West Germany about a publication of his: Musik-Elektronik, which is in a newsletter format. Readers who read German may want to check this out, and we will keep other readers informed of any additional developments.

The annual MIT workshops "Techniques of Computer Sound Synthesis" and "Workshop in Computer Music Composition" will be held June 21, 1982 - July 2, 1982, and July 5, 1982 - July 30, 1982, respectively. Tuition for the first is $1000 and for the second, $1200. A limited number of scholarships are available. For applications and information, write Director of Summer Session, Massachusetts Inst. of Technology, Room E19-356, Cambridge, MA 02139.

# NEWCOMER'S PAGE: GETTING PUBLICATIONS:

-by Bernie Hutchins

In EN#128, we listed some publications in the field of electronic music. Here we will list some more journals, including some that have only occasional offerings in the areas we are most interested in.

Journal of the Audio Engineering Society This is the journal of a professional society, and to get the journal, you become a member. Yearly membership is on the order of $40. Student rates are available and are substantially less. Since this journal is on audio, probably most of the papers in it are of some interest. On the average, there are probably four or five important papers relating rather directly to music synthesis each year. For the serious worker in this area, it is important that you have at least some access to this journal. For membership and other information, write the Audio Engineering Society, 60 E. 42nd St., New York, NY 10017. The same office will also provide photocopies of individual articles at a cost of $3.00 per article.

Journal of the Acoustical Society of America This is another of the professional journals for workers in the area of acoustics. Of interest to us are the writings on musical instruments and on hearing. Occasionally there is something relating directly to electronic music. Newcomers will probably want to hold off on this one as far as membership and journal subscription go, but do look at it when you get a chance in the library. On the average, each issue has about one paper of interest to us. There are quite a large number of pages in each issue, so you will also be getting a lot of articles in other areas of acoustics which are probably of less interest. But, make no mistake, you will eventually want to get into this, and many important papers do appear here. Get to know it in the library, or try to arrange to see copies of selected papers. The address for this is Acoustical Society of America, Americal Institute of Physics, 335 E. 45th St., New York, NY 10017

American Journal of Physics This is another of the publications of the American Institute of Physics (address above). It is one of the "lighter" of physics journals, perhaps being intended more for physics teachers than for researchers. As such, it has a surprising number of articles on musical matters, perhaps three a year on average. For a professional physicists, this is probably recreational reading, but many others will find it just about the right level for what you have in mind. Again, this is probably something to look for in the library.

Scientific American I hope everyone has seen this. It is very well known and is even sold on newsstands, and at the same time, the level of writing is far from superficial. If you have a general interest in science, you may already get this. If not, it is an easy matter to check it at the newsstand each month for that approximate one issue per year that has something interesting to say about music. In scanning the articles, don't neglect to find out what Douglas Hofstadter is doing in his "Metamagical Themas" column and what Jearl Walker is doing in his "The Amateur Scientist" column.

IEEE This is not a publication, but rather an institution. The IEEE (always pronounced "I triple E") is the Institute of Electrical and Electronics Engineers. No, don't ask what the distinction between electrical and electronics is. I guess they needed one more E so as not to be confused with the British IEE. Anyway, they put out a lot of publications, and you can't ignore them. With the advances in electronics over the years, it was just not possible to put all the publications in one journal. Thus the original "Proceedings" was broken up into smaller journals or "transactions" each on a more specific subject. I don't know how many there are, but there are at least 30 in all. As an IEEE member, you pay for and get the ones you favor. Many will eventually choose to join the IEEE, and can choose the journals of most interest. Newcomers will likely prefer to check the library. Of all the journals, there are perhaps two or three papers per year on electronic music, but many additional papers of importance related to what we are doing. Among the transactions to check are: Proceedings of the IEEE; IEEE Trans. on Acoustics, Speech, and Signal Processing; IEEE Trans on Circuits and Systems; IEEE Trans on Instrumentation and Measurement; IEEE Journal of Solid State Circuits, etc.

# A VOLTAGE-CONTROLLED OSCILLATOR WITH THROUGH-ZERO FM CAPABILITY:

-by Bernie Hutchins

## INTRODUCTION:

It seems that musical engineers just can't go for long periods of time without trying out new VCO designs. Indeed much space in earlier issues was devoted to the art of designing VCO's, each one adding new tricks. Much of the "fun" of designing VCO's has been taken from us with the appearance of single-chip, dedicated electronic music VCO's. In particular, the VCO's from CES [1] and SSM [2] have made standard VCO design much simpler. Much of the theory of VCO design is available [3] and our most recent concentrated effort in VCO's goes back to our ENS-76 series from 1977 [4]. In particular, the ENS-76 Series VCO's Options 1 and 2 have been popular and highly praised by users. So why a new VCO design here? Well, there is still room for designs that offer features not available on single chip VCO's, and where an improved design can be offered. The design here uses a reversing VCO for through-zero FM capability. The design has been around in its basic form for several years, having been suggested to us by Douglas Kraul in EN#62 [5]. We have made some modifications, but in most cases, the important ideas were in Douglas' design. What we have tried to make is a VCO that offers through-zero modulation, and which is still well suited to standard VCO applications. Thus the present VCO improves on previous designs of through-zero devices [6,7,8] in the areas of accuracy and stability. It is also easy to build and has no expensive multiplier chips. It features as well a full set of standard waveshapers.

