CURTIS ELECTROMUSIC SPECIALTIES

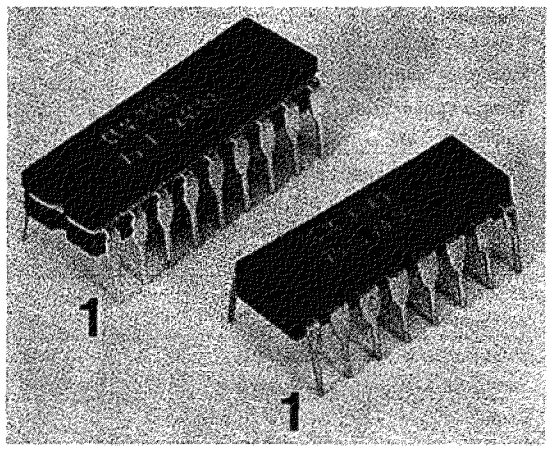
CEM 3340 / 3345

Voltage Controlled Oscillator

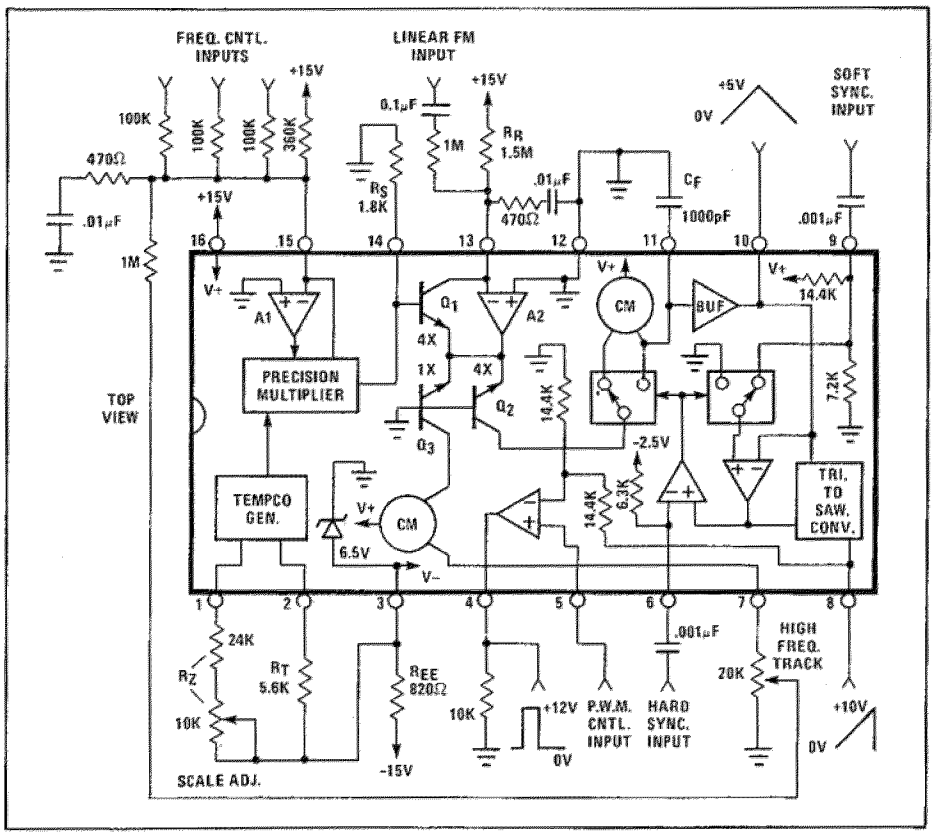
The CEM 3340 and CEM 3345 are completely self contained, precision voltage controlled oscillators, featuring both exponential and linear control scales and up to four buffered output waveforms: triangle, sawtooth, square, and pulse with voltage controllable pulse width. Full temperature compensation makes these VCOs extremely stable, and eliminates the need for a temperature compensation resistor. The highly accurate exponential and linear control inputs are virtual ground summing nodes, allowing multiple control voltages to be mixed within the device itself.

Also included is provision for hard and soft synchronization of the frequency, and an output for easy adjustment of high frequency tracking. Special care in the design ensures oscillation start-up under any power-on sequence and supply conditions.

