# SSM 2030 VOLTAGE CONTROLLED OSCILLATOR

The SSM 2030 is a precision voltage controlled oscillator designed specifically to meet the waveform and accuracy requirements of electronic music systems. It has both exponential and proportional linear sweep inputs which can control frequency over a 1,000,000 to 1 range with the same capacitor. Sweep accuracy is better than 0.25% over a 1,000 to 1 range and 0.1% over 100 to 1. The device has simultaneous sawtooth, triangle and pulse outputs. An internal comparator provides control of pulse output duty cycle from 0 to 100%. Hard and soft synchronisation inputs make possible a rich variety of modulation and harmonic locking effects.

## KEY FEATURES:

- **Simultaneous exponential and proportional linear sweep inputs**
- **High sweep accuracy over audio range**
- **1,000,000 to 1 sweep range**
- **200kHz max. operating frequency**
- **Simultaneous sawtooth, triangle and pulse outputs**
- **Pulse duty cycle voltage control (0 to 100%)**
- **Hard and soft synchronisation inputs**
- **Power supply up to ±18V**

## APPLICATIONS:

- **Music synthesisers**
- **Electronic organs**
- **Electronic games**
- **Waveform generation**
- **V to F and F to V conversion**
- **Modulation control circuits**
- **Wide range phase-locked loops**
- **Frequency multiplication and division**

## DEVICE DESCRIPTION AND APPLICATION

The 2030 from Solid State Micro Technology is the first VCO in integrated circuit form to address the needs of electronic music systems. The device (Figure 1) consists of a pair of matched logging transistors, a precision current mirror, a fast ultra-low leakage buffer, waveshaping circuits for pulse and triangle outputs, a fast comparator and a discharge circuit which includes a capacitorless one-shot. In addition, provision has been made to allow linear FM and synchronising the oscillator to the output of another.

The frequency control circuit shown in Figure 3 is similar to many modular designs now in use. A low input bias op amp is used to force the current in Q1 to be equal to the reference current established by R1 and the linear FM voltage (if any). The current in the output transistor Q2 is:—

$$I_o = (V+/R1 + V_L/R2)e^{V_b q/KT}$$

As can be seen the term in the exponent is temperature dependent. This problem can be addressed by making $V_b$ temperature dependent.

$$\frac{d}{dT}\,\frac{KT}{q} = 3300\text{ppm}/^{o}\text{C} \ @\ 25^{o}\text{C} \qquad V_b = \frac{V_e R3}{R3+R4} \qquad R3 = 1\text{K};\quad R4 = 54\text{k}9$$

Since R4 is large compared to R3 one can use a Tel Lab Q81 resistor (temp. coeff. 3500ppm/°C) to give $V_b$ the necessary temperature dependence. Best results are obtained with the Q81 thermally coupled to the package.

