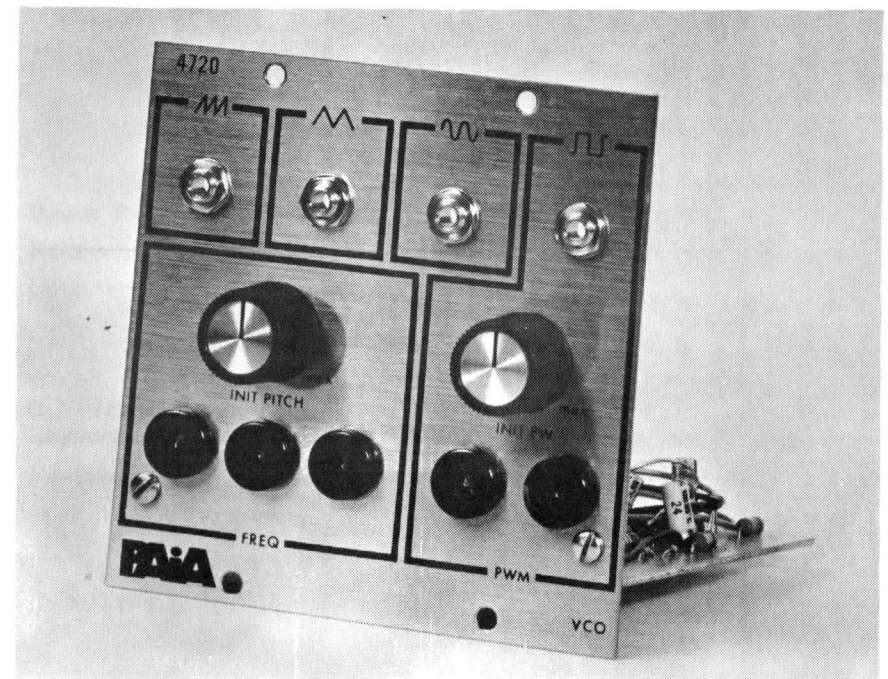# PAiA

ELECTRONICS, INC.

4720 A

Voltage Controlled Oscillator

The 4720 Voltage Controlled Oscillator features simultaneous ramp, triangle, sine and pulse/square wave outputs; manually set or voltage controlled pulse width and 16 Hz. to 16 kHz. frequency response corresponding to 5 volt peak control voltage. Front panel initial pitch control allows multiple oscillators to be offset and track one another chromaticly over the entire operating range. A self-zeroing front end and active on-board voltage regulation combine to make the 4720 extremely linear and stable.

SPECIFICATIONS

|	
Power Req.:	+9v. @ 20 ma.
Range:	16 Hz. to 16 kHz.
Outputs:	Ramp
	Triangle
	Pulse/Square
	Sine
C.V./Freq. Response:	Linear
Features:	Front panel control sets initial pitch of oscillator. Internal Pulse Width Modulator. Wide Range - Exceptionally linear.

SOLDERING

Use care when mounting all components. Use only rosin core solder (acid core solder is never used in electronics work). A proper solder joint has just enough solder to cover the round soldering pad and about 1/16 inch of the lead passing through it. There are two improper connections to beware of: Using too little solder will sometimes result in a connection which appears to be soldered but actually there is a layer of flux insulating the component lead from the solder bead. This situation can be cured by re-heating the joint and applying more solder. If too much solder is used on a connection there is the danger that a conducting bridge of excess solder will flow between adjacent circuit board conductors forming a short circuit. Unintentional bridges can be cleaned off by holding the board up-side down and flowing the excess solder off onto a clean, hot soldering iron.

Select a soldering iron with a small tip and a power rating not more than 35 watts. Soldering guns are completely unacceptable for assembling transistorized equipment because the large magnetic field they generate can damage solid state components.

CIRCUIT BOARD ASSEMBLY

( ) Prepare for assembly by thoroughly cleaning the conductor side of the circuit board with a scouring cleanser. Rinse the board with clear water and dry completely.

Solder each of the fixed resistors in place following the parts placement designators printed on the circuit board and the assembly drawing figure 1. Note that the fixed resistors are non-polarized and may be mounted with either of their two leads in either of the holes provided. Cinch the resistors in place prior to soldering by putting their leads through the holes and pushing them firmly against the board. On the conductor side of the circuit board bend the leads outward to about a 45° angle. Clip off each lead flush with the solder joint as the joint is made. SAVE THE EXCESS CLIPPED OFF LEADS FOR USE AS JUMPERS IN LATER STEPS.

silver or gold - disregard this band
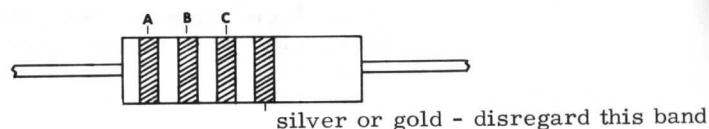
DESIGNATION	VALUE	COLOR CODE A-B-C
( ) R1	270K	red-violet-yellow
( ) R2	270K	red-violet-yellow
( ) R3	270K	red-violet-yellow
( ) R4	100K	brown-black-yellow
( ) R5	2.2 meg ohm	red-red-green
( ) R9	15K	brown-green-orange
( ) R10	1 meg ohm	brown-black-green
( ) R12	1 meg ohm	brown-black-green
( ) R13	330 ohm	orange-orange-brown
( ) R14	330 ohm	orange-orange-brown
( ) R15	2200 ohm	red-red-red
( ) R16	2200 ohm	red-red-red
( ) R17	270 ohm	red-violet-brown

DESIGNATION	VALUE	COLOR CODE A-B-C
( ) R18	68K	blue-grey-orange
( ) R19	150K	brown-green-yellow
( ) R20	68K	blue-grey-orange
( ) R22	4700 ohm	yellow-violet-red
( ) R23	680 ohm	blue-grey-brown
( ) R24	18K	brown-grey-orange
( ) R25	33K	orange-orange-orange
( ) R26	4700 ohm	yellow-violet-red
( ) R27	10K	brown-black-orange
( ) R28	10K	brown-black-orange
( ) R29	82K	grey-red-orange
( ) R30	3900 ohm	orange-white-red
( ) R31	1K	brown-black-red
( ) R32	68K	blue-grey-orange
( ) R33	150K	brown-green-yellow
( ) R34	150K	brown-green-yellow
( ) R36	39K	orange-white-orange
( ) R38	150K	brown-green-yellow
( ) R41	22K	red-red-orange
( ) R42	4700 ohm	yellow-violet-red
( ) R43	470 ohm	yellow-violet-brown
( ) R44	100K	brown-black-yellow
( ) R45	100 ohm	brown-black-brown
( ) R46	100K	brown-black-yellow
( ) R47	4700 ohm	yellow-violet-red
( ) R48	1K	brown-black-red
( ) R50	6800 ohm	blue-grey-red
( ) R52	10K	brown-black-orange
( ) R53	100 ohm	brown-black-brown
( ) R54	100 ohm	brown-black-brown
( ) R55	1K	brown-black-red

NOTE: Not all fixed resistors are used on the printed circuit board. Three remaining resistors will be installed on the front panel.

( ) Using six (6) pieces of excess wire clipped during resistor installation form and install the six wire jumpers as shown by the solid lines in figure 1 and printed on the circuit board.

Install the ceramic disk capacitors. Without exception the value will be marked on the body of the part.

DESIGNATION	VALUE
( ) C1	15 pf.
( ) C7	15 pf.
( ) C3	47 pf.

Install the .01 mfd. polyester capacitor C2. This capacitor will have its value marked on the body of the part.

DESIGNATION	VALUE
( ) C2	.01 mfd.

Up to this point all components have been non-polarized and either lead could be placed in either of the holes provided without affecting the operation of the unit. Electrolytic capacitors are polarized and must be mounted so that the "+" lead of the capacitor goes through the "+" hole in the circuit board. In the event that the "-" lead rather than the "+" lead of the capacitor is marked it is to go through the unmarked hole in the circuit board.

Note that the operating voltage (v.) specified for a capacitor is the minimum acceptable rating. Capacitors supplied with specific kits may have a higher voltage rating than that specified and may be used despite this difference. For instance, a 100 mfd. 25v. capacitor may be used in place of a 100 mfd. 16v. capacitor without affecting the operation of the circuit.