Although a low voltage process has been used to reduce die size, cost, and leakage currents, an on-chip 6.5 volt zener diode allows the device to operate off ±15 volt supplies, as well as +15,-5 volt supplies.



CEM 3340 Circuit Block and Connection Diagram



Features

- Large Sweep Range: 50,000:1 min.
- Fully Temperature Compensated; No Q81 Resistor Required
- Four Output Waveforms Available; No waveform trimming required.
- Summing Node Inputs for Frequency Control
- High Exponential Scale Accuracy
- Low Temperature Drift
- Voltage Controlled Pulse Width
- Hard and Soft Sync Inputs
- Linear FM
- Buffered, Short Circuit Protected Outputs
- ±15 Volt Supplies

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Electrical Characteristics

V_{CC} = +15V V_{EE} = Internal Zener T_A = 20°C				
Parameter	Min.	Typ.	Max.	Units
Frequency Control Range	50K:1	500K:1	—	
Exponential Scale Error, Untrimmed[1]	—	0.2	1	%
Exponential Scale Error, Trimmed[1]	—	0.05	0.3	%
Multiplier Gain Error[2]	—	0.0005	0.008	%/μA
Tempo Cancellation[3]	-150	0	+150	ppm
Oscillator Drift[4]	—	±50	±200	ppm
Triangle Buffer Input Current	—	0.3	3	nA
Triangle Waveform Upper Level	4.85	5.0	5.15	V
Triangle Waveform Lower Level	-15	0	+15	mV
Triangle Waveform Symmetry	45	50	55	%
Sawtooth Waveform Upper Level	9.4	10.0	10.6	V
Sawtooth Waveform Lower Level	-25	0	+25	mV
Triangle Output Sink Capability	400	550	750	μA
Sawtooth Output Sink Capability	640	800	1000	μA
Triangle & Sawtooth Output Impedance[5]	65	100	150	Ω
Pulse Output Source Capability at +10V	2.8	3.5	4.6	mA
Squarewave Output Levels[6], CEM 3345	-1.8,-0.4	-1.3,0	-0.8,+0.4	V
PWM Input Pin Current[7]	.5	1.5	3.5	μA
PWM Input Voltage for 0% Pulse Width	-15	0	+15	mV
PWM Input Voltage for 100% Pulse Width	4.6	5.0	5.4	V
Input Bias Current at Reference and Control Current Inputs	80	200	400	nA
Tempco of Input Bias Currents	-1000	0	+1000	ppm
Offset Voltage at Reference and Control Current Inputs	-5	0	+5	mV
Hard Sync Reference Voltage	-2.3	-2.5	-2.8	V
Hard Sync Input Resistance	5	6.3	7.9	KΩ
Max Capacitor Charge/Discharge Current	400	570	800	μA
Positive Supply Current	4	5	6.5	mA
Positive Supply Voltage Range	+10		+18	V
Negative Supply Voltage Range[8]	-4.5		-18	V

Note 1: This error represents the percentage difference in scale factors (volts per frequency ratio) of the exponential generator anywhere over the exponential generator current range of 50nA to 100μA. Most of this error occurs at the range extremities.

Note 2: This error represents the percentage difference in multiplier gains at any two input currents, within the range of 20 μA to 180 μA, per μA difference between the two corresponding outputs.

Note 3: This spec represents the difference between the actual tempco of the multiplier output voltage (expressed relative to the maximum output excursions) and the tempco required to precisely cancel the tempco of the exponential scale factor (q/KT).

Note 4: The multiplier output is grounded.

Note 5: For exponential generator currents less than 10 μA; above 10 μA, impedance drops to 1/3 this value as the highest current is approached.

Note 6: With respect to the hard sync input reference voltage.

Note 7: For PWM control inputs between -1 and +6 volts. This current is significantly greater for inputs outside of this range.

Note 8: Current limiting resistor required for negative supplies greater than -6 volts.