## THEORY OF OPERATION:

The through-zero VCO, (TZVCO) is based on the reversing oscillator principle. The block diagram of Fig. 1 will give the basic ideas. It is composed of a basic triangle/square oscillator based on the integrator-Schmitt-trigger principle. Here however the Schmitt trigger has the capability of switching state in a triggered manner, not just in response to the reaching of upper or lower trip levels. The Schmitt trigger will change output level when the input voltage reaches the trip levels, but it can also be triggered to reverse at will through the use of a triggerable flip-flop. All that remains to do then is to arrange to make the triggered reversals at the zero crossings of the linear control, and to rectify the linear control voltage.

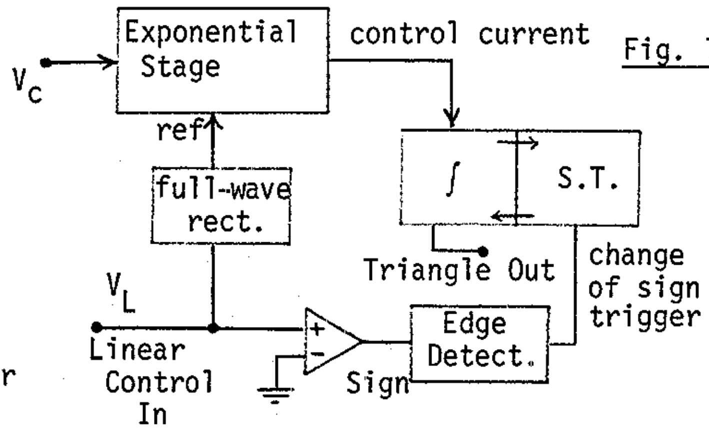

Fig. 1

Here we will not need to go into details about the FM synthesis process or the through-zero FM process. Information on FM synthesis can be found in [9] and a fairly recent summary of through-zero interpretations can be found in [10]. Consideration of these results leaves us only with the tasks of determining what a through-zero VCO should do, and how to implement these processes. We find that the waveform of an oscillator passing through zero should become level as zero is approached, and at zero control, it should then reverse direction (see again [10]). The system of Fig. 1 accomplishes these tasks. First, the reference current to the exponential stage is proportional to the magnitude of the linear control voltage. Secondly, at the time that the sign of the linear control changes, the Schmitt trigger is "flipped" to cause the oscillator to reverse direction.

The circuit diagram of the TZVCO is shown in Fig. 2, with Fig. 2a showing the oscillator circuitry, and Fig. 2b showing the added waveshaping circuitry. Most of the circuitry will likely be familiar to readers of this newsletter. Much of the circuitry not involving the through-zero process comes from ENS-76 VCO Option 2.