Mount the following electrolytic capacitors and solder them in place. Their values, voltage rating and polarization are marked on the body of the part.

| DESIGNATION		DESCRIPTION
( )	C4	2.2 mfd. 6v. electrolytic
( )	C5	2.2 mfd. 6v. electrolytic
( )	C6	2.2 mfd. 6v. electrolytic
( )	C8	2.2 mfd. 6v. electrolytic
( )	C9	100 mfd. 10v. electrolytic
( )	C10	100 mfd. 10v. electrolytic

Install the transistors. Orient as illustrated in figure 1 and the parts placement designators printed on the circuit board. All semi-conductors are heat sensitive and may be damaged if allowed to get too hot while soldering. To be on the safe side heat sink each transistor lead during the soldering operation by grasping it with a pair of needle nose pliers at a point between the circuit board and the body of the transistor.

DESIGNATION		TYPE NO.
( )	Q1	2N4126
( )	Q2	2N4126
( )	Q3	2N5129
( )	Q4	2N4871
( )	Q5	2N3391
( )	Q6	2N2712
( )	Q7	2N5129
( )	Q8	2N5129
( )	Q9	2N5129
( )	Q10	2N5129

2N5129
2N4126

2N4871

- or -

2N2712
2N3391

* Selected low-leakage transistors
  - bagged separately.

Install all diodes. Like transistors these parts are heat sensitive and the precautions listed for transistor installation apply here also. The physical appearance of the diodes is related to their schematic representations in the accompanying drawings

DESIGNATION		TYPE NO.
( )	D1	1N914
( )	D2	1N914
( )	D3	1N914
( )	D4	1N914
( )	D5	1N914
( )	D6	1N914
( )	D7	5.6v. zener

1N914   zener
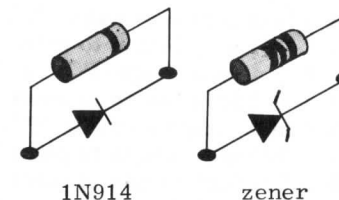
Install the integrated circuits. Note that the orientation of integrated circuits is keyed by a notch at one end of the case which aligns with the semi-circular key on the designators printed on the circuit board. Use particular care when installing these parts, like any other semi-conductors they are heat sensitive and should not be exposed to extraordinarily high soldering temperatures. Make sure that the orientation is correct before soldering. Once these parts are in place they cannot be removed without destroying them.

DESIGNATION		TYPE NO.
( )	IC-1	748 op-amp
( )	IC-2	LM-3900 or CA-3401E Quad Norton Amplifier

Install the trimmer potentiometers.

DESIGNATION		VALUE
( )	R6	50K
( )	R11	500K
( )	R21	50K
( )	R35	50K
( )	R49	10K
( )	R51	10K

In the following steps wires will be soldered to the circuit board which will in later steps connect to front panel controls and jacks. At each step prepare the wire by cutting it to the specified length and stripping 1/4 inch of insulation from each end of the wire. "Tin" each end by twisting the exposed strands tightly together and melting a small amount of solder into the wire.

Using the wire provided make the following connections to the circuit board.

( )   A 9-1/4 inch length to point "N".
( )   A 6-1/4 inch length to point "H".
( )   A 6-1/4 inch length to point "J".

( )   A 6 inch length to point "E".
( )   A 5-3/4 inch length to point "M".
( )   A 4-3/4 inch length to point "K".
( )   A 4-1/2 inch length to point "G".
( )   A 4 inch length to point "F".
( )   A 3-3/4 inch length to point "D".
( )   A 2-3/4 inch length to point "L".
( )   A 2-3/4 inch length to point "C".
( )   A 2-1/4 inch length to point "B".
( )   A 1-3/4 inch length to point "A".

THIS COMPLETES ASSEMBLY OF THE 4720 CIRCUIT BOARD.
TEMPORARILY SET THE CIRCUIT BOARD ASIDE AND PROCEED
TO THE MOUNTING OF THE FRONT PANEL CONTROLS AND JACKS.

Place the front panel face down on a soft rag during these operations to prevent marring the finish.

( )   Place a black pin jack J1 in the hole provided as shown in figure 3 and fasten in place with a tinnerman nut as shown in detail drawing figure 2. Press the tinnerman nut down firmly.

( )   In a similar manner mount black pin jack J2.

( )   In a similar manner mount black pin jack J3.

( )   In a similar manner mount black pin jack J4.

( )   In a similar manner mount black pin jack J5.

Figure 2
Tinnerman nut detail

( )   Mount the open circuit phone jack J6 on the front panel in the position shown in figure 3. Orient the jack as shown and fasten in place with the nut provided.

( )   In a similar manner mount the open circuit phone jack J7.

( )   In a similar manner mount the open circuit phone jack J9.

( )   In a similar manner mount the open circuit phone jack J8.

( )   Mount the 100K ohm potentiometer R7 in the location shown in figure 3. Use two 3/8 inch nuts provided, one behind the front panel as a spacer, and the second on the front side of the panel to secure the potentiometer. Adjust the rear nut so that none of the threaded shaft of the control is exposed when the front nut is tightened down. This will allow the control knob which will be mounted in a later step to seat as closely as possible to the front panel. Orient as illustrated in figure 3.
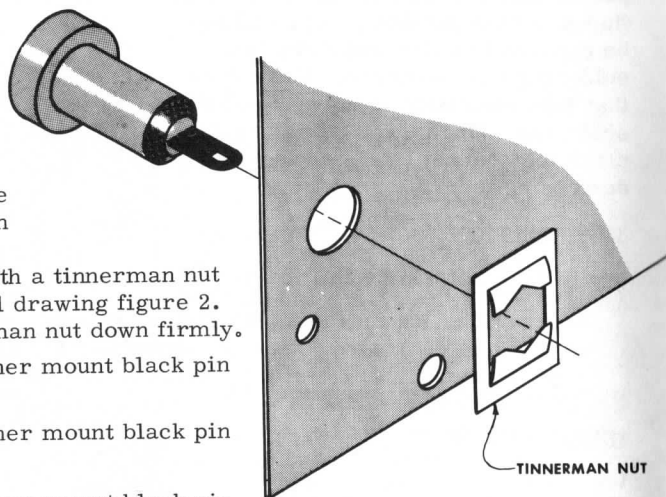
( )   In a similar manner mount 75K ohm potentiometer R37.

( )   Using the bare wire provided make the connections between lug #1 of R37 (Do not solder), lug #2 of J8 (do not solder), lug #2 of J9 (do not solder), lug #2 of J7 (solder), and lug #2 of J6 (solder). At J8, J9 and J7 this wire need only be passed through the hole in the lug, a tight crimp connection is not necessary.

THE FRONT PANEL MAY NOW BE BOLTED TO THE CIRCUIT BOARD
AS FOLLOWS:

( )   Fasten the two "L" brackets to the front panel using one 4-40 X 1/4 inch machine screw, two lockwashers and one 4-40 nut on each bracket. Note that the unthreaded hole in the "L" bracket is used in this operation as shown in figure 4. DO NOT completely tighten these screws at this time.