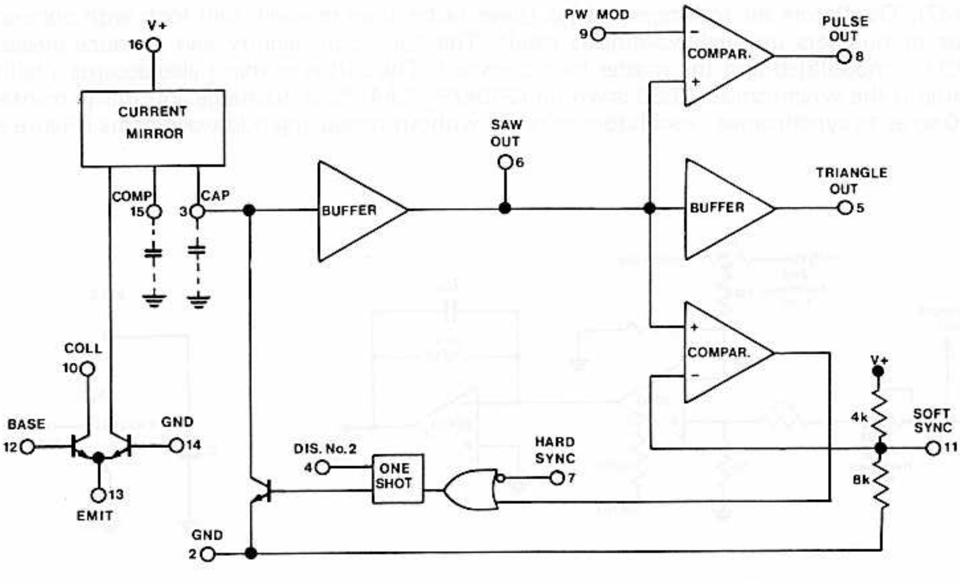


Figure 1 Functional Block Diagram

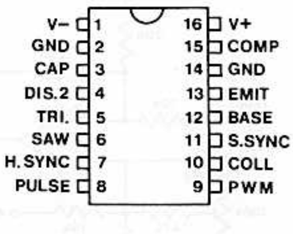


Figure 2 Pin Configuration

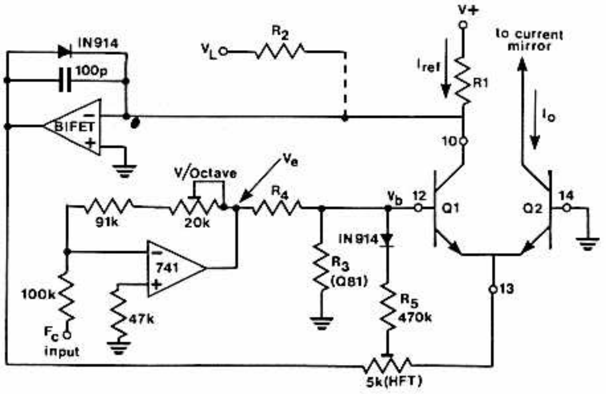


Figure 3 Control Circuit

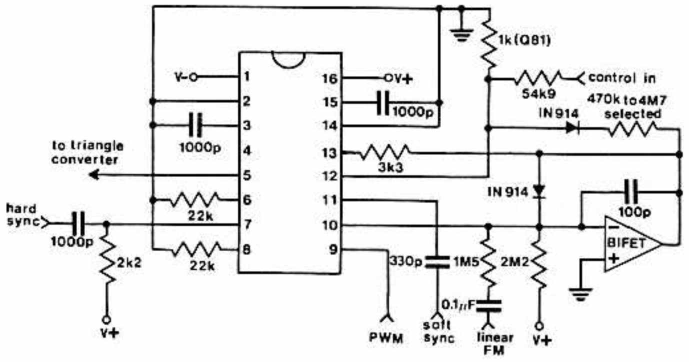


Figure 4 Basic Connection

Two other sources of error exist which can affect sweep accuracy: the input bias current of the buffer at the low end (the 2030 spec. is $I_b$ less than 1nA); and the bulk emitter resistance of the logging transistors at the high end. In Figure 3, the diode-R5 network compensates for this latter effect by providing extra base drive at high current to the sweep circuit. The integrating capacitor must have good temperature stability (e.g. polystyrene type.)

For proper operation the Volt/octave trimmer is adjusted to give a true octave at 200Hz to 400Hz. The HFT preset potentiometer is then trimmed for a true octave at 4000Hz to 8000Hz. Using this procedure one can get better than 0.25% absolute sweep accuracy from 20Hz to 10kHz with 0.1% in the critical range between 100Hz to 8000Hz. Since the small remaining errors tend to be similar from oscillator, matching between oscillators is even better than the absolute frequency accuracy — an important benefit in designing polyphonic systems.

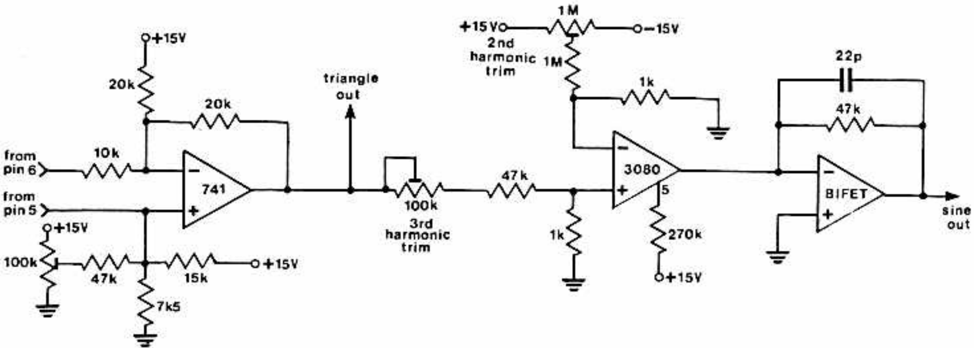
Within the chip, the exponential current is mirrored and direct integration yields a sawtooth whose discharge results from the comparator triggering the one-shot. The sawtooth waveform is 0-10V. The sawtooth and "triangle" output pins are both emitter followers from the internal sawtooth. The triangle waveshaping circuit (Figure 5) uses the sawtooth output and an emitter follower from the same point which is biased to give half a sawtooth. The subtraction performed by the 741 of the sawtooth from this waveform yields a triangle output of ±5V. A true 741 type op amp must be used as its lower slew rate ignores the fast negative going discharge ramp which would otherwise cause a glitch in the output. Any sine shaping circuit may be used, if required, and that shown in Figure 5 uses few components and produces a ±5V sine wave with about 2% THD when trimmed.

The variable width pulse output is derived by internally comparing the sawtooth to the pulse width input. The PWM pin is thus a voltage input with a fixed 10%/V sensitivity (100% at 0V descreasing to 0% at 10V.) The output is –0.5V low and 7V high.

The circuit shown in Figure 4 provides linear frequency modulation with a 10%/V sensitivity for the components used. Although it is shown AC coupled so as to avoid errors from any DC drift it may be DC coupled if required.

The auxiliary discharge output (Pin 4) can be used to drive a large geometry transistor for discharging capacitors from 2nF to 10nF in low frequency oscillators used for modulation purposes (Figure 6).