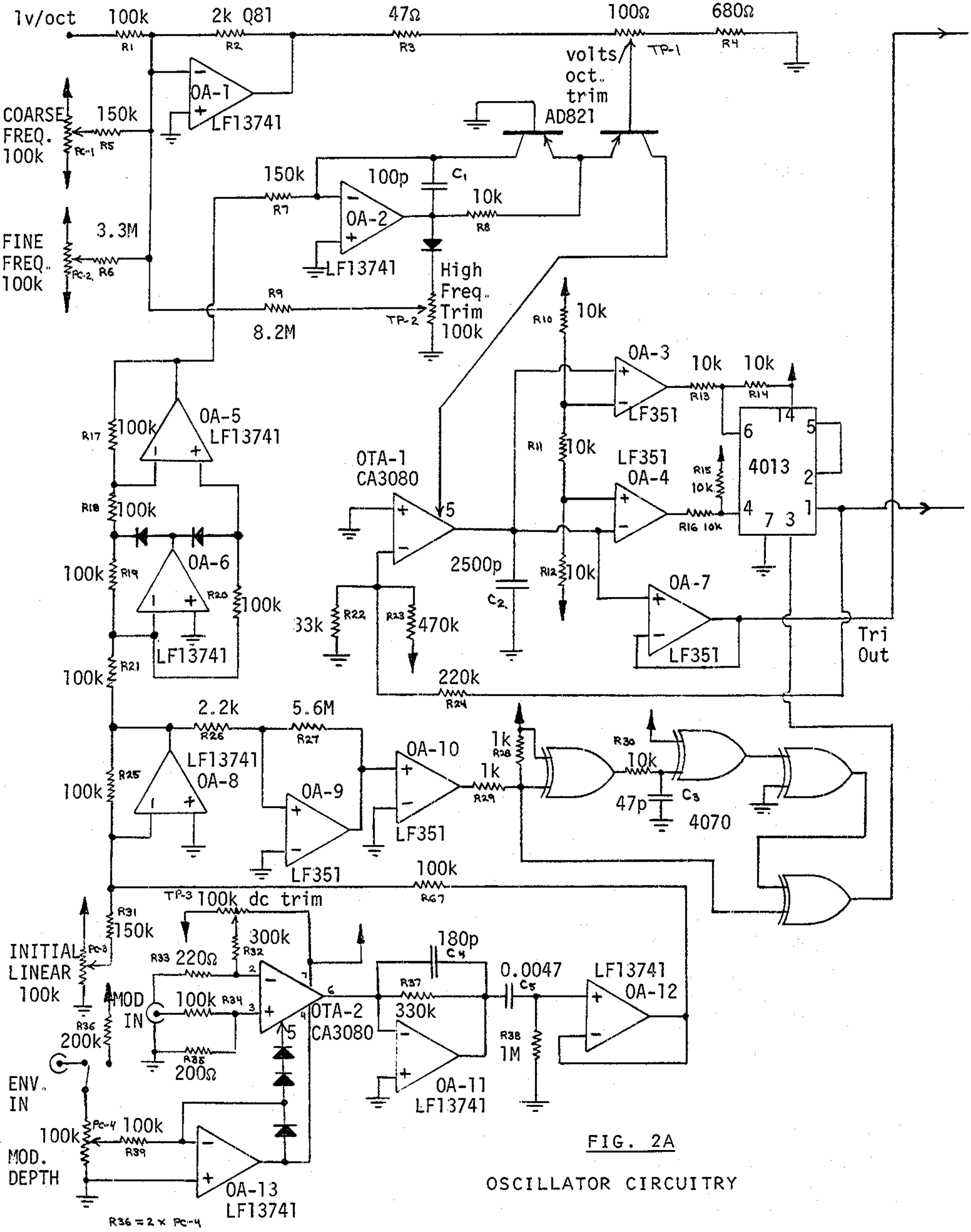

FIG. 2A

OSCILLATOR CIRCUITRY

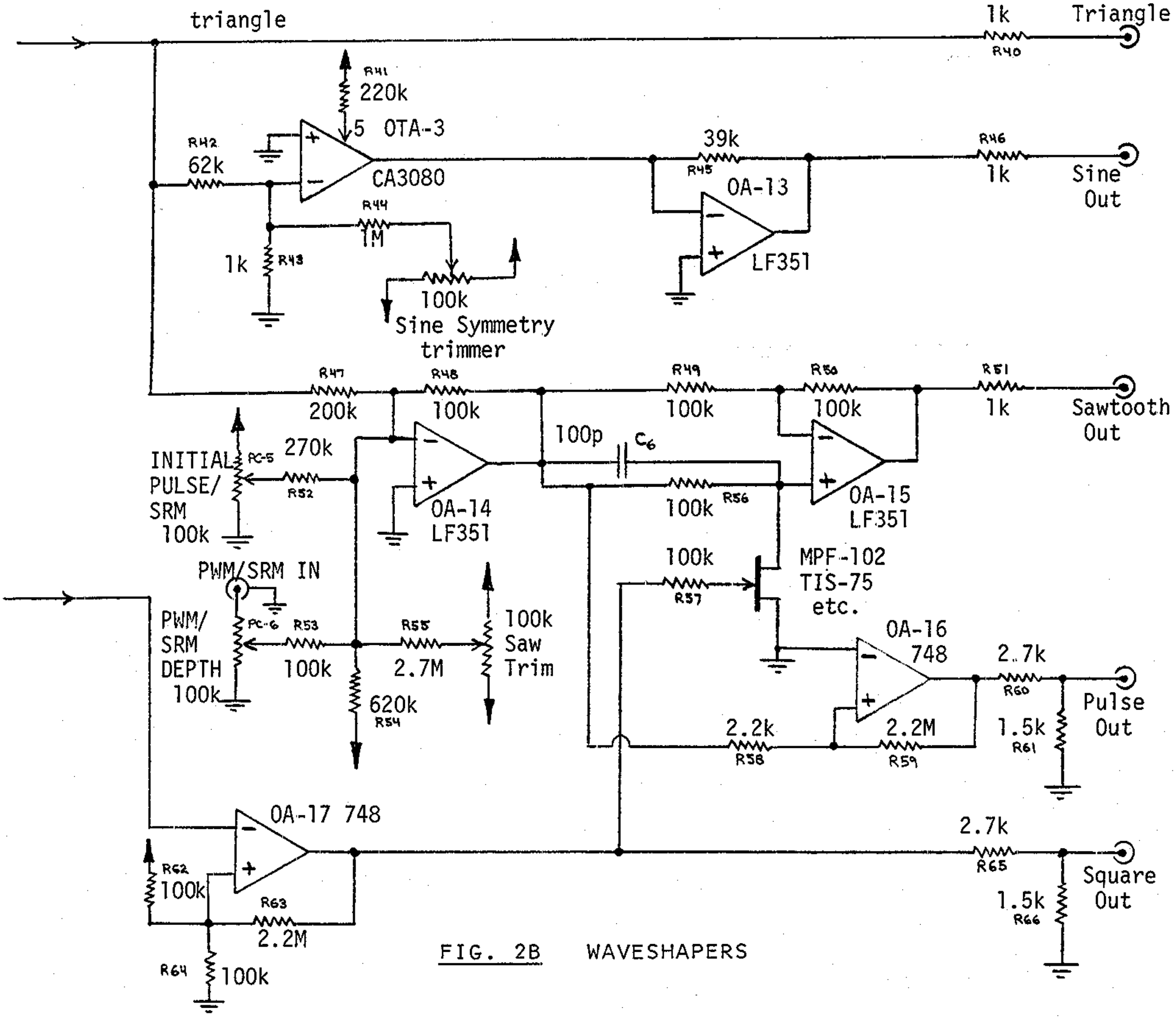

FIG. 2B WAVESHAPERS

The circuitry around OA-1, OA-2, and the AD821 matched PNP transistor pair, is our more or less standard exponential stage. The actual triangle oscillator is composed of OTA-1, OA-3, OA-4, OA-7, and the 4013 flip-flop. OA-6 and OA-5 form the full-wave rectifier for the magnitude of the linear control, as summed by OA-8. The sign of the linear control is determined by the op-amp Schmitt trigger (OA-9) and comparator (OA-10), with the circuitry around the 4070 quad exclusive-OR gate being the edge detector. The lower portion of Fig. 2a is an added section, not shown in Fig. 1. It is basically a built-in voltage-controlled amplifier for the purpose of handling a dynamic modulating signal. It is composed of OTA-2, OA-11, and OA-13, with OA-12 providing AC coupling for additional rejection of the control envelope. Fig. 2a above shows the remainder of the VCO circuitry, the waveshapers. OTA-3 and OA-13 form the sine shaper. OA-15 along with the FET below it is the heart of the triangle-to-saw converter. This configuration, as fed by the offset triangle from OA-14, provides the symmetrized ramp as well as the saw. The same driving waveform from OA-14 is fed to OA-16, providing a variable width pulse. OA-17 is an additional comparator forming the square wave from the flip-flop, with this square wave also being of the proper phase to control the triangle-to-saw converter above.

It will be useful at this point for the reader to study the circuit and sort out in his own mind the various sections, and to note in particular that the circuit is really two circuits in one. First, there is the more or less conventional VCO. Secondly, there is the additional circuitry for linear FM and through-zero FM. Roughly speaking, the upper portion of Fig. 2a (except OA-5 and OA-6) and all of Fig. 2b constitutes the conventional VCO. Thus the lower portion of Fig. 2a is the added linear FM circuitry. In fact, when either the modulating signal or the envelope is disconnected, the circuit behaves like a normal VCO.