Application Hints

Supplies

Since the device can withstand no more than 24 volts between its supply pins, an internal 6.5 volt ± 10% Zener diode has been provided to allow the chip to operate off virtually any negative supply voltage. If the negative supply is between -4.5 and -6.0 volts, it may be connected directly to the negative supply pin (pin 3). For voltages greater than -7.5 volts, a series current limiting resistor must be added between pin 3 and the negative supply. Its value is calculated as follows:

$$R_{EE} = (V_{EE} - 7.2) / .008$$

Although the circuit was designed for a positive supply of +15 volts, it may be operated anywhere between +10 and +18 volts. The only effect is on the positive peak amplitude of the output waveforms in accordance to the following: The triangle peak is one third of the supply, the sawtooth peak is two thirds of the supply, and the pulse peak is 1.5 volts below the supply.

Operation of the Temperature Compensation Circuitry

The exponential generator is temperature compensated by multiplying the current sourced into the frequency control pin (pin 15 on the CEM3340, pin 17 on the CEM3345) times a coefficient directly proportional to the absolute temperature. As this control current is applied to the exponential generator, its coefficient cancels that of the exponential generator, q/KT. This coefficient is produced by the tempco generator using the same mechanisms that create it in the exponential generator; cancellation is therefore nearly perfect.

The output of the precision multiplier (pin 14 on the 3340,

pin 16 on the 3345) internally connects to the control input of the exponential generator (base of Q_1). This output is a current and is given by:

$$I_{OM} = \frac{22V_T}{R_T}(1 - I_C R_Z/3.0)$$

where $V_T = KT/q = 26$ mV @ 20°C, and where I_C is the total current flowing into the frequency control pin and must remain positive for proper operation (a negative input current will produce the same output as a zero input current). Since the frequency control input pin is a virtual ground summing node, any number of control voltages may be summed simply with input resistors to this pin.

The current output of the multiplier is converted to the required drive voltage with a resistor from the multiplier output pin to ground. For greatest multiplier accuracy, this resistor, R_S, should be 1.8k and the current flowing out of pin 2, $22V_T/R_T$, should be close to the current flowing out of pin 1, $3.0/R_Z$.

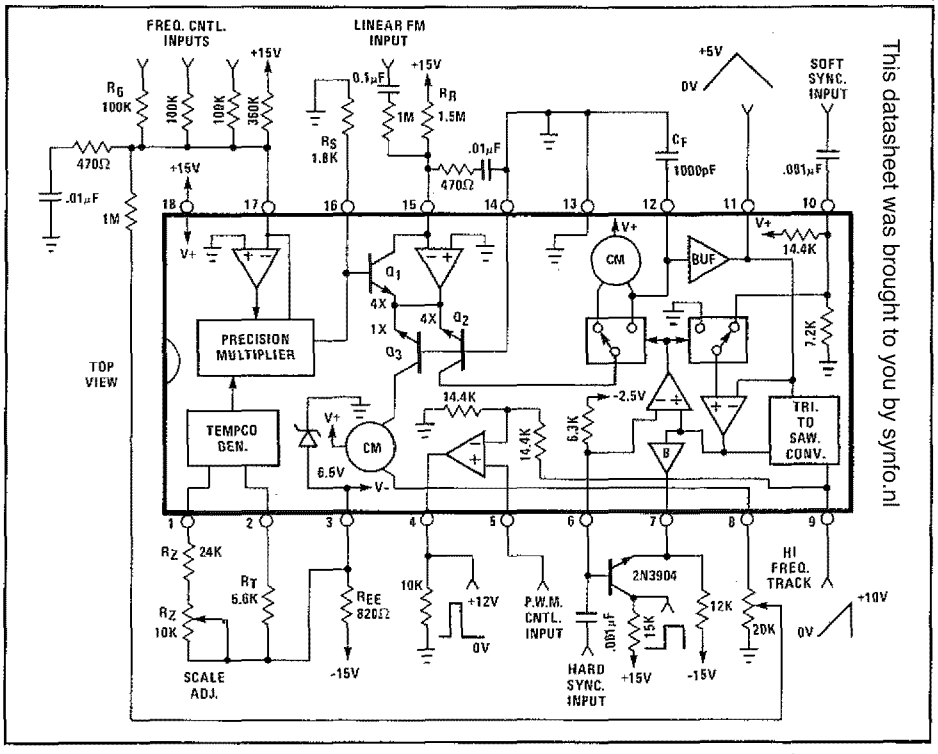
Since the components associated with the tempco generator and multiplier determine the maximum voltage excursion possible at the base of Q_1, they should be selected to provide the desired frequency control range of the oscillator. The exponential generator itself is capable of delivering a current for charging and discharging the timing capacitor from greater than .5mA down to less than the input bias current of the buffer, thus allowing for a typical frequency range greater than 500,000:1. The most accurate portion of this current range, from 50nA to 100μA, should be used for the most critical portion of the desired frequency range.