The hard sync input senses a falling edge, such as another 2030's sawtooth discharge, and forces an immediate discharge of the synchronised 2030 (Figure7). Oscillators set to integral ratios (slave faster than master) will lock with coherent waveforms but when set to ratios of numbers unusual waveforms result. The hard sync facility can produce pleasant timbral effects when the slave VCO is modulated and the master held constant. The soft sync input also accepts a falling edge but it will only force discharge if the synchronised 2030 is within (240k/$R_S$+2k4) % of discharge and this percentage is normally kept between 5 and 10 so as to synchronise oscillators to ratios without producing odd waveforms (Figure 8).



triangle converter

sine shaper

Figure 5

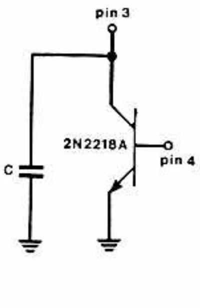


Figure 6

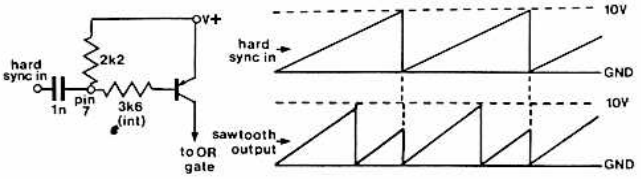


Figure 7 Hard Synchronisation

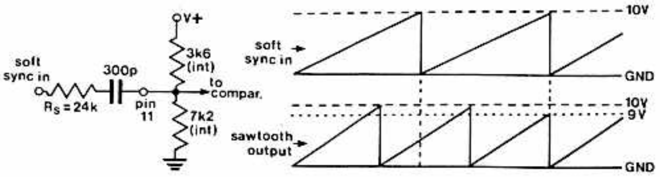


Figure 8 Soft Synchronisation

## SPECIFICATIONS: $V_S$ ±15V, $T_A = 25^{o}C$, CAP = 1nF

| Parameter | Conditions | Min | Typ | Max |
|---|---|---|---|---|
| $V_s$ | | ±9V | ±15V | ±18V |
| Supply Current | $I_C = 1$ mA | 8 mA | 12 mA | 16 mA |
| Buffer Leakage | $I_C = 0$ | | 100 pA | 1 nA |
| Sweep Range | | $10^6$: 1 | $10^7$: 1 | – |
| Operating Frequency | | 0.02 Hz | – | 200 kHz |
| Sawtooth Amplitude | | 9.5 Vpp | 10 Vpp | 10.5 Vpp |
| Pulse Amplitude | | 7.0 Vpp | 7.5 Vpp | 8.0 Vpp |
| Sawtooth Fall Time<br>Buffer Output<br>Buffer Input | | <br>–<br>– | <br>500 nsec<br>200 nsec | <br>–<br>– |
| Pulse Output<br>Fall Time<br>Rise Time | | <br>–<br>– | <br>200 nsec<br>200 nsec | <br>–<br>– |
| Exponential Conformity (Trimmed)<br>1000: 1<br>100: 1 | <br>20Hz-20kHz<br>100Hz-10kHz | <br>–<br>– | <br>0.25%<br>0.1% | <br>–<br>– |
| 1000: 1 Oscillator Matching | 20Hz-20kHz | – | 0.1% | – |
| Linearity (Trimmed) 1000: 1 | 20Hz-20kHz, $V_e$ = GND | – | 0.05% | – |
| Output Current (before clipping)<br>Sawtooth Output<br>Triangle Output<br>Pulse Output | | <br>1.8 mA<br>1.8 mA<br>3.5 mA | <br>2.4 mA<br>2.4 mA<br>4.6 mA | <br>3.4 mA<br>3.4 mA<br>6.5 mA |
| Control Circuit $V_{OS}$ | $I_e = 100\ \mu A$ | – | 1 mV | 3 mV |
| Power Supply Sensitivity | | – | 0.5%/V | 1%/V |
| Pulse Mod Input Bias | | – | 1 µA | 2.5 uA |
| Temperature Stability | $V_e$ = GND | – | 50ppm/$^{o}$C | |

**REFERENCES:** Application Note and Data Sheet published by **Solid State Micro Technology, Santa Clara, U.S.A.**

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# SSM 2020 DUAL LINEAR-ANTILOG VOLTAGE CONTROLLED AMPLIFIER

The SSM 2020 is a dual two quadrant multiplier designed to be used with op amps in a wide variety of precision audio frequency applications including AGC circuits, dividers and as a Biquad tuning element. Each channel has separate control and differential signal inputs and a current output. The device offers an exceptionally flexible control circuit for each channel which allows simultaneous linear and exponential voltage control of gain or either polarity of current control. Both channels are fully temperature compensated and have 84dB signal to noise ratios at less than 0.1% distortion.