Although it would be the usual practice to first describe the circuit, and then go on to applications, it will be useful here to show the basic sort of patch in which this circuit would be useful. This patch is shown in Fig. 3b, with Fig. 3a showing the block diagram of a through-zero FM system, with the blocks that are contained in the present TZVCO being within the dotted lines. It is possible to see that this TZVCO is a nearly complete through-zero system, lacking mainly the modulating VCO, but the depth-control VCA (VCA-2 in Fig. 3a) has been put inside. One could also include an internal VCO-2, etc., and this does not seem necessary. Avoiding the necessity of patching in VCA-2 each time however seems worth the trouble, so this is the purpose of the circuitry around OTA-2 in Fig. 2a. In addition, the dedicated internal VCA makes it possible for us to make certain additional control rejection features which are very important here. These will be described later.

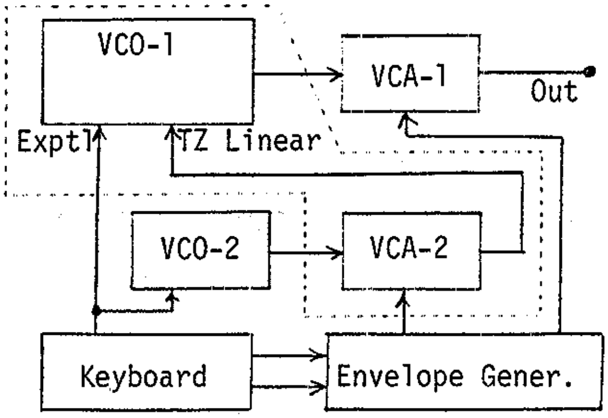

Fig. 3a Block TZ - FM System

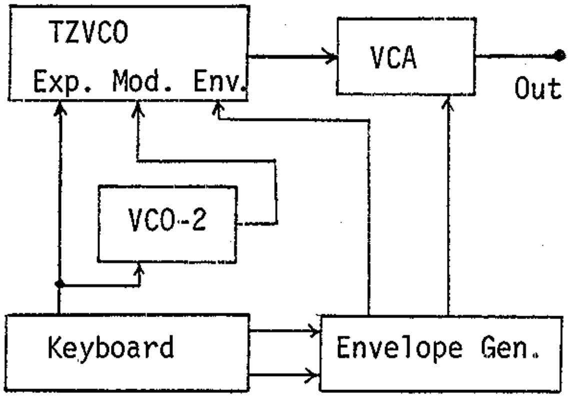

Fig. 3b Patch of the Present TZVCO

## DETAILED DESCRIPTION OF THE CIRCUITRY:

The basic exponential stage is shown in Fig. 2a around OA-1, OA-2, and the AD821 matched pair. We should point out a few features of this that have perhaps not been seen before, or which need review. We have not included an envelope input to this stage, but only the Coarse, Fine, and 1 volt/octave controls. If desired, the envelope input can be added exactly as in previous circuits [11]. The AD821 matched pair is a good choice, but unfortunately, Analog Devices is apparently not making this anymore. Many readers still have these in stock however, and we will be looking for a good replacement to suggest. Other good quality PNP pairs should work well. For a start, you can just use two unmatched transistors of the same type. In fact, I always build my circuits this way first and get them working, putting in the AD821 pair last after much of the danger of destroying it accidently during construction and testing is over. The main problem with unmatched transistors will be thermal drift of frequency over time. Note that the 150k resistor attached to the (-) input of OA-2 is what would normally be the reference current set, running to -15 volts. Here it is attached to the full-wave rectifier, which provides a negative voltage proportional to the magnitude of the linear control sum. Finally, note the use of high-frequency compensation of the exponential stage through the diode attached to the output of OA-2 and through TP-2 and R9. This type of compensation, as suggested by Rossum [12], is similar to that of Moog and Hemsath [13]. It's theory and operation will be discussed later when we get to the tune-up procedures.