Consideration of this critical range determines the value of

Absolute Maximum Ratings

Voltage Between V_{CC} and V_{EE} Pins	+24V,-0.5V
Voltage Between V_{CC} and Ground Pins	+18V, -0.5V
Voltage Between V_{EE} and Ground Pins	-6.0V,+0.5V
Voltage Between Frequency Control Pin or Reference Current Pin and Ground Pin	±6.0V
Voltage Between Multiplier Output Pin and Ground Pin	+6.0V, -1V
Current through Any Pin	±40mA
Storage Temperature Range	-55°C to +150°C
Operating Temperature Range	-25°C to +75°C

CEM 3345 Circuit Block and Connection Diagram



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C_F, the timing capacitor. The oscillation frequency is given by:

$$f = 3\, I_{EG}/(2V_{CC}\, C_F)$$

where I_{EG} is the output current from the exponential generator. If, for instance, the most important frequency range is from 5Hz to 10kHz, then C_F should be 1000pF at V_{CC} = +15V (a low leakage, low tempco capacitor, such as mica, should be used for C_F).

Next the reference current for the exponential generator (Current into pin 13 on the 3340, pin 15 on the 3345) is selected. This current ideally should be the geometric mean of the selected generator current range, but consideration of the temperature coefficient of

the bias current for op amp A2 usually dictates a higher value for the reference current. Although this bias current has been temperature compensated, it could have a worst cast tempco of 1000ppm and maximum value of 400nA. Under these conditions, a reference current of 10μA through Q_1, for instance, would have a tempco of 40ppm. It is recommended that, in general, the reference current be selected in the 3μA to 15μA range.

Since the reference current pin is a virtual ground summing node, the reference current may be set up with a temperature stable resistor to V_{CC}, or other positive stable voltage source. A negative current into this pin will simply gate the exponential generator completely off.

With the value of C_F and reference current now selected, the voltage excursion at the multiplier output, which drives the base of Q_1, is now determined for the desired frequency control range. If this range were 1Hz to 20kHz, the exponential generator current, I_{EG}, would have to range from 10nA to 200μA in the above example, requiring the base drive voltage, V_B, to vary from +180mV to -78mV, since

$$I_{EG} = I_{REF}\, e^{-V_B/V_T}$$

The most positive voltage at the base of Q_1 occurs when the control current, I_C, is zero, and is $22V_T$ R_S/R_T. Therefore, in the above example, $R_T = 22V_T \cdot 1.8K/.18V = 5.72K$, and $R_Z = 3.0R_T/22V_T = 30K$ nominal. Finally, since the multiplier output current must range from +100μA to -43μA to produce this desired voltage excursion at the multiplier output and on the base of Q_1, the control input current, I_C, ranges from 0 to 143μA. A resistor from V_{CC} to the control input pin may be used to set the oscillator frequency at some initial value with no control voltages applied.