## KEY FEATURES:

- **Dual design (independent control selection)**
- **2% channel gain matching**
- **100dB control range**
- **Simultaneous linear and exponential gain control**
- **Differential signal inputs**
- **Current output**
- **84dB signal to noise**
- **0.1% distortion**
- **Fully temperature compensated**
- **± 6V to ±18V supplies**

## APPLICATIONS:

- **2 and 4 quadrant multipliers**
- **Dividers**
- **AGC circuits**
- **Voltage controlled filters**
- **Voltage controlled quadrature oscillators**
- **Volume controls**
- **Equalisers**
- **Compandors**
- **Antilog amplifiers**
- **Voltage controlled current sources**

## DEVICE DESCRIPTION AND APPLICATION

The SSM 2020 is a dual two quadrant multiplier and the functional diagram of one half of the device is shown in Figure 1. The use of a matched transistor pair as the input stage greatly simplifies exponential control circuits. Temperature compensation is also provided by an internal resistor having a nominal resistance of 450 ohms and temperature coefficient of +2,000ppm/°C.

The output signal to noise ratio of the 2020 into a 10k metal film resistor with an input signal of 10 volts peak to peak is about 84dB and THD is typically less than 0.1% for all input levels less than 6 volts peak to peak.

Offset in the 2020 is best thought of referred to the output rather than the signal inputs. Due to the nature of the design, the DC offset appearing at the output will be a small fraction of the control current, typically 2%, with both signal inputs grounded. If the control current is kept under 500 µA the offset can be trimmed out with a pre-set stretched between the supplies and the wiper connected to one of the signal inputs. Offset and control rejection are related and both can be trimmed out with the same adjustment. Control rejection for the 2020 is typically 24dB untrimmed and 56dB trimmed.

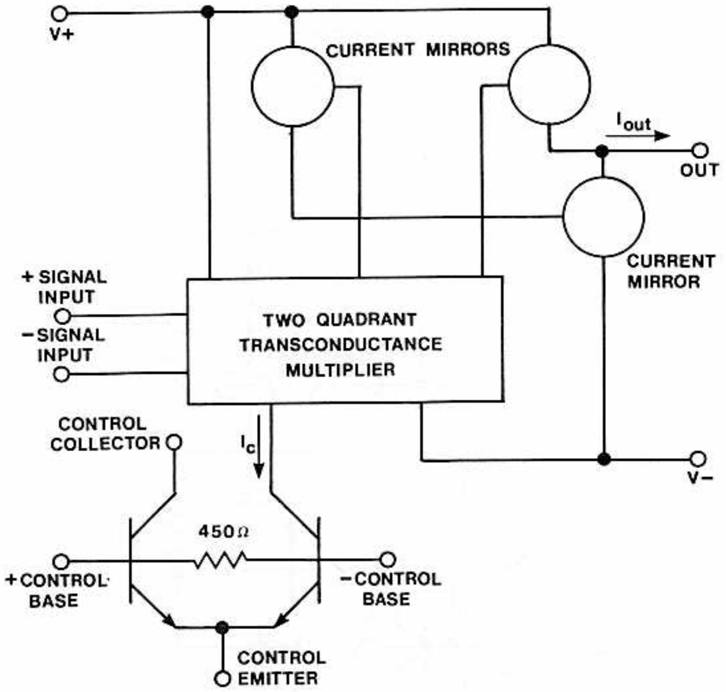


Figure 1 Block Diagram (One Side)