The actual oscillator circuit is composed of OTA-1, OA-3, OA-4, and the 4013 flip-flop, with OA-7 acting as a buffer for the triangle voltages. The oscillator is similar to others described [5, 14]. The OTA-1 serves as a current-controlled current source, driving the 2500 pf capacitor C2, thus forming an integrator. The voltage on the capacitor is fed to the buffer OA-7, and also, in parallel, to the two inputs to comparator op-amps OA-3 and OA-4. Although this means that there are three inputs connected to the capacitor voltage, the op-amps are low input bias types, and by using them in this parallel manner, we avoid any slowing down due to a buffer (that is, if OA-7 buffered the capacitor and then fed to OA-3 and OA-4). Note that the resistor string R10, R11, R12 sets the (-) input of OA-3 at +5 volts and the (+) input of OA-4 at -5 volts. The capacitor voltage normally will remain within these limits. If the capacitor voltage tries to exceed +5 volts, which would normally occur with the (-) input of the OTA-1 negative, then OA-3 will go high. This will set the flip-flop through pin 6. This will cause pin 1 of the flip-flop to go high (Q=1) and the (-) input of OTA-1 will be positive, causing the capacitor voltage to ramp negative. At the lower transition level (-5), a similar process occurs through a reset of the flip-flop through OA-4 and pin 4 of the flip-flop. This describes the basic oscillator which produces a triangle wave. Note for the moment that we do have pin 3, the clock pin of the flip-flop, that can also flip the output. This will be discussed later.

OA-8 is the linear control voltage summer. It sums an initial linear voltage from the pot with the output voltage from OA-12, which is the modulating signal. The full-wave rectifier around OA-6 and OA-5 does nothing more than give the negative of this linear control sum, thus modulating the reference current to the exponential control stage (through R7). We also need to know the sign of this linear control sum, and this is the purpose of OA-9 and OA-10. It was found experimentally that neither the single comparator (OA-10) nor the weak Schmitt trigger comparator (OA-9) would give reliable triggering over a wide frequency range. The combination works well however. Now, we are not interested in the direction of transition, but only in the fact that the sign changes. Thus we need an edge detector, and this is formed around a single package of exclusive-OR gates in the 4070 package. Basically the idea is the feed the two inputs of an exclusive-OR gate with the same signal, but to delay the path to one of the inputs. Thus the upper three EXOR gates along with the R30-C3 delay serve to delay the comparator output to the upper input of the lower EXOR gate. The EXOR has "one and only one" logic, and most of the time, the two inputs are the same, and the output is low. At the moment of transition, the direct path changes immediately, while the delayed path does not. Thus for a moment, there is one and only one, and the output goes high. After a moment (about a half microsecond), the two inputs become the same, and the output of the gate goes low again. This short pulse is the one that triggers the flip-flop, reversing the oscillator at the zero crossings of the linear control.

As mentioned briefly above, OTA-2, OA-11, OA-12, and OA-13 form the VCA to control the depth of the modulating signal. The circuitry is quite conventional [15, 16] and uses Jung's method [17] of driving the CA3080. In theory, there is no reason that we could not drive the (-) input of OA-8 directly from the current output of OTA-2. In practice however, it is advantageous to use OA-11 and OA-12, driving OA-8 through R67. The reason for this is that we have to be very careful with DC drifts and control envelope feedthrough, all of which can distract from the FM process. Our first step here is to zero the offset of OTA-2 using TP-3. OA-11 is a current-to-voltage converter. The 180pf capacitor is needed to remove some instability at a certain voltage level, which otherwise caused erratic triggering all the way through to the flip-flop. Next, we use a high-pass filter, C5-R38, to remove any residual DC feedthrough of the envelope. This filter, as buffered by OA-12, has a cutoff around 30 Hz, so modulating signals of a lower frequency are attenuated. [If desired, a switch to short out C5 for lower modulating frequencies can be used.] The overall circuit provides a clean DC-free controlled-depth modulating signal.

Fig. 2b shows the waveshaping circuitry as described briefly above. Since it is very similar to that presented in the ENS-76 Option 2 VCO [4], we need not take space here to review it. We will make a few comments on it when we discuss the tune-up procedures of the entire circuit.