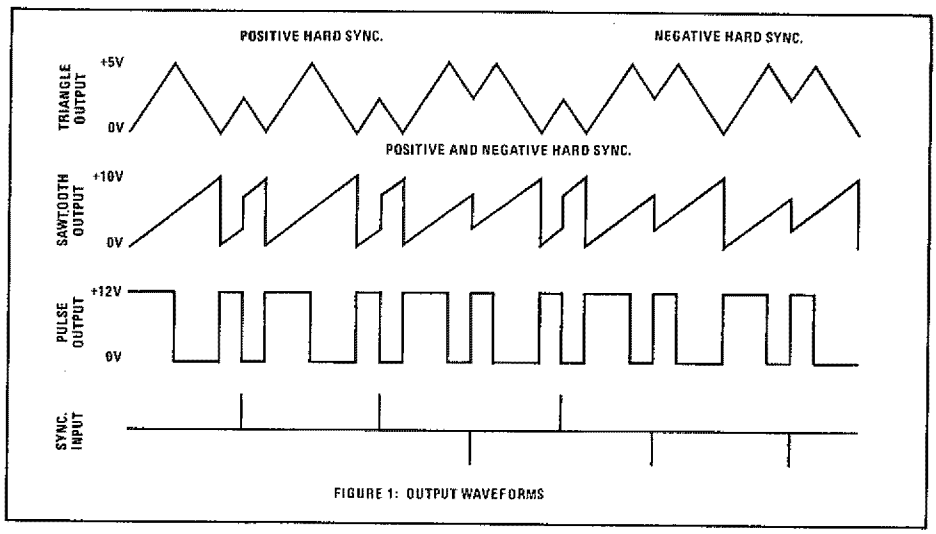

FIGURE 1: OUTPUT WAVEFORMS

The frequency control scale is determined by the value of the input resistor to the control pin, the value of the Q_1 base resistor, R_S, and the multiplier current gain. Since the multiplier current gain, set by the ratio of the pin 2 current to pin 1 current, should be near unity and R_S should be 1.8K, the control input resistor is the component which should be selected for the desired control scale. For the industry standard scale of 1 octave/volt, the input summing resistors become 100k. The recommended method for trimming the control scale is to tweek the multiplier current gain by adjusting the value of R_Z ±20% about the nominal value.

Both the multiplier and the exponential generator are compensated with the 470Ω - .01μF networks shown in the Block Diagrams and are therefore necessary in any application. Since the bandwidth of the multiplier extends beyond the audio range, it may be desirable to limit the bandwidth to reduce possible noise at the base of Q_1, thereby reducing FM noise and frequency jitter. This is best accomplished by bypassing R_S to ground with a capacitor, where the corner rolloff frequency is given by: $f_{LP} = 1/(2\pi R_S C)$.

Trimming The Scale Error

There are two basic sources producing exponential conformity error in the control scale: One is the exponential current generator and the other is the precision multiplier.

The error from the exponential converter is due partly to the bulk emitter resistance of Q_2, becoming significant at generator currents greater than 100μA, and partly to the comparator switching delay, becoming significant at frequencies greater than 5KHz. These two effects cause the oscillator frequency to go flat, but only at the uppermost octaves.

Circuitry has been provided to correct for these effects. The output of the hi-frequency track pin (pin 7 on the 3340, pin 8 on the 3345) is a current which is one fourth the generator output current, I_{EG}. This current may be converted with a grounded resistor to a voltage, a portion of which is

then fed back to the control input pin. As the frequency is increased, this feedback voltage will tend to sharpen the control scale, but only at the upper end, since the feedback voltage becomes significant only at the higher generator currents. The amount of voltage fed back is adjusted so the scale is sharpened just enough to compensate for the inherent high end flatness

The method recommended for trimming the control scale is as follows: The hi-frequency track adjust is first set so that no correction voltage is fed to the control input. The oscillator frequency is set around 200Hz and the scale adjust trimmer is adjusted for the desired scale factor (e.g. 1.000 octave/volt). Then the oscillator frequency is set to around 10KHz, and the hi-frequency track trimmer is adjusted for the same scale factor.

The source of error from the precision multiplier is due to the multiplier's gain (nominally unity) changing as the control input current changes. This type of error causes the frequency to become increasingly sharp or flat as the control current is increased. The percentage difference in multiplier gains, and hence scale factors, at any two inputs to the multiplier may be calculated as the percentage error given in the specifications times the difference in μA between the two corresponding outputs. For example, suppose the scale were adjusted for precisely 1 octave/volt at mid-range. At one octave above this adjusted octave, with the multiplier output 10μA different, the scale factor could be .08% different worst case. This would produce a volts/octave error at the base of Q_1 of .08% x 18mV = 14.4μV, which would cause this octave to be .06% (1 cent) sharp or flat. At five octaves above the adjusted octave, the scale factor could be 0.4% different worst case, producing a volts/octave error of 0.4% x 18mV = 72μV. This fifth octave would thus be 0.28% (5 cents) sharp or flat. Note that if octaves above the adjusted octaves were sharp, those octaves below the adjusted octave would become increasingly flat, and vice versa.