NOTE THREADED HOLE

( )   Fasten the circuit board to the front panel "L" brackets by passing two 4-40 X 1/4 inch machine screws up through the holes in the circuit board and threading them into the threaded holes in the "L" brackets. Securely tighten all screws.
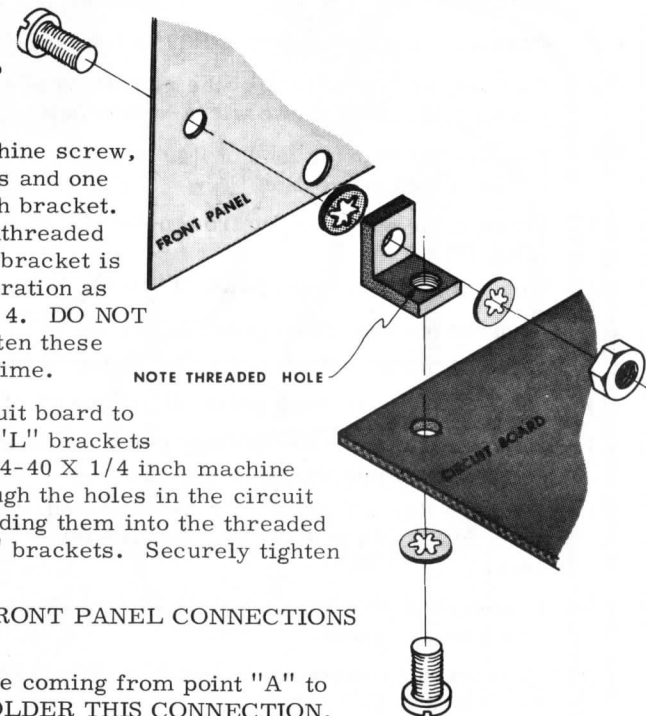
MAKE THE FINAL FRONT PANEL CONNECTIONS
AS FOLLOWS:

( )   Connect the wire coming from point "A" to pin jack J3. SOLDER THIS CONNECTION.

( )   Connect the wire coming from point "B" to pin jack J2. SOLDER THIS CONNECTION.

( )   Connect the wire coming from point "C" to pin jack J1. SOLDER.

Figure 4
Front panel circuit board mounting detail

NOTE: Make sure that the solder lug of J1 does not touch the metal portions of trimmer resistor R6. This may require bending the solder lug of J1 slightly.

( )   Connect the wire coming from point "D" to lug #3 of R7. NOTE: During calibration this connection may need to be opened. DO NOT make a tight crimp in the wire at this terminal. SOLDER.

( )   Connect the wire coming from point "E" to lug #2 of R37. SOLDER.

( )   Connect the wire coming from point "F" to pin jack J5. DO NOT SOLDER THIS CONNECTION AT THIS TIME.

( )   Connect the wire coming from point "G" to pin jack J4. DO NOT SOLDER.

( ) Cut two 3/4 inch lengths of the plastic tubing provided.

( ) Prepare two 68K (blue-grey-orange) resistors by cutting one lead of each resistor to a length of 5/8 inch and slipping a length of the previously prepared tubing over the untrimmed lead. When the end of the plastic tubing is flush with the body of the resistor clip the longer lead of each resistor so that 1/4 inch of the lead extends beyond the end of the tubing.

( ) Connect the longer lead of one of the previously prepared 68K resistors (R39) to pin jack J4. Solder two wires at this point.

( ) Connect the shorter lead of R39 to lug #1 of R37. DO NOT SOLDER.

( ) Connect the longer lead of the remaining 68K resistor (R40) to pin jack J5. Solder two wires at this point.

( ) Connect the shorter lead of R40 to lug #1 of R37. Solder three wires at this connection.

( ) Connect the wire coming from point "H" to lug #1 of phone jack J6. SOLDER.

( ) Connect the wire from point "J" to lug #1 of phone jack J7. SOLDER.

( ) Connect the wire from point "K" to lug #1 of J8. SOLDER.

( ) Connect the wire from point "L" to lug #1 of phone jack J9. SOLDER.

( ) Connect the wire from point "M" to lug #3 of R37. Solder.

( ) Connect the wire coming from point "N" to lug #2 of J8. Solder two wires at this connection.

( ) Prepare R8, a 2.7K ohm (red-violet-red) resistor, by cutting one lead to a length of 1/2 inch. Cut the other lead to a length of 3/4 inch.

( ) Connect the shorter lead of R8 to lugs #1 and #2 of R7. Solder these connections.

( ) Connect the remaining lead of R8 to lug #2 of phone jack J9. Solder two wires at this connection.

( ) Rotate both potentiometer shafts fully counter-clockwise as viewed from the front of the panel.

( ) Once the control knobs are installed they will be difficult to remove. Before installing the knobs align the pointer on each knob so that it is in the 7 O'clock position. Push the two knobs firmly onto their shafts.

( ) Locate and install a "flea" clip at test point 1 (TP1).

( ) Three additional "flea" clips have been included to facilitate power supply connections. Insert these clips into the holes in the end of the circuit board marked +9, ⏚ and -9. These clips are a tight fit. It may be necessary to bend the narrow end of the clips slightly so that they will fit the holes.

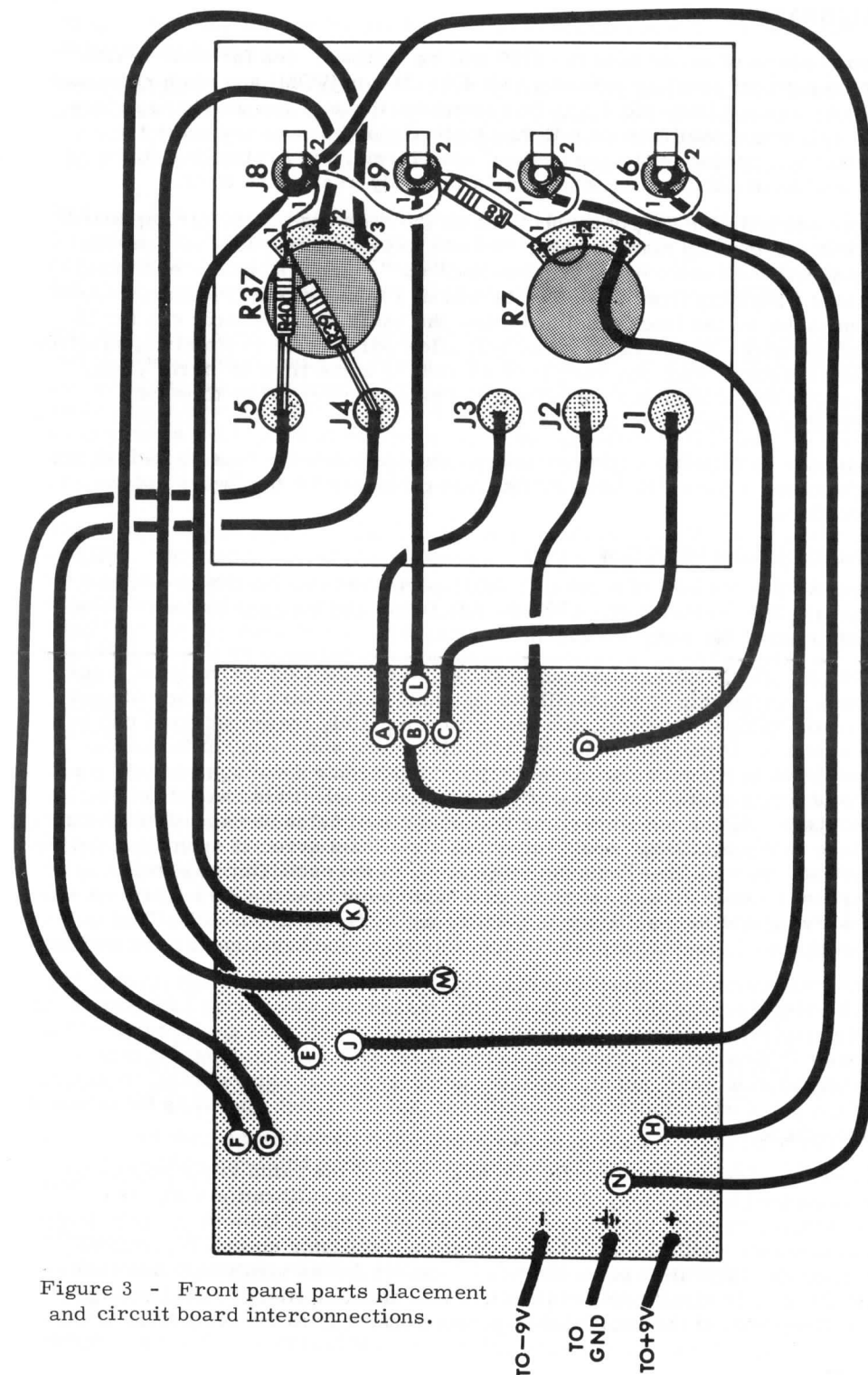THIS COMPLETES ASSEMBLY OF THE 4720 VOLTAGE CONTROLLED OSCILLATOR.