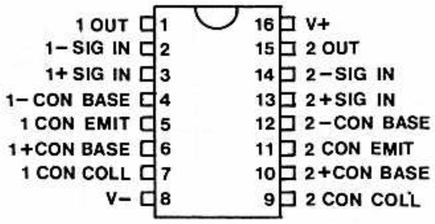


Figure 2 Pin Configuration

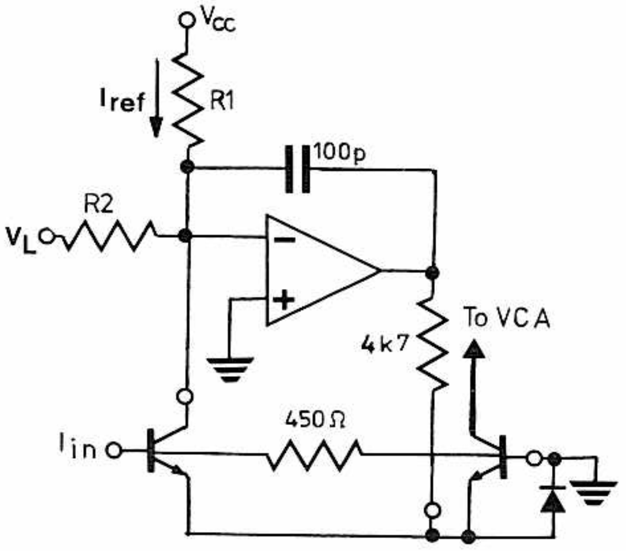


Figure 3 Exponential VCA

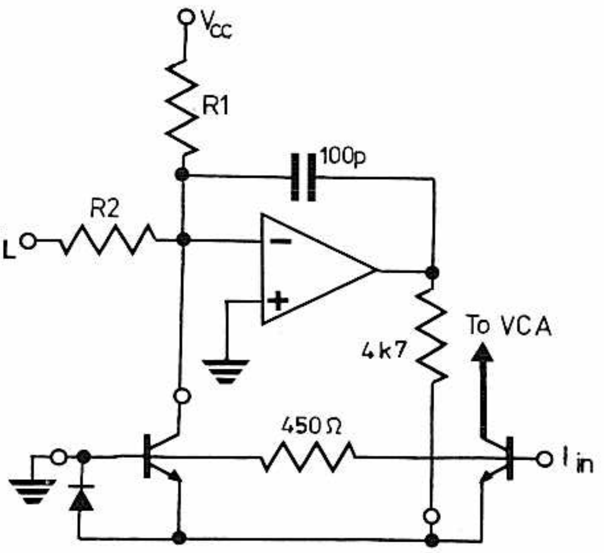


Figure 4 Exponential VCA

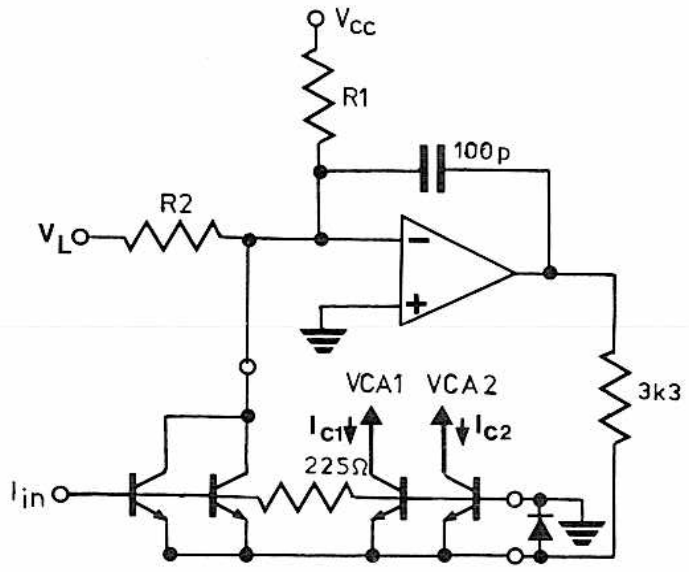


Figure 5

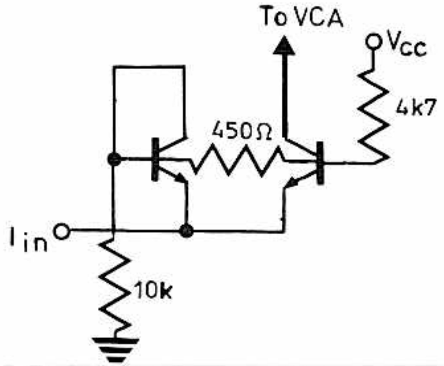


Figure 6 Current Sink

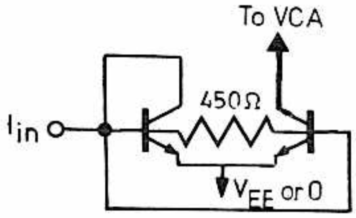


Figure 7 Current Source

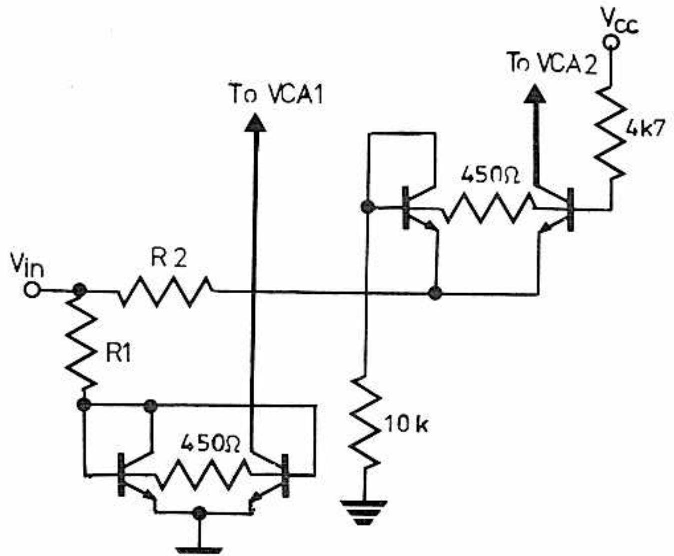


Figure 8 VC Pan or Mix

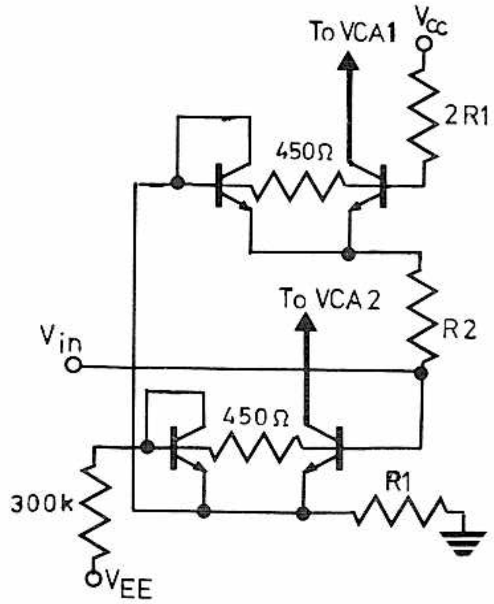


Figure 9 VC Centre Off Mix

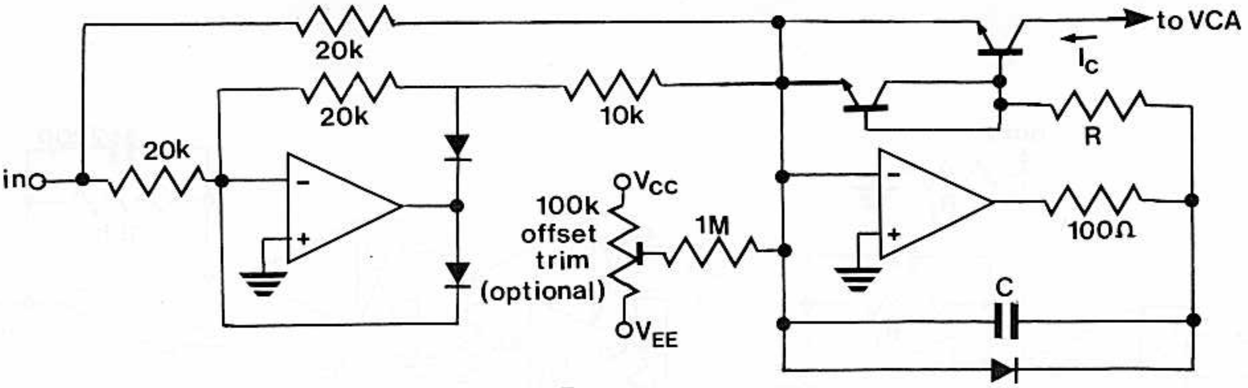


Figure 10

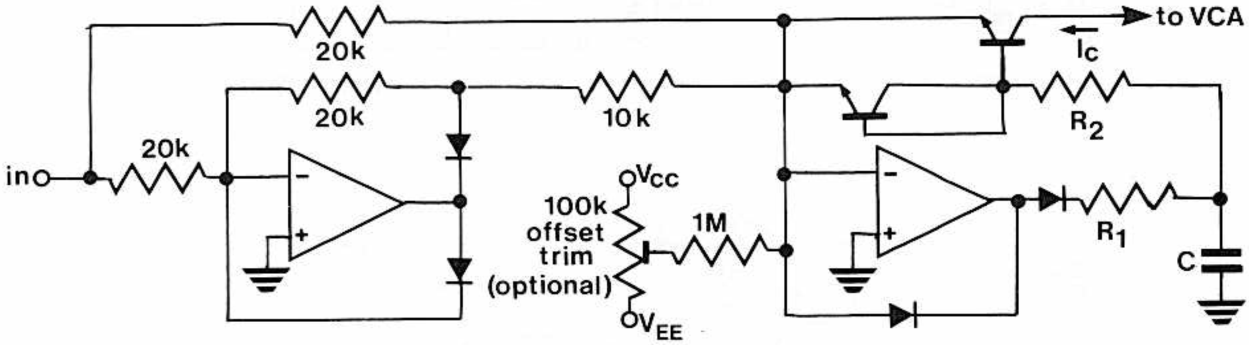


Figure 11

The versatility of the SSM 2020 is illustrated by the variety of control configurations and Figures 3 to 11 show some of the control techniques that may be used.

Figures 3 and 4 are used to produce linear and/or exponential voltage control of gain. Resistor R1 establishes a reference current in the circuit which, for maximum temperature stability, should be chosen at the logarithmic centre of the control range. For example, if one desires a control range of 500 µA to 50nA the reference current would be 5 µA. A control voltage and a resistor are used to produce $I_{in}$. The in-built resistors largely compensate for the T factor in the exponential control equation. Due to variation in the 450 ohm resistor value with processing some selection or trimming of the input resistor may be required to produce the desired scale factor.

Linear control of gain with cut-off can be achieved by grounding both bases and eliminating R1. The control current will then be equal to $V_L/R2$ with $I_c$ going to zero with $V_L$ at ground or below.

Figure 5 shows both VCA control circuits ganged to the same control voltages. With this connection the control currents in the two VCA's will match and track.

Figures 10 and 11 show two circuits for producing a control current that is proportional to the amplitude of an AC input signal. Figure 10 is an AC to DC converter that has equal attack and decay times.

Figure 11 is a peak detector circuit that has fast attack and slow decay. Both circuits are useful in compandor and AGC applications. Inexpensive 741 type op amps can be used without trimming for good results over a 50dB range but for frequencies in excess of 10kHz then BIFET type op amps are recommended.