## CONSTRUCTION AND TUNE-UP:

There should be little difficulty in the layout and construction of this circuit. The only unusual parts are the AD821 matched pair (discussed above) and the 2k Q81 resistor (+3500 ppm/°C), R2. The rest of the parts are fairly standard. The op-amps marked LF351 should be of that type or some equivalent BiFET of similar speed. The op-amps marked LF13741 are the type with BiFET input and type 741 output (slower). These are used where speed is not needed because they are cheaper in some cases. LF351's can be used for these if desired. In Fact, LF351's can also be used for the two 748 op-amps if desired. The OTA's are type CA3080, and the two logic IC's (4013 and 4070) are standard CMOS IC's. Resistors are 1/4 watt 5% tolerance types, except for R1 which is better if made a 1% type. Panel pots and trim pots could actually have any value in the general range of 10k to 200k, and need not be the value shown as 100k (except for TP-1 which must be 100 ohms). If possible, C2 should be some sort of plastic film capacitor, and its value need not be exactly 2500pf (2000 pf to 3000 pf is good). The power supply lines should be bypass with 0.02mfd capacitors (not shown in the schematic) at two or three places in the circuit (for each supply). A good place for these is in the vicinity of the pulse handling circuits: OA-9, OA-10, OA-3, OA-4, and the 4013 and 4070 IC's. These capacitors are connected from the supply line to ground, and serve to keep spikes on the lines from moving to other areas of the circuit.

Naturally it is a good idea to (at least mentally) isolate and separately test the various parts of the circuit. When the circuit is turned on, it should begin oscillating immediately, producing a triangle wave at the output of OA-7. If it does not, connect a 33k resistor from pin 5 of OTA-1 to ground, first removing the line from the AD821 pair. If it still does not oscillate, there is a problem in the basic oscillator (OTA-1, OA-3, OA-4, 4013, OA-7). If it does work, then check out the exponential circuit at the top of Fig. 2a, and reconnect the line to pin 5 as in the original circuit. [Make sure there is some non-zero setting of the INITIAL LINEAR control (some negative voltage at the output of OA-5) as well, or the oscillator might be running very slowly.]

With the oscillator now running normally, we need to check the reversing circuitry, and there are several ways to do this. You should plan to make several of the tests to assure yourself that the circuit is working properly. For these tests, the INITIAL LINEAR control should be set about 1/4 of the way up. A signal (sine or triangle best) should be of ±5 volt level and attached to MOD IN. Then the switch on the MOD DEPTH control should be put in the 200k resistor position, so that the control itself sets the depth (not depending on an envelope). The tests are as follows:

1. Set the oscillator to a comfortable frequency with the MOD DEPTH control all way down. Set the modulating frequency to some audible value (say 100 Hz to 200 Hz). Now, listening carefully to the output (sine or triangle of the VCO suggested), turn up the modulation depth slowly. You should hear the depth and complexity increase continuously with the control. There should be no points in the control setting where there is a sudden jump of output pitch or timbre, or other instability. Repeat the test for a variety of modulating and VCO frequencies.

2. Drop the VCO to a low frequency (1 Hz or lower) and the modulating oscillator even lower if possible. Turn the modulation depth all the way down. Observe the output waveform as it moves up and down between +5 and -5. Now turn the modulation depth all the way up. There should now be points in the output waveform where the direction changes within the limits of +5 and -5 rather than at them. (See Fig. 4a).

3. Turn the VCO and modulating frequencies back up, and the depth back down to zero. Listen to the square-wave output (or pin 1 of the flip-flop). The pitch should be the same as that of the triangle or course. Now, short out capacitor C2 with a jumper. The VCO should stop. Now turn up the modulation depth. At some point, an output will be heard from the square wave again. Check to see that this pitch is the same as that of the modulating frequency. Note the level

of the depth at which the square wave output starts up again. You may note that this is the same point at which the output of the full-wave rectifier changes from a sine wave to a rectified one (as in Fig. 4b). This is the position (for this setting of INITIAL LINEAR and of modulating signal level) where the modulation goes through zero. [Note that what is happening here is that the normal reversals have been prevented by the jumper on C2, and all that is getting through is the change-of sign pulses from the modulating signal.]

4. Leaving the INITIAL LINEAR control alone, you can now make a direct listening and visual test (oscilloscope waveform). Try to set the modulating frequency to something like 1/5 of the VCO's starting frequency. Observe the waveform and slowly turn up the depth. As you approach the through zero point (determined from 3 above), you will see "flat spots" appearing in the waveform (see Fig. 4c). As you go even higher, these flat stopping points will turn into actual reversals (see Fig. 4d). You should be able to identify these reversal points with the zero crossings of the modulating waveform. Once this all checks out, again do a careful listening test passing through the zero point. Note that nothing drastic happens. The through-zero case is just a continuation of the process that was going on above zero. If you do hear a drastic change, then something is wrong. Probably the flip-flop is not triggering on both edges.

With the oscillator working properly in both its normal mode and its through-zero mode, it is time to check out the envelope circuitry. To do this, connect up a voltage of about +5 volts to the MOD IN (or use 200k in series with the input and connect to +15). Trigger an envelope generator from a low-frequency oscillator for a periodic envelope, and connect this envelope to ENV IN. [You can also trigger envelopes by hand by pressing a key on the keyboard if this is convenient.] Now, short out capacitor C5 with a jumper. Listening to the VCO output, adjust TP-3 for minimum change of pitch during the envelope cycle. [Or you can observe the DC feedthrough directly at the output of OA-11]. Finally, remove the short from C5, and the feedthrough of control envelope should be minimal.