Figure 3 - Front panel parts placement and circuit board interconnections.

CALIBRATION

Two methods of calibrating the 4720 will be outlines; one for those whose test equipment consists only of a Volt-Ohm Meter (VOM) and pitch reference (piano-organ-guitar, etc.) and the second for those of you who have access to a calibrated oscilloscope. Either method may be used and while the second will produce "picture perfect" waveforms, the first relies on the ear and an oscillator that sounds right is really what we're after.

Apply power to the supply connections on the rear edge of the circuit board: +9 volts to the clip marked "+9", -9 volts to the clip marked "-9" and the common ground point to the clip marked "⏚". Apply a source of control voltage (anything from .5 to 5 volts will do) to one of the frequency control input jacks on the front panel and allow the oscillator to simply run for 10 to 15 minutes. This "aging" time will allow parts value to stabilize, electrolytic capacitors that may have been stored for some time to "form", etc. Note that this stabilizing period will not be necessary every time the oscillator is used, only the first time.

While the oscillator is aging we can productively use the time to analyze the high points of the calibration method and get a feel for the "whys" of the procedure.

CALIBRATION PREVIEW

The two parameters of most critical importance in an oscillator of this type are the "zero intercept" of the oscillator and the peak to peak amplitude of the ramp waveform.

The zero intercept is important because unless the Control voltage/ frequency relationship of the oscillator extrapolates to zero frequency for zero control voltage, the oscillator will not chromaticly transpose from one key to another. It not only would be difficult to turn some control inside the oscillator to produce zero frequency for zero control voltage (exactly zero frequency is more than just difficult to determine); it also would not be accurate. Slight non-linearities that occur well below the specified operating range of the oscillator would introduce significant error in such a procedure. Instead, we will first "null the integrator" in the oscillator to eliminate current leakage errors and then, at a later point, set the zero intercept by observing that the oscillator is performing as it ideally should. That is, that it does in fact transpose chromaticly from one key signature to another.

The ramp waveform must be very close to the design amplitude (in this case 4.5 volts) because the formation of the rest of the waveforms are "keyed" to this amplitude. Higher or lower peak to peak amplitudes of the ramp will result in a variety of problems including excessively distorted (or non-existent) sine wave output, apparent compression or expansion of the action of the pulse width modulator, oscillator cut-off at high operating frequencies, and others.

In the oscilloscope procedure, the amplitude of the ramp is set simply by measuring it; but if only a VOM is available as a calibration tool, other techniques must be used. Specificly, we will apply a known control voltage (as measured with the VOM) and adjust the oscillator so that it produces a specific calibration pitch (G# below concert A - an admittedly odd, but mathematicly significant set point). Since for a constant control voltage the frequency of the oscillator is proportional only to the reciprocal of the ramp amplitude, this technique will get us to within about 7% or better of where we want to be.

Before beginning either procedure; rotate both the Initial Pitch (INIT PITCH) and Initial Pulse Width (INIT PW) front panel controls fully counter-clockwise(CCW) and set all 6 internal trimmers (ZERO, INT TRIM, PW TRIM, TRI SYM, RANGE and SINE SYM) to the mid-points of their rotation.

Both calibration procedures begin with the same adjustment; trimming the integrator so that for no current input there is no change in the output voltage. This is going to be a DC voltage measurement, so if your scope is not direct coupled you had better abandon it temporarily for a VOM.

For this adjustment the summing voltage to current converter at the front end of the oscillator must be disabled so that we can be sure it is supplying no current to the integrator. The easiest way to accomplish this is to apply a <u>negative</u> control voltage to one of the inputs. Remove the positive voltage from the input that was being used during aging of the oscillator and jumper one of the control voltage inputs directly to the "-9" power supply clip on the rear edge of the oscillator card.

The voltage at the output of the integrator (the pin marked TP1 between Q3 and Q5) may now be measured directly. NOTE: If a VOM is being used we highly recommend that the measurement be referenced to the negative supply line; that is, the minus lead of the VOM connected to the "-9" supply pin on the rear of the card rather than ground. Set the range of the VOM so that 10 volts DC can conveniently be read. A DC coupled scope can easily measure both positive and negative voltages and can be referenced to ground. The positive lead of the VOM or signal input of the scope connects directly to test point 1 (TP1).

Observe that the setting of R11 (INT TRIM) effects the <u>rate</u> at which the voltage present at test point one changes. With the trimmer fully CCW, the voltage measured at TP1 will decrease to a minimum reading in the 1 to 2 volt range (referenced to -9v) and hold. Rotating the control fully clockwise (CW) will cause the voltage to slowly increase. Full CW rotation of R11 may or may not produce a slow oscillation evidenced by the meter reading rising to a peak level and then falling back several volts only to increase again.

By carefully setting R11, the voltage measured at TP1 can be made to hold steady at some intermediate value. The exact value at which the reading is stable is not at all critical (as long as it is not the upper or lower extreme) and complete stability is not necessary. If a five second observation of the voltage reading shows no <u>obvious</u> drift, it's set.

Disconnect the jumper between the negative power supply connection and control voltage input and procede to the procedure appropriate for your test equipment.

OSCILLOSCOPE

Apply some moderate control voltage (1 volt or so - not critical) to the input of the VCO and set the vertical sensitivity of the 'scope to a scale that will conveniently measure 5 volts peak to peak (one volt per division is ideal) . Connect the input of the scope to test point 1 (TP1)

and adjust triggering and sweep rate for a stable pattern. Under the conditions described the pattern should be ramp.

Adjust R51 (RANGE) until the peak to peak amplitude of the ramp is as close to 4.5 volts as possible.

Move the test probe of the 'scope to the triangle output of the oscillator (lug #1 of J7) and re-set the vertical sensitivity to something on the order of .1 volts, iv. Adjust R49 (TRI SYM) so that the bottom of the triangle closes.

NOTE: A careful examination of the triangle (and ramp) waveforms may reveal a slight "hook" at the bottom of the ramp and the right side of the bottom of the triangle. This hook represents both frequency and harmonic content errors in these waveforms. The frequency error will be nulled in later steps with the zero control and the harmonic content error is in our opinion negligible. Similarly, the "flyback" blip at the bottom of the triangle is a harmonic content error but the high order harmonics generated by this blip are well above the limits of human hearing (in a properly operating VCO) and therefore not significant. Many bench-type 'scopes will not show these features at the present operating point, so don't spend a lot of time looking for them.

With the bottom of the triangle closed, procede to the Sine wave output (lug #1 of J8). Adjust R21 (SINE SYM) for the most symmetrical sine wave possible. (The VOM procedure has a method for exactly setting this symmetry - you may want to refer to that technique.)

Move the scope probe to the pulse output (lug #1 of J9) and rotate R35 (PW TRIM) fully CCW as viewed from the rear edge of the board. Connect a jumper between ground (either front panel ground or the power supply ground connection on the rear edge of the board) and one of the front panel pulse width modulation inputs. Advance R35 in a clockwise direction until a readily discernible pulse is seen on the 'scope. Removing the ground connection to the pulse width modulation input will now make the width of pulse increase slightly because of the errors in the control voltage summation of these inputs.

THIS COMPLETES INITIAL CALIBRATION OF THE 4720 VCO. Procede to the "Setting Zero" procedure at the end of this section.

VOLT-OHM METER

Those of you who will be calibrating the 4720 using only a VOM and pitch source will be using the procedure that is unquestionably more demanding of the skills and patience of the individual; but by taking your time and following the procedure carefully you will finish with results that are comparable to techniques involving considerably more expensive test equipment.

In order that the summing voltage to current converter and integrator combination consist of only the most accurate components, and to get the range of the oscillator down to a frequency that we can conveniently work with, it is necessary to remove the front panel pitch control from the circuit. This is not complicated, simply un-solder the wire running from circuit board point "D" to lug #3 of the initial pitch control R37. Unsolder this wire at the potentiometer lug (not at the circuit board) and move it clear of any possibility of short circuits. DO NOT touch this sensitive input during the following steps or induced 60 Hz. hum will throw your readings off.

