ON CHIP SYSTEMS

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C E M 3 3 9 4

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uP CONTROLLABLE SYNTHESIZER VOICE

Preliminary, January 1985 (Supersedes December 1983)

Description

The CEM 3394 is a complete analog music synthesizer voice-on-a-chip intended for software control by a microprocessor system. Included inside the compact 20 pin package is a fully temperature compensated wide range voltage controlled oscillator providing triangle, sawtooth, and variable pulse waveforms; a voltage controlled mixer for adjusting the balance between the internally generated VCO waveforms and any external signal; a dedicated four-pole low-pass voltage controlled filter with voltage controllable resonance; a modulation amount VCA for modulating the filter frequency by the triangle waveform output of the VCO; and a final VCA for allowing the final output to be enveloped. Envelope control for both the VCF and final VCA may be provided either by a hardware envelope generator such as a CEM 3371, or may be accomplished completely through software generators.

Ranging between -4 and +4 volts, all eight control inputs are provided with internal very high input impedance, low bias current buffers. Thus interface to a microprocessor system may be accomplished simply with a single DAC, 4051 CMOS multiplexer, and 8 hold capacitors.

Requiring a bare minimum of other external components, the CEM 3394 is ideal for low cost polyphonic or polytimbric musical instruments featuring rich, analog sound.

Features:

* Low Cost
* Complete Synthesizer Voice On a Single Chip
* 20 Pin DIP Package
* Sample & Hold Buffers On-Chip for Easy Interface to a uP
* Fully Temperature Compensated VCO
* Independently Selectable VCO Waveforms
* Constant Loudness v.s. Resonance VCF Characteristic
* Rich Sounding VCF Design
* Filter FM for More Timbre Possibilities
* Low Noise, Low Feedthrough Final VCA
* Few External Components

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CEM 3394 Specifications, Preliminary 12/01/83

Vcc = +5.0V Vee = -6.5V Ta = 20 C
Ct = 2000pF Rz = 270K Cf = .033uF

Parameter	Min.	Type	Max.	Units
VCO				
Frequency Range	10	---	20K	Hz
C.V. Input Range	-4.0	---	+4.0	V
C.V. Scale Factor	---	-.75	---	V/octave
Exponential Error	---	0.3	10	%
Frequency Temp. Coefficient	-500	---	+500	ppm
Reference Voltage (pin 1-3)	1.1	1.3	1.5	V
C.V. Input Current	---	±.3	+3	nA
Frequency at C.V. = Ø	330	500	750	Hz
WAVE SHAPER				
Waveform Select Thresholds				
Triangle	-.25	-.37	-.45	V
Triangle + Sawtooth	+1.0	+1.2	+1.4	V
Sawtooth	+2.3	+2.7	+3.1	V
Wave Select Input Current	---	-50	-300	nA
Pulsewidth C.V. for 0% P.W.	0	---	+0.2	V
Pulsewidth C.V. for 100% P.W.	+1.9	---	+2.2	V
Wave Select C.V. Feedthrough				
Triangle	-30	---	+30	uA
Triangle + Sawtooth	-50	---	+50	uA
Sawtooth	-20	---	+20	uA
Pulsewidth C.V. Feedthrough	-30	---	+30	uA
Pulsewidth C.V. Input Current	---	±1	±10	nA
FILTER MODULATOR				
Max Modulation Depth	.01X	---	2.0X	Freq.
C.V. for 0% Modulation	+0.1	---	+0.3	V
C.V. for Max Modulation	+3.0	---	+4.0	V
C.V. Input Current	---	-.5	-5	nA
FILTER INPUT MIXER				
External Input Level for 5% Distortion	---	80	---	mV.P.P.
External Input to Output Gain	4.5	6.0	7.5	mmho
C.V. for 80 dB Attenuation of Ext. Input & ØdB of Internal Signal	-1.5	---	-1.7	V
C.V. for 80 dB Attenuation of Internal Signal & ØdB of Ext. Input	+1.5	---	+1.7	V
C.V. Input Current	---	-.3	-3	nA
External Input Bias Current	---	-0.3	-0.7	uA
C.V. Feedthrough	-30	---	+30	uA