The waveshapers should be simple to adjust. The sine shaper is adjusted with the symmetry trimmer for the same shape top and bottom. There may be a slight suggestion of the triangle's point at the top, but this is normal for the lowest distortion level with this shaper [18]. This oscillator has the Pulse-Width Modulation (PWM) and Symmetrized Ramp Modulation [SRM] features previously reported [4, 19]. With the INITIAL PULSE/SRM control all the way down or all the way up, the waveform at the saw output should be very close to sawtooth. With the control all the way down, adjust the Saw Trim control for the best possible alignment of the sawtooth segments. [If this does not work out, a likely problem is that the FET is connected wrong. You can try all possible combinations of the FET's leads without any danger to the FET or the circuit.] The pulse output should respond to the initial pulse control. Note that the pulse width will be zero or close to it with the INITIAL PULSE/SRM control at zero or at maximum, so assure that it is somewhere in the middle when testing the pulse output. The square waveshaper needs no adjustment and is obviously working if the sawtooth is. If it is not working somehow, then the sawtooth converter won't work either.

The circuit should now be working, and it is time for the final tune up of the exponential response. This is done by adjusting TP-1 and TP-2. To set up for this, you will need a frequency counter or a good ear, or perhaps you can rig up a flip-flop (e.g. the unused side of the 4013) to provide an octave reference. Set a reference voltage to -1.000 volts. Set the coarse and fine frequency controls to their center zero position, and set the INITIAL LINEAR control so that the output of OA-5 is about -10 volts. Disconnect any modulation signals. The frequency of the VCO should be about 1200-1300 Hz. Connect the -1.000 volt signal to the 100k input (R1) and the frequency should drop to about half. Assure that TP-2 is in its lower position and adjust TP-1 until the -1.000 signal gives you exactly half the original frequency. Adjust the input voltage to +4.00 (4.000 if your meter will do this). Multiply the zero volt frequency by 16. The actual frequency will likely be a bit on the flat side of this target value. If so, adjust TP-2 upward until the correct value is reached.

Fig. 4a Low-Freq. Reversals

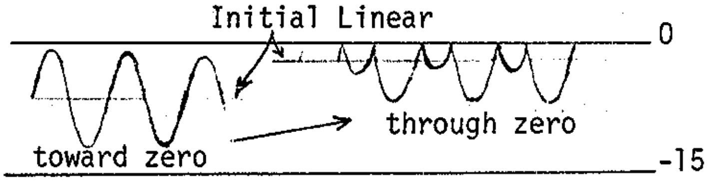

Fig. 4b Full-Wave Rectifier Output

Fig. 4c Near-Zero Approach

Fig. 4d Through-Zero

Now it is up to you how much more work you want to do on this calibration. If you have the desire, equipment, and time, you can run the control voltage up and down, and make minor adjustments of TP-1 and TP-2 until you get a very accurate response function. The values below for my oscillator will give you some idea of what can be achieved with about a half-hour's playing around.

| VOLTAGE | WITH TP-2 AT BOTTOM | | WITH TP-2 ADJUSTED UPWARD | |
|---|---|---|---|---|
| | FREQUENCY | RATIO | FREQUENCY | RATIO |
| -5.00 | 39 | | 39 | |
| | | 2.000 | | 2.000 |
| -4.00 | 78 | | 78 | |
| | | 2.000 | | 2.000 |
| -3.00 | 156 | | 156 | |
| | | 1.994 | | 2.000 |
| -2.00 | 311 | | 312 | |
| | | 2.000 | | 2.003 |
| -1.000 | 622 | | 625 | |
| | | 2.002 | | 1.992 |
| 0 | 1245 | | 1248 | |
| | | 2.002 | | 2.002 |
| +1.000 | 2493 | | 2499 | |
| | | 1.989 | | 2.000 |
| +2.00 | 4959 | | 4998 | |
| | | 1.985 | | 2.000 |
| +3.00 | 9844 | | 9994 | |
| | | 1.998 | | 1.997 |
| +4.00 | 19668 | | 19959 | |

The above values do indicate that the circuit is quite satisfactory over the normal audio range. The actual range of the oscillator is from well below 1 Hz to about 29,000 Hz. Note that the curve for the uncompensated oscillator first goes flat, and then starts to go sharp again, a strange behavior seen in a similar oscillator [4]. Since we can only measure frequency to the nearest Hz, you should note that the value of frequency for the compensated case, -1.000 volts, might have been 624 Hz instead of 625, and this would have made the response nearly perfect. Probably the most important feature of the TP-2 high frequency trim is its improvement in the 5000 - 10000 Hz octave. It should be noted that some drift at the 20,000 Hz level was noted. The frequencies were initially a bit higher than those listed above, but drifted downward to those listed after a minute or two. Use of such high frequencies is rare anyway, but you might make a mental note that for occasional short high notes, the results may be a bit sharp. The best guess is that some sort of self-heating is going on at these higher frequencies (higher controlling currents). It is not a real problem.