Apply a measured source of 5 volts to one of the control voltage inputs of the VCO (your VOM is probably no more accurate than 5%, but still take some time to make the reading as close as possible) and connect the Ramp output of the VCO to the input of an amplifier. Using trimmer R51 (RANGE) adjust the oscillator so that it is zero-beat* with the output of a tuned musical instrument producing G# below concert A (415.3 Hz.).

When satisfied that the VCO is zero-beat with the pitch reference, the hardest part of the job is done and the remainder of the waveforms can be calibrated. Re-solder the wire previously removed from lug #3 of the pitch control and re-set the control voltage input to a level of 1 volt.

Change the amplifier input from the ramp output of the VCO to the triangle output.

While listening to the triangular output of the oscillator, slowly turn the control knob of trimmer potentiometer R49 (TRI SYM) and observe what change this control makes in the sound. Notice that at the extremes of the rotation of this control the sound has a raspy "edge" to it (the discontinuity in a triangle that is not closed produces higher order harmonics that can readily be heard) while at some point between the extremes the tone becomes considerably more mellow. Adjust R49 for the "mellowest" tone possible.

To adjust the Sine wave output we will again use the VOM. With the negative probe connected to the ground supply terminal on the rear of the circuit board, connect the positive lead to the junction of R29 and R26. (There is no terminal provided at this test point but the lead that is the junction of these components is marked TP2) Set the VOM at its lowest DC scale and rotate the control knob of R21 (SINE SYM) fully clockwise. The VOM should show a positive deflection. Now slowly bring the knob of R21 back in a CCW direction observing that the VOM deflects down-scale. R21 is properly set when the VOM is reading exactly zero. NOTE: the low impedance of most VOM's when set to their lowest voltage scales will cause a decrease in level to the sine converter circuitry that will prevent its proper operation. Do not

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* The "beat note" is a term used to describe the sound produced when two notes that are very close to the same frequency or very close to an octave apart are played at the same time. It can be heard as a slow speed volume change of the sound produced. As the two notes become closer and closer to the same frequency (or an integral number of octaves apart) the beat note slows until it stops when the notes are identical (zero beat). The beat note is most noticeable when the two notes are close to the same frequency and decreases in volume as the notes become a greater number of octaves apart.

try to visually or aurally judge the effectiveness of the sine output with the VOM attached to TP2.

Connect the amplifier input to the pulse output of the 4720 and temporarily jumper one of the Pulse Width control voltage inputs to either front panel or power supply ground.

Starting with the knob of trimmer R35 (PW TRIM) fully CCW (as viewed from the rear of the module) rotate this control in a clockwise direction until the buzz of the pulse output can just be heard from the amplifier. Notice that when the jumper that is grounding the PW modulation input is removed, the volume and "fullness" of the tone increases indicating that the pulse width has increased slightly.

THIS COMPLETES THE MAJOR PORTION OF THE CALIBRATION OF THE 4720. Proceed to "Initial Zero Calibration".

INITIAL ZERO CALIBRATION

We have come to what is by far the most critical portion of our calibration procedure, setting the oscillator's zero control. As mentioned earlier, this setting is not easily measured. However, with a simple measuring technique we can get the zero very close to correct, after which the VCO can be connected to a keyboard and "fine tuned" with the aid of a 'scope or good musical ear.

Using a 'scope or voltmeter set to a scale which will easily read 10 volts, connect the negative or ground lead of the test instrument to the ground lug at the rear of the oscillator. Using the positive lead, observe the voltage at the output (pin 6) of the 748 op-amp, IC-1. Alternatively, you can see the same voltage at the base of Q1, and it would probably be an easier location to clip a test lead.
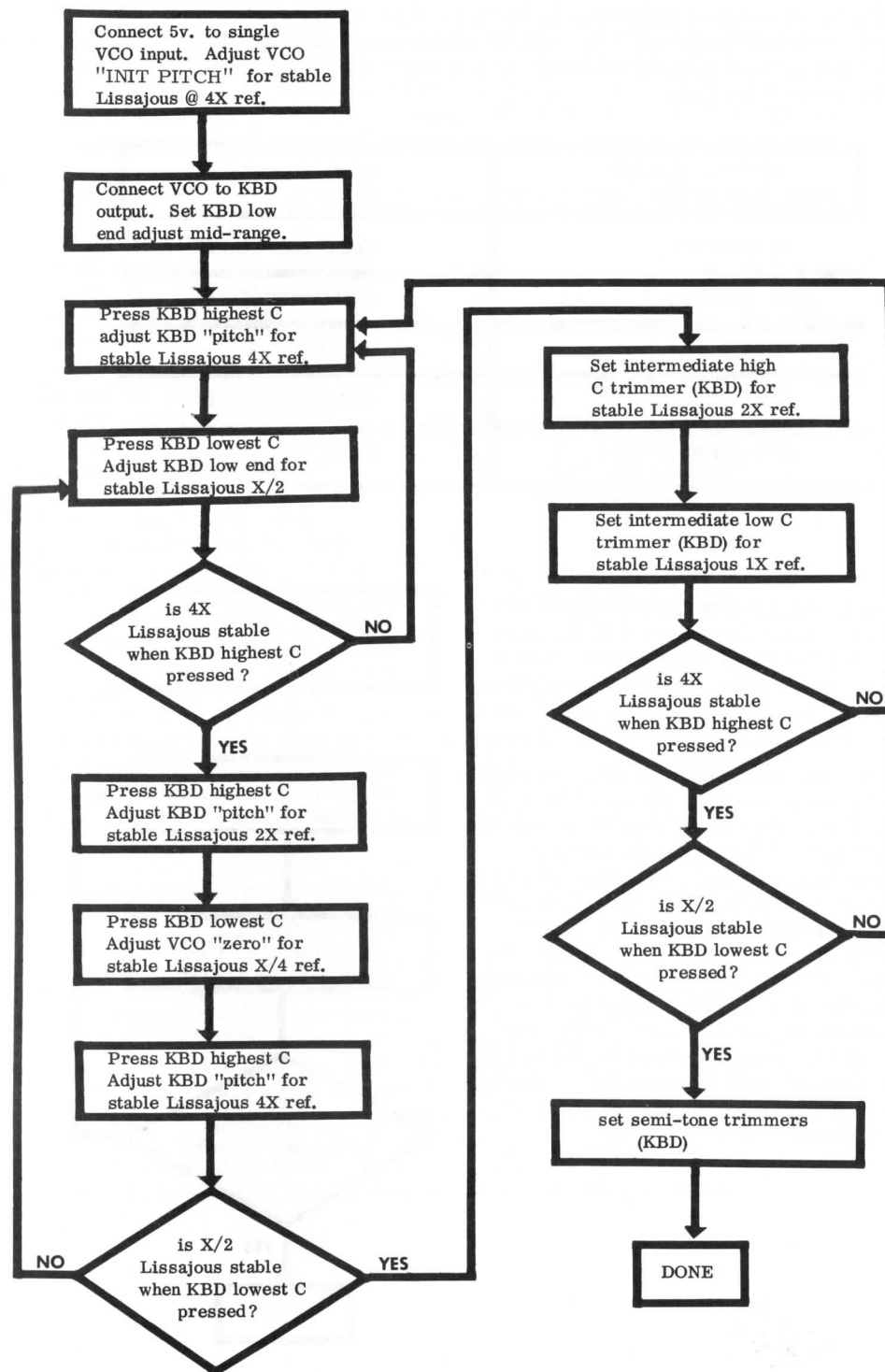
Using a small clip test lead, connect one of the control voltage inputs (J1, J2 or J3) to Ground, such as the flea clip at the rear of the circuit board.

While observing the voltage reading at the op-amp output, slowly rotate the zero control, R6. You should find a point where the op-amp output suddenly switches from +8 volts to a slightly negative voltage around -1 volt. Right after this voltage falls slightly negative is approximately the proper setting for R6.

At this point, the VCO should be connected to a keyboard and tested for proper tracking and linearity. It is possible that your initial zero calibration is slightly off, and can ge slightly "tweaked" to fine tune the calibration. However, there should be no need to appreciably change the setting of the zero control. If so, the problem lies elsewhere.