The design equations relating to Figures 1 and 11 are shown below:

| **Figure** | **Function** | **Control Current** | **Notes** |
|---|---|---|---|
| 1 | One Side SSM 2020 | $I_C$ | $I_{OUT} = I_C(V_+ - V_-)/14V$ |
| 3 | Linear-Exponential VCA | $(V_L/R_2 + Vcc/R_1)\ e^{-450 I_{in}\ q/KT}$ | $KT/q = 25mV$ @ 25°C |
| 4 | Linear-Exponential VCA | $(V_L/R_2 + Vcc/R_1)\ e^{450 I_{in} q/KT}$ | 450Ω TEMPCO = +2000ppm/°C |
| 5 | Ganged Linear-Exponential VCA | $1/2\ (V_L/R_2 + Vcc/R_1)\ e^{-225 I_{in} q/KT}$ | $I_C = I_{C_1} = I_{C_2}$ |
| 6 | Current Sink | $-I_{in}$ | |
| 7 | Current Source | $I_{in}$ | |
| 8 | Voltage Controlled<br>Pan or Mix | $(V_{in} - 0.7)/R_1$<br>$(9.3 - V_{in})/R_2$ | $I_{C_1}$ @ Vcc = 15V<br>$I_{C_2}$ @ Vcc = 15V |
| 9 | Voltage Controlled<br>Center-Off Mix | $3(V_{in} - 5.7)/2R_1$<br>$(4.3 - V_{in})/R_2$ | $I_{C_1}$ @ Vcc = 15V<br>$I_{C_2}$ @ Vcc = 15V |
| 10 | AC to DC Converter | Vpp in/40K | $f > 1/2\pi RC$ |
| 11 | Peak Detector | Vpp in/40K | $f > 1/2\pi R_2C$<br>Attack Time = $R_1C$<br>Decay Time = $R_2C$ |