Typically the error produced by the multiplier is much less than the above example. However, if maintaining a tighter tolerance is required for the particular application, the multiplier error may be trimmed out for each device. The trimming procedure requires that both R_Z and R_S be made adjustable ±30% about the nominal value; R_Z is first adjusted so that the multiplier gain is constant over the selected input current range; then R_S is adjusted for the desired scale factor (adjusting R_S will reintroduce some error, so R_Z may have to be readjusted).

Should for some reason it be desired not to use the temperature compensation circuitry, the multiplier/tempco generator may be bypassed simply by leaving pin 1, pin 2, and the control input pin open, and applying the control voltage to the base of Q_1 via the multiplier output pin.

Waveform Outputs

All waveform outputs are short-circuit protected and may be shorted continuously to any supply without damaging the device. Each output, however, has differing drive capabilities.

Although the triangle output can sink at least .4mA and source over several mA, care must be exercised in loading this output. Because the output has a finite impedance and drives the comparator, a change in load will change the frequency of the oscillator. Adding a 100K resistor to ground, for instance,

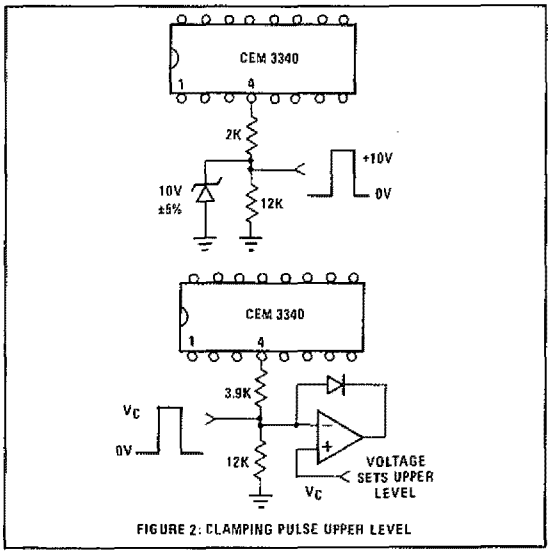

FIGURE 2: CLAMPING PULSE UPPER LEVEL

could lower the frequency by 150/100K = 0.15% (2.5 cents) worst case. A load capacitance will act like a resistor with a value $1/(2fC_L)$ and requires the same considerations as above. A continuous load no greater than 10K and/or 1000pF to ground is recommended.

Since the sawtooth output is buffer isolated from the oscillator circuitry, it can sink at least .6mA and source over several mA with no effect on oscillator performance, and only negligible effect on sawtooth waveshape. Stray capacitance at this output greater than 40pF, however, will cause a small high frequency oscillation. A 100Ω resistor between the output and load is all that is required to isolate more than .01μF.

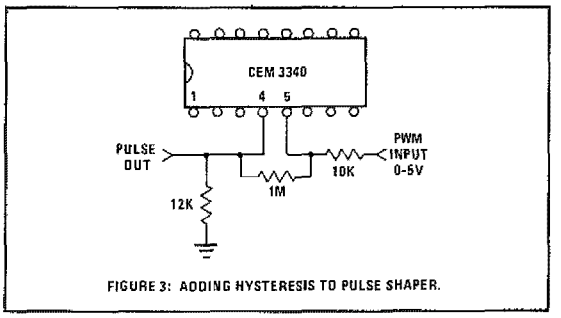

FIGURE 3: ADDING HYSTERESIS TO PULSE SHAPER.

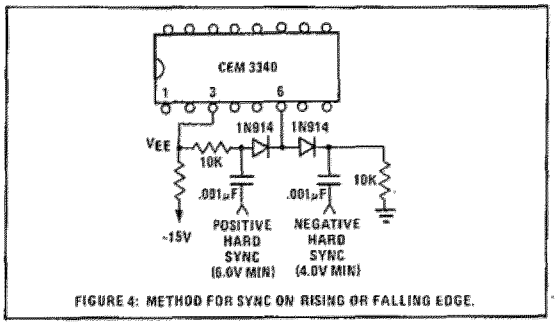

FIGURE 4: METHOD FOR SYNC ON RISING OR FALLING EDGE.