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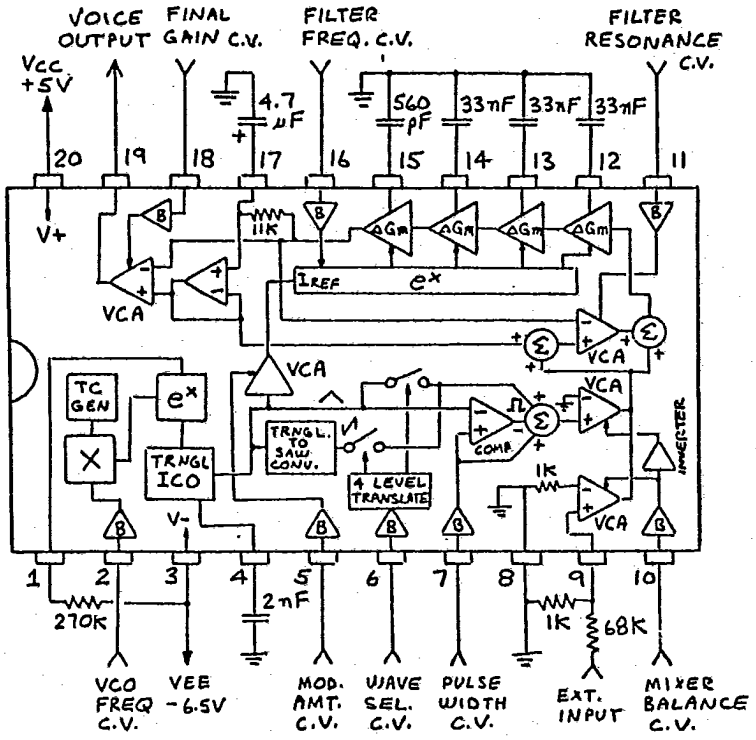

CEM3394 µP CONTROLLABLE VOICE
BLOCK AND EXTERNAL CONNECTIONS DIAGRAM

3A

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4-POLE LOW-PASS FILTER				
Frequency Range	3	---	30K	Hz
C.V. Input Range	-3.0	---	+4.0	V
Frequency at C.V. = ø	0.9	1.3	1.8	KHz
C.V. Scale Factor	---	-.38	---	V/octave
Frequency Temp. Coefficient	---	-1000	---	ppm
Freq. C.V. Input Current	---	-0.3	-3	nA
Freq. C.V. Feedthrough	---	±15	±30	uA
Resonance C.V. for No Resonance	0	---	±0.1	V
Resonance C.V. for Oscillation	+2.5	---	+3.5	V
Resonance C.V. Input Current	---	-0.3	-3	nA
No Resonance Output Level to Full Resonance Output Level (Peak to Peak) Ratio	---	1:1	---	---
FINAL VCA				
Attenuation at C.V. = ØV	80	90	---	dB
C.V. for Max Output	+3.8	---	+4.3	V
C.V. Scale Factor	---	20	---	dB/V
Max. Waveform Output Levels				
Triangle	190	265	370	uA.P.P.
Triangle + Sawtooth	255	355	495	uA.P.P.
Sawtooth	150	210	295	uA.P.P.
Square	120	165	230	uA.P.P.
All	300	420	590	uA.P.P.
C.V. Feedthrough	---	±1	±5	uA
C.V. Input Current	---	-0.3	-3	nA
Output Voltage Compliance	Vee+1	---	Vcc-1	V
POWER SUPPLIES				
Positive Supply Range	+4.75	---	+8.0	V
Negative Supply Range	-4.75	---	-16.0	V
Positive Supply Current	+13	+16.5	+21	mA
Negative Supply Current	-13	-16.5	-21	mA

NOTES:
1. Most of error occurs at frequency extremes. Typical value is at mid-range.
2. When switching from the no waveforms condition.
3. Filter frequency C.V. = ØV.
4. This scale holds from max attenuation to approximately 20 dB of attenuation. Thereafter, scale is approximately linear.

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CEM 3394 Application Hints

Power Supplies

The CEM 3394 was designed to operate from +5V and -6.5V supplies. The non standard negative supply was necessary to not compromise the VCO frequency control voltage resolution, which ranges from -4V to +4V, in favor of a standard -5V supply. Any one of the readily available 3 terminal adjustable regulators may be used to supply the negative -6.5V. A -5V supply volt supply may be used, with the only detrimental effects being a limit on the maximum negative control voltage of -1.5V for VCO frequency and -2V for all other parameters. Since the stability and jitter of the VCO are directly affected by the positive supply, a supply as stable and clean as possible should be used for the +5 volts. The stability of the negative supply is not critical. A positive supply up to +8V or negative supply as large as -16V may be used at the expense of substantially greater power dissapation. Maximum supply allowable across the entire device is 25 volts.

VCO

The control scale of the VCO is temperature compensated with an internal +3300 ppm tempco generator and multiplier. Thus, as chip temperature changes, the control voltage applied to the exponential voltage-to-current converter through the multiplier changes proportional to temperature, effectively cancelling the -3300 ppm tempco of the control scale.