APPLICATIONS:

If you have never heard dynamic-depth or through-zero FM tones before, you will be pleased with the wide range of interesting sounds you will get from this simple circuit. Note however that through-zero is an extension of dynamic depth. In conventional linear modulation, we are able to use dynamic depth, but the instantaneous frequency can only approach zero, so the peak depth is limited. A through-zero device can have a much larger peak depth, since it does not have to stop at zero. But it must be realized that going through zero in itself is not dramatic. The difference between going to within 1% of zero, and going through zero by the same 1%, is not much different than that between 1% and 2% on the positive side.

The principal application of this oscillator will be to the production of tones with dynamically varying spectra. If the ratio between the original VCO frequency (called the carrier) and the modulating frequency is an exact integer, then the resulting through-zero FM tone will be harmonic. Otherwise (the general case), it will be composed of non-harmonic partials. The latter case is very useful for the production of bell-like and other percussive sounds. The basic patch here is that of Fig. 3b. Note that you can easily set this up as the basic voltage-controlled patch, leaving out the VCF. [Of course you can use the VCF if you want, but for now you will just want to hear the FM process itself.] Once the patch is working in its basic form, you just plug a VCO output into the MOD IN, and an envelope (the same, or better, a different one than that going to the VCA) into ENV IN. You are now ready to explore the different timbres that can be achieved. You will want to spend some time with this patch.

It should be noted (see Fig. 5) that in general all modulated tones will begin with modulation above zero, and go through zero as the depth increases, with the modulating voltage increasing about an Initial Linear level with the depth. Thus by selecting the depth and the Initial Linear, we can modulate over any range we please. However, note that the original frequency (carrier) of the VCO changes with the Initial Linear setting (since that is the VCO's reference current). What this means is, for example, that if we want the VCO's frequency to go further through zero, we can increase the depth (obviously) or we can lower the Initial Linear. If we increase the depth, then the total range swept is increased. If we lower the Initial Linear, the original pitch drops. This latter case is no real problem, as we can simply raise the exponential control back to give the original pitch. Therefore, there are no real restrictions here. However, as a matter of convenience, it might be nice if we could change the Initial Linear and have the VCO carrier remain the same. A way of

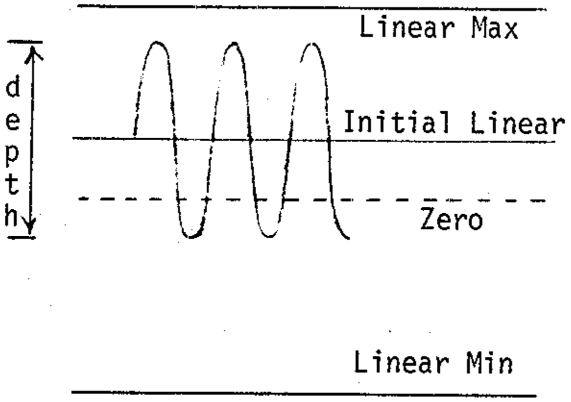

Fig. 5 Effect of Initial Linear and Mod Depth controls

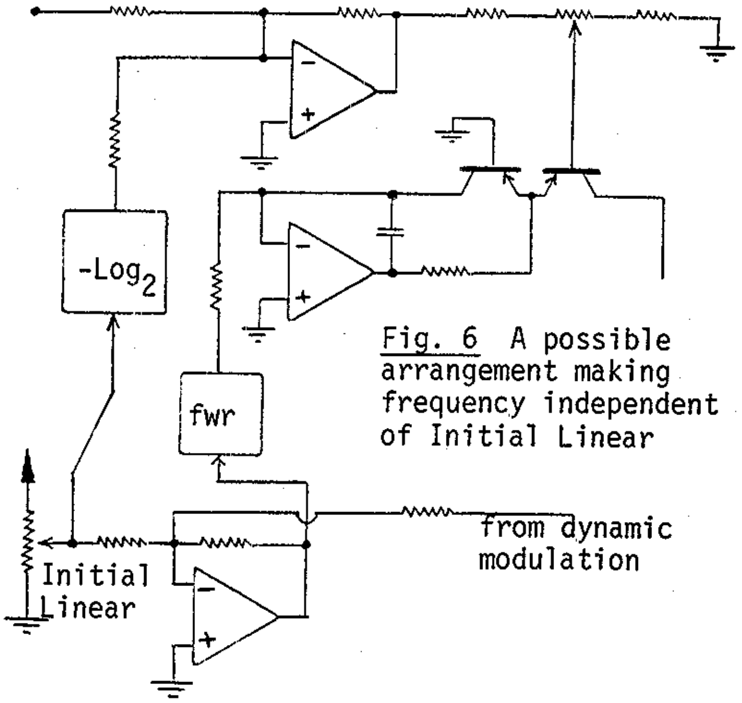

Fig. 6 A possible arrangement making frequency independent of Initial Linear

achieving this is shown in Fig. 6. We just need to add a log converter. Thus for example, if the Initial Linear were changed from 8 volts to 4 volts, the carrier would normally change to 1/2 its original frequency. But with the added $\text{Log}_2$ loop, we would get a change of +1 volt back at the exponential converter, moving the carrier frequency back up one octave. There is probably some neat way of doing this. In particular, it looks as though we could avoid the path through the upper op-amp of Fig. 6 and just connect the base of the left transistor of the exponential converter (here shown grounded) to a base of one of the transistors in the log converter. The details of this and other possible developments may be reported in a later issue.

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