TUNING KEYBOARD AND OSCILLATOR

The worst case that can be encountered is when both the keyboard and VCO are untuned. In general, the keyboard will have to be tuned only once as it is a simple resistive voltage divider and unless physically abused will stay in tune for extended periods of time. The procedure is illustrated using a reference oscillator set for 260 Hz. and an oscilloscope configured to produce lissajous patterns.

Connect 5v. to single VCO input. Adjust VCO "INIT PITCH" for stable Lissajous @ 4X ref.

Connect VCO to KBD output. Set KBD low end adjust mid-range.

Press KBD highest C adjust KBD "pitch" for stable Lissajous 4X ref.

Press KBD lowest C Adjust KBD low end for stable Lissajous X/2

is 4X Lissajous stable when KBD highest C pressed ? — NO / YES

Press KBD highest C Adjust KBD "pitch" for stable Lissajous 2X ref.

Press KBD lowest C Adjust VCO "zero" for stable Lissajous X/4 ref.

Press KBD highest C Adjust KBD "pitch" for stable Lissajous 4X ref.

is X/2 Lissajous stable when KBD lowest C pressed? — NO / YES

Set intermediate high C trimmer (KBD) for stable Lissajous 2X ref.

Set intermediate low C trimmer (KBD) for stable Lissajous 1X ref.

is 4X Lissajous stable when KBD highest C pressed? — NO / YES

is X/2 Lissajous stable when KBD lowest C pressed? — NO / YES
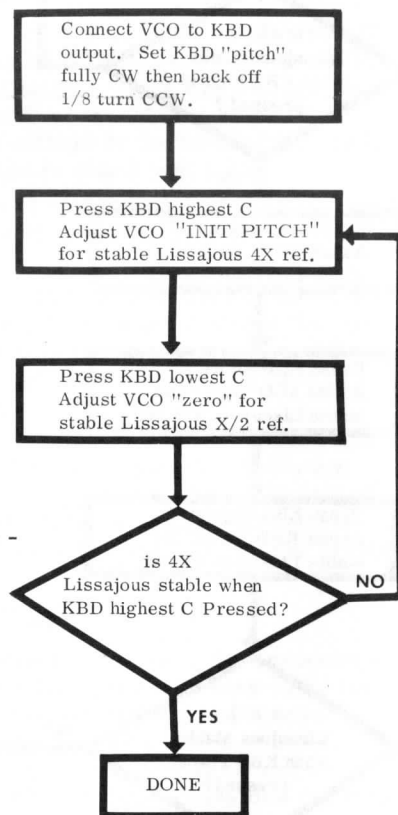
set semi-tone trimmers (KBD)

DONE

If a tuned musical reference is being used for calibration, substitute aural "zero beat" for stable lissajous patterns and the following musical pitches for the mentioned multiples of the reference frequency.

reference multiple where X is 260 Hz. ref.	musical pitch
4X (1040 Hz.)	2nd C above middle C
2X (520 Hz.)	C above middle C
1X (260 Hz.)	middle C
X/2 (130 Hz.)	C below middle C
X/4 (65 Hz.)	2nd C below middle C

The more common (and fortunately far simpler) procedure will be used in claibrating an unknown oscillator to a known calibrated keyboard. This procedure is illustrated in the chart to the right and described as follows:

If an unknown oscillator is to be tuned to be the same as a known calibrated oscillator this same procedure can be used except that instead of stable lissajous patterns you will be listening for zero-beat between the two oscillators which are both being driven from the same keyboard. Adjust the "INIT PITCH" control of the unknown oscillator when the highest keyboard C is pressed and the "zero" when the lowest C is being pressed. Iterate the procedure until the oscillators are zero - beat for both cases without further adjustment.

Connect VCO to KBD output. Set KBD "pitch" fully CW then back off 1/8 turn CCW.

↓

Press KBD highest C Adjust VCO "INIT PITCH" for stable Lissajous 4X ref.

↓

Press KBD lowest C Adjust VCO "zero" for stable Lissajous X/2 ref.

↓

is 4X Lissajous stable when KBD highest C Pressed? NO

YES ↓

DONE

DESIGN ANALYSIS

For analysis purposes, the 4720 can be divided down into six separate sections: 1) summing voltage to current converter 2) integrator and Schmitt trigger, 3) ramp to triangle shaper, 4) triangle to sine shaper, 5) ramp to variable duration pulse converter and 6) reference voltage supply.

SUMMING VOLTAGE TO CURRENT CONVERTER

Control voltages applied to the three frequency control inputs (J1 - J3) are summed by resistors R1 - R3 and used to control the darlington pair current source comprising Q1 and Q2. Inspection of this circuit shows that the base-emitter junctions of both of these transistors are within the feed-back loop of operational amplifier IC1 and consequently all of their undesirable non-linearities and temperature dependent characteristics are cancelled by the gain of the amplifier.
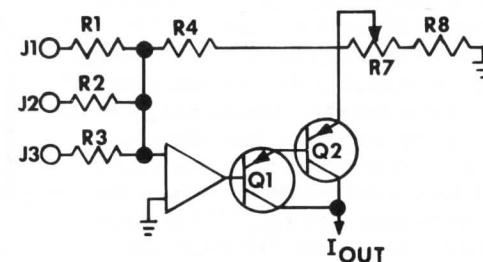
SUMMING VOLTAGE TO CURRENT CONVERTER

A second desirable characteristic of the circuit is that the two resistances which parallel to determine the current produced for a given input voltage (R4 and the series combination R7 and R8) terminate at a virtual ground and system ground respectively. The significance of this is that the circuit is "self-zeroing" assuring that for zero control voltage in, there will be zero output current.

Trimmer potentiometer R6 (PITCH ZERO) is used to null input offset voltage of the summing amplifier.

The amount of output current produced for a given input voltage determines the frequency at which the oscillator will be operating and is in turn determined by the setting of the initial pitch control R7. Input and feed-back resistance of the summing amplifier are constant so that for a given input voltage the voltage that appears at the emitter of Q2 (and consequently across R7 and R8) will always be the same. The current that this voltage produces is a function of the setting of R7 and as this resistance is decreased more current must flow to maintain the voltage. The current that flows through R7 appears as one of the major components of the total output current.
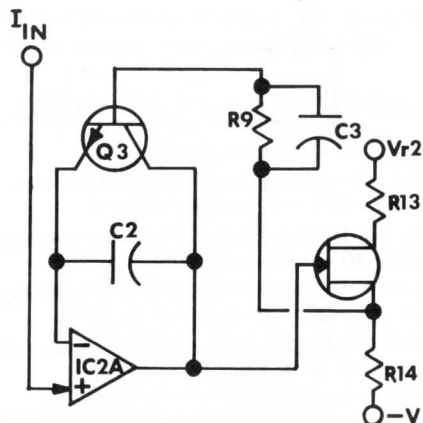
INTEGRATOR / SCHMITT TRIGGER

Current differencing amplifiers (such as the LM 3900) that are operating in a linear mode must, by definition, have essentially identical currents flowing into both their inverting "-" and non-inverting "+" inputs. The integrator that is built up around IC2a (one stage of four that are in the single package IC2) is both example and proof of this. Into the "+" input of this amplifier we are pumping the output of the current source and for a constant input voltage to the summing amplifier just discussed, this current will also be constant. We have said that by definition the current flow into the "-" input must equal that into the "+" input which means that a constant current must flow through the feed-back network.

INTERGRATOR SCHMITT TRIGGER

In this case the feed-back network is the capacitor C2 (Q3 is a simple switch to be discussed shortly). There is only one way that a constant current can flow through a capacitor and that is to constantly and linearly increase (or decrease) the potential difference across the capacitor. A voltage ramp appearing at the output of IC2a fulfills this requirement.

If the current into the "+" input of the integrator increases, the rate at which the output voltage rises must also increase to meet our identical current flow requirements and this increased rate of change translates into higher frequency.

The phrase "essential identical currents" is the hooker in the above paragraphs. The LM-3900 is not a precision circuit and one of the reasons that it's not is that the two inputs are not really identical. Because of this, these devices have a relatively large input offset current that ordinarily prevents their use in precision circuitry. But, there's a way out (there usually is). IC2b is the key to turning a a non-precision circuit into an amazingly precise one. Here we are using a second stage of the amplifier to supply a current that exactly matches the input offset current of the first amplifier and in the process we get, for free, a super fringe benefit; excellent temperature stability. The temperature stability comes about because both amplifiers are in the same package and therefore are always at the same temperature. Ambient temperature changes that introduce errors in the operating characteristics of IC2a produce identical changes in IC2b and the two errors cancel one another exactly.