The current controlled oscillator directly generates a triangle waveform, which is converted to a sawtooth waveform by the triangle-to-saw converter and at the same time applied to a comparator which generates a variable width pulse waveform.

The resistor Rz from pin 1 to the negative supply sets up an internal reference current for the exponential voltage-to-current converter; its value and the value of the timing capacitor, Ct, determine the nominal initial frequency of the VCO at 0 control volts as follows:

$$Fzcv = \frac{Vref}{Vcc} * \frac{1}{Rz\ Ct}$$

Where Vref is the voltage between pin 1 and pin 3, nominally 1.3V. The other consideration is the current range of the exponential V to I converter, which is a maximum of 400 uA and most accurate over the range of 300 nA to 80 uA. The timing capacitor should be first selected so that the highest frequency where good accuracy is desired corresponds to a current of 80 uA:

$$Ct = \frac{80\ uA}{Fmax/acc * Vcc}$$

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Then the frequency corresponding to a control voltage = 0V should be selected to be in the middle of the range desired for good accuracy. With Ct and the 0 C.V. frequency selected, the value of Rz may be calculated from the first equation.

For example, suppose best accuracy in the range of 32 Hz to 8kHz is desired. Thus Fmax/acc = 8 kHz, and Ct calculates to be 2 nF. The middle of this range is 500 Hz which should be set to equal Fzcv; Rz then becomes 260K. Note that since the control voltage can range between +4V and -4V and the scale factor is nominally 0.75 V/octave, the VCO can be swept nominally between 12 Hz and 20 kHz.

As another example, assume a negative supply of -5V is used, so that the most negative control voltage possible is -1.5V, allowing a maximum frequency 2 octaves higher than Fzcv. Since with this supply voltage, the VCO can be swept only 7.5 octaves, the frequency range is selected to be 32 Hz - 4 kHz. With Fmax/acc = 4 kHz, Ct becomes 4 nF and Fzcv must be set at 1 kHz; Rz then becomes 65K.

Since the VCO was designed to be software adjusted, a simple multiplier was used with slight non-linearity at its two extremes. Therefore, for best results, it is recommended that the scale factor and scale linearity be auto corrected through software means.

Waveform Selection

The three waveforms may be independently selected with the Waveform Select pin (pin 6) and Pulse Width C.V. pin (pin 7). The Waveform Select is a four level control: A control voltage more negative than -0.45V turns off both triangle and sawtooth waveforms; a C.V. between -.25 and +1.0V selects triangle waveform only; a C.V. between +1.4V and +2.3V selects both waveforms, and a C.V. greater than +3.1V selects sawtooth waveform only. Since this control input is also high impedance, the necessary voltages may be supplied in the same manner as the other control voltages -- with the CMOS multiplexer and a hold capacitor connected to this pin.

The pulse width may be turned off simply by setting the Pulse Width control voltage slightly negative to ensure a pulse width of 0%. A unique circuit on-chip keeps the average D.C. level of the pulse waveform constant regardless of duty cycle, so that pulse width may be modulated without annoying control signal feedthrough.

The relative amplitudes of the three waveforms have been set as follows to give approximately equal loudness when heard: The triangle is about 27% larger than the sawtooth which is about 27% larger than the pulse wave.

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External Input

The external input may accomodate any input signal up to about 80 mV.P.P.; normally a resistor divider is required to attenuate the input signal to this level. The resistance to ground should be 1K to keep the VCA balanced, and the input signal should be capacitively coupled to minimize control voltage feedthrough. A small adjustable offset of ± 20mV may be applied to this input to further reduce control voltage feedthrough if desired.

The internal signal and external signal are nominally in equal balance -- each being 6 dB down from its maximum -- when the control voltage is at 0V. The control scale is roughly audio taper, so that the first 20dB of range is controlled linearly within ± 1V while the remaining 60dB is controlled exponentially from ± 1 to ± 1.6V.

This external input is ideal for adding noise, a second VCO (such as a CEM 3340 or 1/2 CEM 3374), or both.

VCF

Able to sweep over a minimum of 14 octaves, the filter is the classical wide range 4-pole low-pass type designed for musical instruments.