The pulse output is an open NPN emitter, and therefore requires a pull-down resistor to ground or to any negative voltage. Any pull-down voltage between ground and .5 volt above the voltage on the negative supply pin will precisely determine the lower level of the pulse wave. For pull-down voltages more negative than this, the lower level will be nearly the negative supply pin voltage. The nominal upper level of the pulse wave is given by: V_{CC} - 0.3V -1.3K · I_{PLD} for $I_{PLD} >$ 0.6mA, and V_{CC} - 0.9V for $I_{PLD} <$ 0.6mA, where I_{PLD} is the pull down current. A maximum value of 3mA for I_{PLD} is recommended. For those applications which require a more stable, well defined upper level, the circuits shown in Figure 2 may be used.

The pulse width of the pulse output may be set from 0 to 100% with a 0 to +5V external voltage (V_{CC} = +15V) applied to the PWM control input pin (pin 5 on the 3340 and 3345). The fall time of the pulse wave is slower than the rise time due to finite comparator gain. It may be speeded up considerably by adding hysteresis as shown in Figure 3. Care should be exercised in the layout to prevent stray capacitive coupling between the pulse output and the PWM input,as this can cause comparator oscillation.

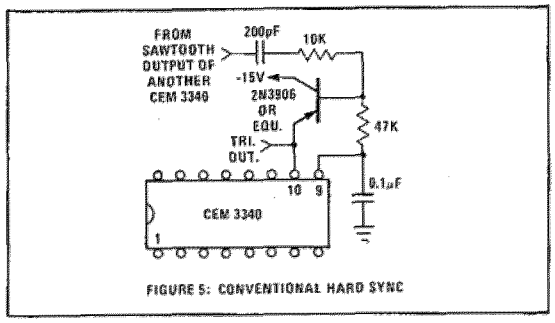

FIGURE 5: CONVENTIONAL HARD SYNC

The square wave output (pin 7) from the CEM 3345 also requires a pull down resistor to any negative supply greater than -4 volts. It provides an output swing from nominally 1.3 volts below the hard sync reference voltage to a level nominally the same as the hard sync reference voltage. The Block Diagram shows a convenient way of generating a full swing square wave from this output. The current pulled down from this output should also be limited to a maximum of 3mA.

Frequency Synchronization

The oscillator frequency may be hard synchronized in several different ways. One way is to couple positive pulses, negative pulses, or both, into the hard sync input pin (pin 6 on the 3340 and 3345). A positive sync pulse will cause the triangle wave to reverse directions only during the rising portion of the triangle, while a negative sync pulse will cause direction reversal only during the falling portion. The resulting waveforms are shown in Figure 1, and provide a wider variety of synchronized sounds than possible through conventionally synchronized oscillators. Simple capacitive coupling as shown in the Block Diagrams allows hard synchronization on both the rising and falling edge of a rectangle wave. Figure 4 shows circuitry for allowing only one or the other of the edges to synchronize the oscillator. The peak amplitude of the pulses actually appearing on the sync pin should be restricted to 1 volt minimum and 3 volts maximum for best operation.

Another method of hard synchronizing the oscillator is shown in Figure 5. Negative pulses only are coupled into the base of the PNP transistor, with a peak amplitude of 8 to 10 volts for best results at V_{CC} = +15V. This method will produce the same waveforms generated by the conventionally synchronized sawtooth oscillators.

Finally, the oscillator may be soft synchronized by negative pulses applied to the threshold voltage pin (pin 9 on the 3340, pin 10 on the 3345). These pulses cause the triangle upper peak to reverse direction prematurely, causing the oscillation period to be an integral multiple of the pulse period. The peak amplitude of these negative pulses should be limited to 5 volts maximum and positive pulses should be avoided entirely. If this input is not used for synchronization purposes, it is recommended that it be bypassed with a 0.1μF capacitor to ground to prevent synchronization or jitter to noise pulses on the V_{CC} supply line.

Linear FM

The reference current input pin may be used for linear modulation of the frequency. The external input is summed with the reference current simply through a resistor terminating at this pin. For audio FM, it is recommended that a coupling capacitor be used to prevent frequency shift when connecting to the external source. The value of the input resistor should be selected so that the maximum peak to peak input signal produces a plus and minus current equal to the reference current.

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