The ramp voltage that appears at the output of IC2a will obviously increase all the way to the saturating point of the amplifier unless

we do something to stop it and the thing that we do is hang a Schmitt trigger on the output. We're using a silicon Uni-junction Transistor (UJT) for the Schmitt because they're fast and compact.

As the voltage ramp rises, a point is eventually reached at which the UJT "fires" and when it does a voltage pulse appears across R14 that is coupled through R9 and "hurry up" capacitor C3 to Q3. This voltage pulse turns Q3 on which in turn quickly discharges C2 so that the charging cycle can start again.

The point at which the UJT fires is a function of the voltage applied to the top end of R13. By varying this voltage we set the peak-to-peak amplitude of the ramp and consequently the frequency produced for a given current flow into the integrator.
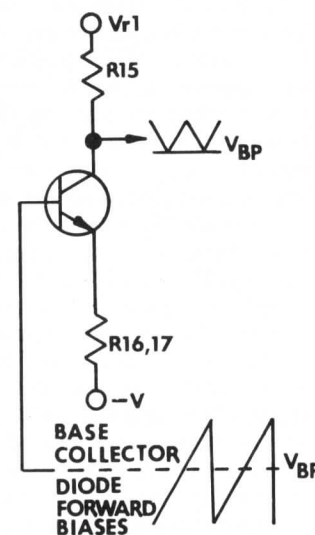
RAMP TO TRIANGLE SHAPER

We've all probably seen complicated ramp to triangle converters consisting of one or more operational amplifiers, switching diodes and an assortment of other parts. Here's a really simple one that may be old as the hills but was still a serendipitous discovery on our part.

The ramp output of the integrator connects to the base of Q5 which for low base voltages can be considered to be a phase splitter; that is, the signals that appear at this transistor's collector and emitter are mirror images of one another. The collector of this transistor is really what we're interested in so let's take a look at what happens there.

As the base voltage increases, current flow through the transistor increases causing an increasing voltage drop across R15 so that an inverted replica of the ramp appears at the collector of Q5.

**V_{BP} BREAK POINT VOLTAGE
RAMP TO TRIANGLE CONVERTER**

The transistor is acting as a simple unity gain inverter. At some point on the ramp, however, the base voltage becomes greater than the collector voltage and at this point the base-collector diode forward biases. From this point on, the transistor is not an amplifier but simply a diode connected to resistor R15 and the remaining portion of the ramp is no longer inverted. If we set the voltage at the high end of R15 properly, the collector voltages corresponding to the top and bottom of the ramp are identical and the output waveform closes on itself to become a triangle.

Amplifier stage IC2c serves as a simple inverting amplifier that both buffers the output of this somewhat impedance sensitive triangle converter and provides a control of DC level (R21 - SINE SYM) into the sine wave shaper that follows. At the output of the buffer, voltage divider R22 and R23 attenuate the signal prior to capacitive coupling to the triangle output jack J7.

The emitter of Q5 is not affected by any of this and the ramp waveform appears here simply as a ramp which is attenuated by the voltage divider action of R16 and R17 and capacitively coupled to the output jack J6.

PULSE WIDTH MODULATOR

The ramp output that appears at the emitter of Q5 is the signal that is applied to the voltage controlled pulse width modulator consisting of Q7, Q8 and associated components. This circuit is a comparator that, in simple terms, compares the voltage appearing at the base of Q7 to a voltage that appears across R45 (as most will realize, this is not strictly true but it is a close enough approximation for our purposes). The voltage at the base of Q7 is the sum of several components: the ramp applied through R32, a bias current supplied through R35 and R36, a voltage that is dependent on the setting of the front panel initial pulse width

FIXED REFERENCE

C.V. VARIES RAMP D.C. LEVEL

P.W. MODULATOR

control R37, and two externally applied control voltages that appear across R39 and R40. When the sum of all these components exceeds the reference, the circuit changes state. Q7 which was off turns on and causes Q8 to turn off. When the end of the ramp is reached and the voltage goes back to its lowest value, Q7 once again turns off and consequently Q8 turns on. As Q8 turns off and on a voltage pulse appears across R43 and this voltage is capacitively coupled to the output jack J8. Voltages applied to the control voltage inputs, or provided by R37 all serve to change the point on the ramp at which the circuit changes state and consequently the duration of the pulse that appears at the output.

TRIANGLE TO SINE CONVERTER

The circuitry that converts the triangle output of buffered amplifier IC2c to an approximation of a sine wave (diodes D1 - D6 and associated resistors) fully exploits the non-linear V/I characteristics of diodes. These diodes not only break the triangle into several sections of varying slopes but also "round" the individual sections. Note that D2 and D3 are biased into conduction by R27 and R28 respectively.
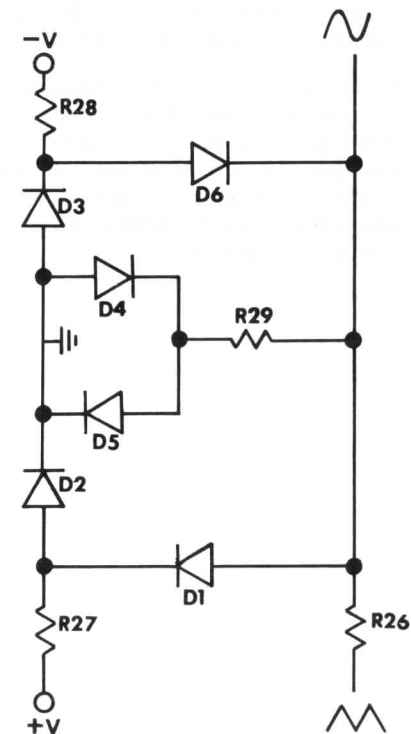
As the voltage of the triangle waveform applied to R26 increases above ground, D5 begins to conduct resulting in a current flow
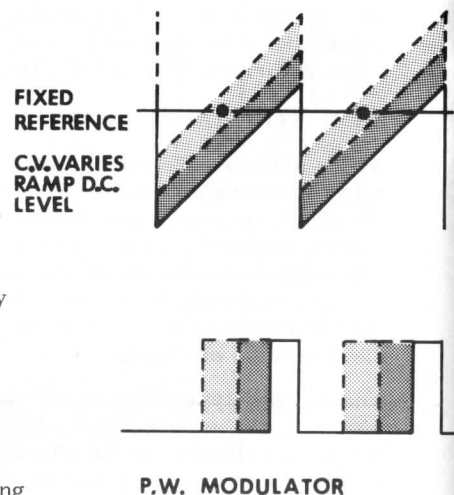
through R26. Because of the non-linear properties of diodes, the current flow does not increase in exact proportion to the applied voltage and the result is a slight "tapering" of the voltage that appears at the junction of R26 and R29. This is the beginning of the rounding of the sine wave.

As the voltage increases further, the point is reached at which D1 becomes forward biased and additional current begins to flow through R26 into D1 and D2. This additional current produces a "break point" that further decreases the slope of the rising voltage at the junction of R26 and R29 and this section is further "rounded" by the non-linearity of the diodes. As the triangle waveform peaks, D1 and D2 are essentially saturated so that the top of the sine wave shows a very slow rate of change. On the way back down to ground the situation goes in reverse with D1 and D2 first coming out of saturation, followed by D1 ceasing conduction entirely and the voltage drop across R29 decreasing back to zero. During negative half cycles of the triangle the situation repeats itself in reverse with D4 initially conducting followed by D6 turning on and D3 and D6 saturating. The overall result being the "bending" of the triangle into a sine wave. Emitter follower Q6 serves to buffer the output of the sine shaping circuitry and the voltage divider R30 and R31 attenuates the voltage before it is capacitively coupled to the output jack J9.