The control scale has twice the sensitivity as that for the VCO, being nominally 3/8 V per octave. The first three stages of the filter are unity gain transconductors while the last stage provides a gain of 57 and consequently has a transconductance of 1/57 of the first three, requiring its capacitor (pin 15) to be 1/57 of the other three filter capacitors. The frequency of the -12dB point on the cut-off slope is given by

$$Fzcv = \frac{Gm}{2\pi C} = \frac{Iref}{4\pi C * Vt}$$

where Vt = KT/q = 26mV at 20°C. The reference current is set up internally and given a +3300 ppm to compensate the Vt term in the denominator. Thus, this equation may be reduced to

$$Fzcv = \frac{4.3 * 10E\text{-}5\ (\pm\ 40\%)}{C}$$

The major portion of the wide 40% tolerance is due to the variation in the monolithic diffused resistors which sets up the reference current.

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Selection of the four filter capacitors (C = C1 = C2 = C3 = 57xC4) is again determined by the maximum desired cut-off frequency and optimum operating range of the transconductors. The maximum possible transconductance is 10 mmho while the optimum range is between 5 umho and 5 mmho. Thus

$$C = \frac{5 * 10E\text{-}3}{2\pi\ Fmax}$$

As an example, assume the highest desired cut-off frequency is 24 kHz to allow all harmonics through when the filter is wide open; C1-C3 become 33 nF and C4 becomes 580 pF. The frequency at 0 control volts is then approximately 1300 Hz; 24 kHz will be reached 4.2 octaves above this point, or at -1.6V, while 4Hz will occur 8.3 octaves below at +3.2V. Note that the filter can be opened up to 48 kHz with these value capacitors; at voltages much above +3.2V, the control freedthrough begins to become excessive, effectively limiting the practical low end to 8-9 octaves below the frequency at 0 control volts.

The resonance VCA feedback circuit has been designed so that, unlike most VCFs of this type, as the resonance is increased the apparant loudness remains constant, providing a much richer resonant sound. Note, however, that the peak-to-peak level of a waveform such as pulse actually doubles as resonance is increased, due to the ringing on its fast transistions.

Modulation

The modulation VCA allows the VCO triangle wave to modulate the reference current of the VCF, and hence the cut-off frequency. The Modulation Amount control voltage (pin 5) controls the amount of Iref modulation from 0 to ± Iref; at maximum modulation, the filter frequency is swept from a very low value to twice its unmodulated value. Since the modulation is linear, the apparant filter frequency does not shift as modulation is increased.

One application for this control is to set the filter into oscillation for obtaining linear audio FM of one VCO by another (the filter becomes a second VCO). However, an equally interesting application is to audio FM the filter while it is filtering; the result is strong timbral effects, especially with some resonance added.

Final VCA

The final VCA is a low noise, low control feedthrough design which substantially reduces fast envelope "click" and "pop" noises without the need for an adjusting null trimmer. The output of the filter is essentially AC coupled to the VCA input by means of the bypass capacitor connected to pin 17. Thus, its

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value along with the 11K internal resister sets the low corner frequency; a value of 4.7 uF results in a -3dB point of 3Hz. This pin may also be used to extract the filter output signal before it has passed through the VCA: The end of the capacitor normally connected to ground is instead connected to the inverting input of an op amp with a 10K feedback resistor; the filter output will then appear at the op amp output for use elsewhere in the system.

The final VCA control scale is approximately audio taper. The first 20dB of attenuation from a control voltage of +4V to +2.5V is essentially linear in scale; the next 60-80dB of attenuation from +2.5V to 0V is controlled exponentially. This allows the natural sound of exponential decays to be produced with simple linear envelope control, which is much simpler to generate in software than exponentially shaped envelopes.

The signal output appearing at pin 19 is a current with a voltage compliance of Vee+1V to Vcc-1V. This allows the outputs of multiple 3394s to be mixed together simply by connecting all pin 19s together; the summed current can then be converted to a voltage simply with a single resistor to ground, or an op amp with feedback resistor. The major portion of the ± 40% tolerance on the maximum output swing (nominally ± 210 uA) is again due to the monolithic diffused resistors setting up these currents. Although the output variations are typically much less than this, output levels as well as the filter initial frequency may be more closely matched simply by matching the resistance between the Vcc and Vee pins (pin 20 to pin 3).

Input Control Voltage Buffers

With the exception of Waveform Select whose control voltage is not critical, the input bias current to all control inputs is typically less than 1 nA, and have maximum values of 3 and 5 nA. Hold capacitor values can be in the range of 2 to 20 nF before causing multiplexing problems and DAC output instability. The amount of droop is given by

$$Vdroop = \frac{Ibias - Tupdate}{Chold}$$

With a hold capacitor of 10nF and update time of 10 mS, maximum droop would be 5 mV or between .06 and .12% of full scale. Typically, the droop is a factor of 10 less than these worst case values.

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