REFERENCE VOLTAGE SUPPLY

Several reference voltages are required throughout the oscillator and these references are all derived from the single reference source comprising the last stage of LM 3900 (IC2d) and zener diode D7. The circuit is a common realization with the reference element in the feedback loop of the amplifier so that currents required by the circuitry to


**TRIANGLE TO SINE CONVERTER**
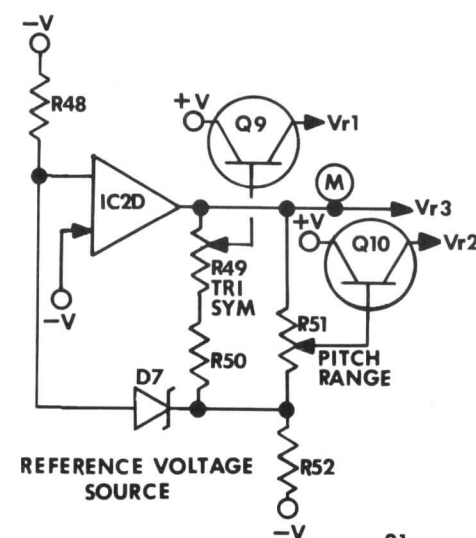
REFERENCE VOLTAGE SOURCE

which the constant voltages connect is supplied by the amplifier. Under these conditions the current that flows through the zener is constant which in turn produces a more constant reference. The only slightly unusual feature is the addition of the two series pass transistors Q9 and Q10 and their corresponding voltage adjusting trimmers R49 and R51.

The main output of the reference (Vr3) is used to stabilize the offset at the output of the triangle buffer amplifier and the voltages at the input of the pulse width modulator. The adjustable outputs are used to set the upper threshold of the UJT and consequently the peak to peak amplitude of the ramp waveform (Vr2) and the total voltage which appears across R5 which in turn determines the break point of this triangle shaper (Vr1).

NOTE: DIODES D1 THRU D6 1N914

From
KBD
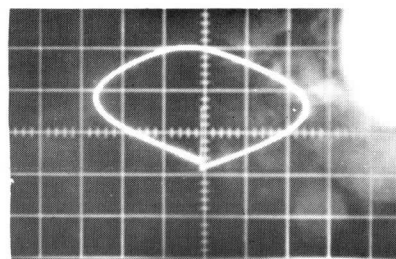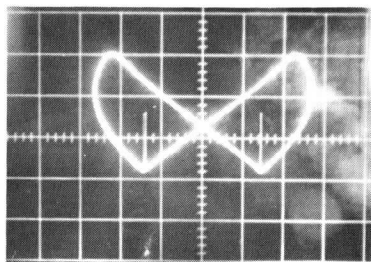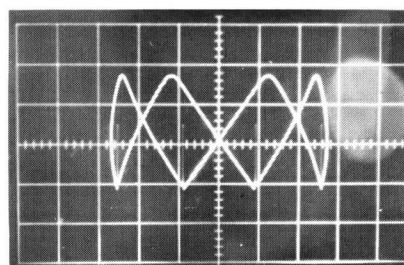
4720

AUDIO GEN   'SCOPE

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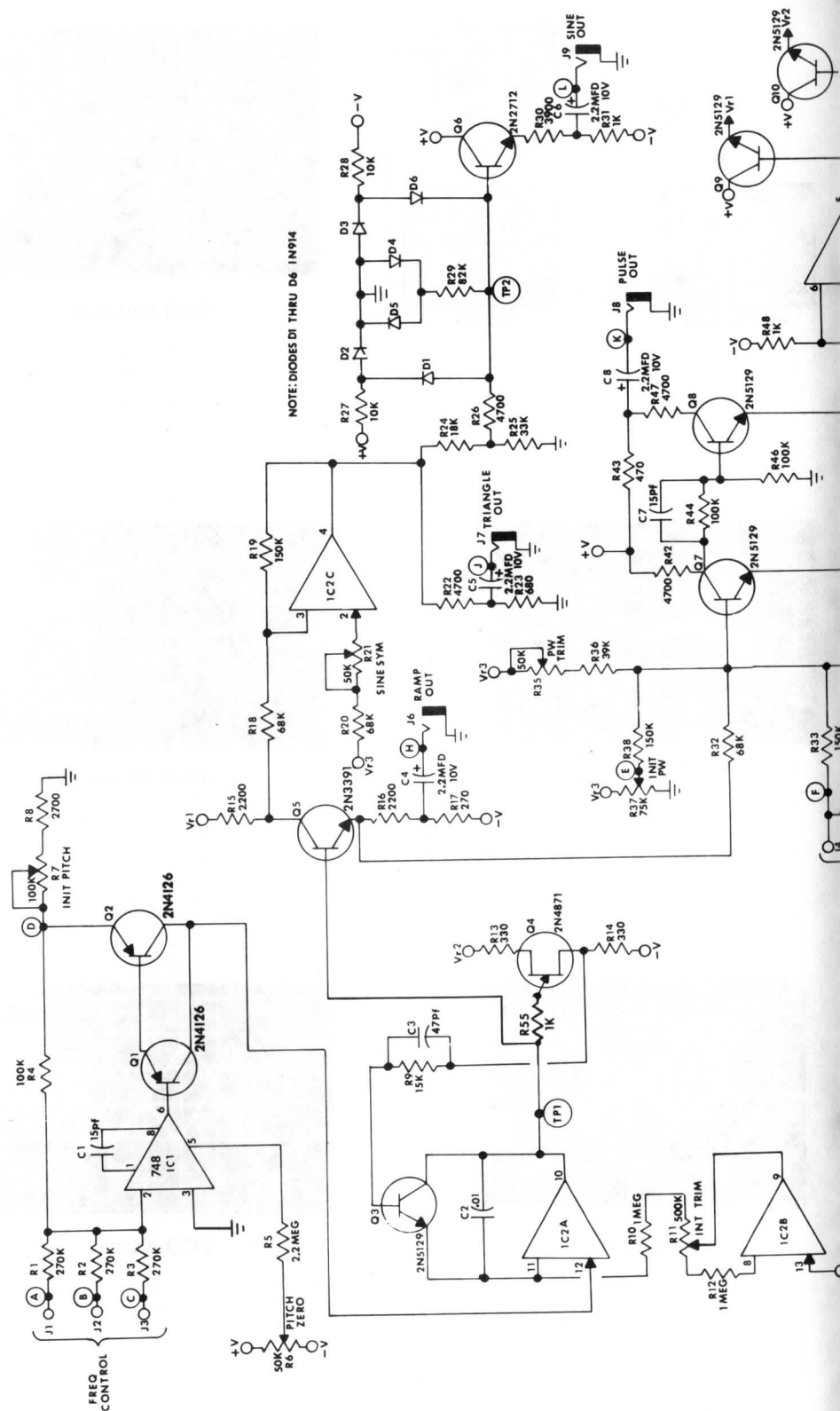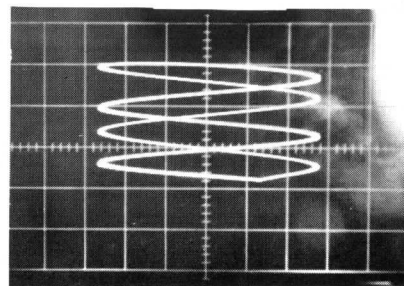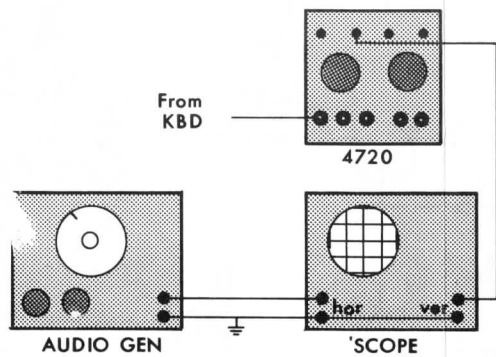
VCO X/4 ref.
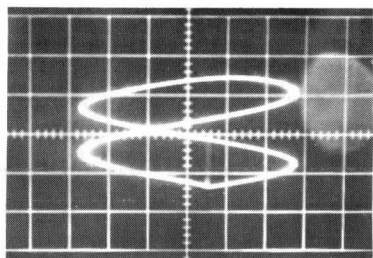
VCO X/2 ref.

VCO 1X ref.

VCO 2X ref.

VCO 4X ref.