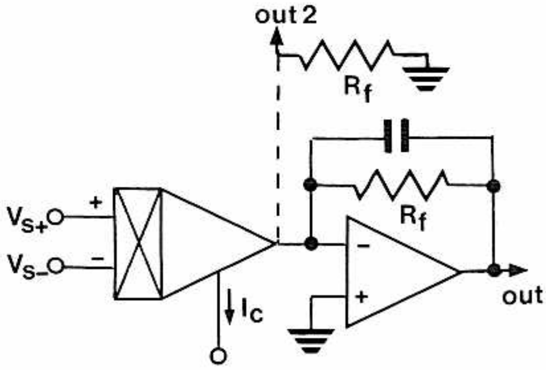


Figure 12

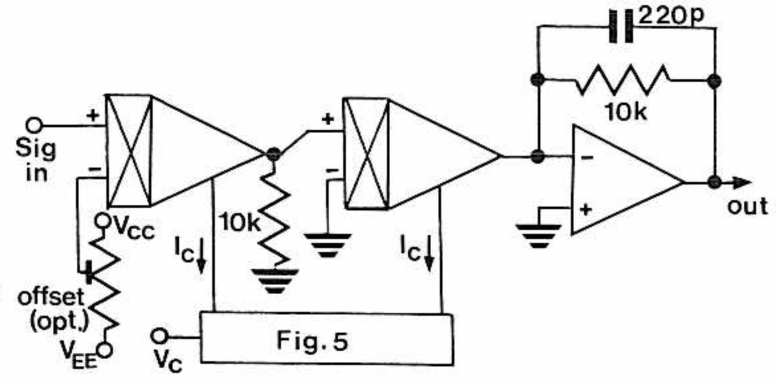


Figure 13

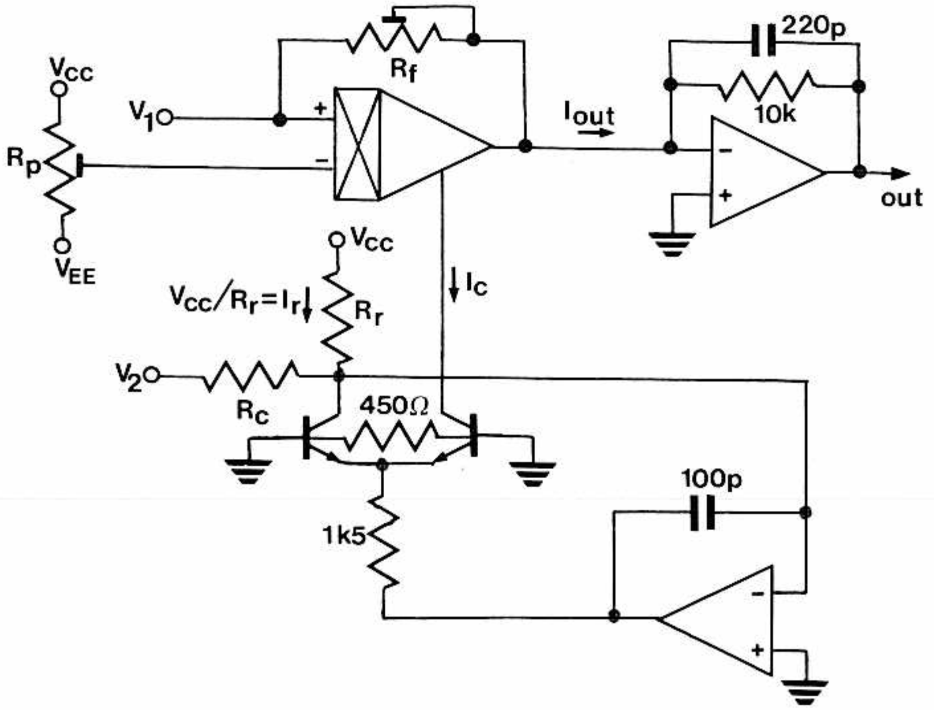


Figure 14

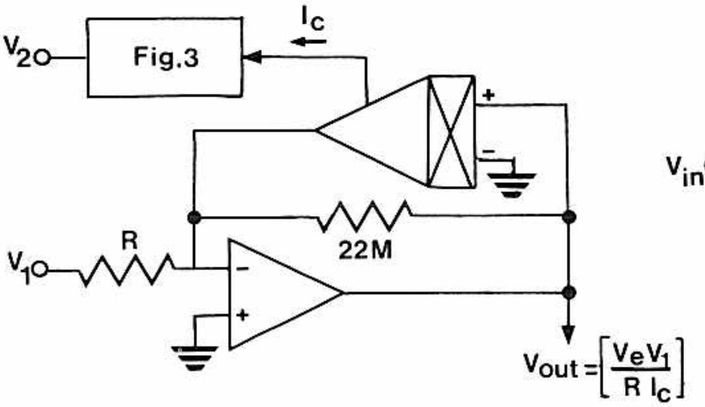


Figure 15

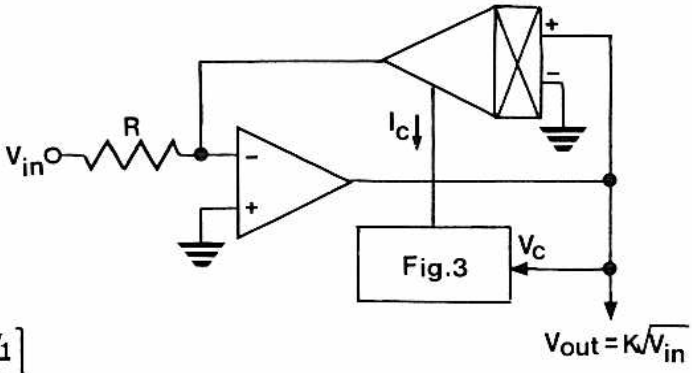


Figure 16

VOLTAGE CONTROLLED AMPLIFIER. Figure 12 shows half of a dual VCA used in its principle application. The output voltage is related to the input voltages and control current by:—

$$V_{out} = I_c\,(V_+ - V_-)R_f/V_E\,;\ V_E = 14V$$

A linear or antilog voltage to current converter sets the control current and a resistor (shown by 'out 2') or an op amp ('out 1') converts the output current to an output voltage. The output op amp is necessary only if a low impedance output is required. The capacitor in parallel with the feedback resistor is necessary to prevent oscillation. For 10k feedback resistor, 150 to 220pF should be sufficient, giving a bandwidth of about 100kHz. Offset and control feedthrough can be nulled by connecting the wiper of a pre-set potentiometer stretched between the two power supplies to an unused signal input.

ANTILOG VCA WITH 130dB CONTROL RANGE. In Figure 13 both halves of a dual VCA are cascaded to produce an antilog VCA with a 130dB control range. The control current in each half of the device is designed to vary only from 500 μA to 250nA, making it possible to maintain a signal bandwidth in excess of 50kHz down to the extreme low end. This approach also improves distortion and signal to noise values at the low end of the control range.

In Figure 14 half of a VCA is used as a four quadrant multiplier and the appropriate control circuit is shown. The output current into a virtual ground is:—

$$I_{out} = -V_1V_2/R_cV_E$$

To adjust the circuit for proper operation, a signal is applied to the $V_2$ input with $V_1$ grounded and $R_p$ trimmed for minimum feedthrough. $V_2$ is then grounded, a signal applied to $V_1$ and $R_f$ trimmed for minimum feedthrough which should occur when:—

$$R_f = 11.8/I_{ref}$$

A maximum bandwidth of about 250kHz will be obtained with $I_{ref}$ = 200 μA. The op amp converts the current to a buffered voltage. If the $V_1$ and $V_2$ inputs are tied together the output will be the square of the common input.

In Figure 15 one half of a VCA is shown connected with an op amp to form a divider circuit. The output is proportional to $V_1/V_2$. The 22M resistor connected in the feedback is optional and prevents complete loss of feedback when $I_c$ goes to zero. By connecting the $V_2$ input to the output, a square root circuit is formed (Figure 16).

MIXERS, FADERS AND PANNING CIRCUITS. Figure 17 is the basic circuit for voltage controlled mixing. This circuit can be expanded to accommodate more inputs by connecting additional VCA outputs to the summing node of the op amp. Two Figure 3 circuits can be used to independently control the mix level from the two inputs. If control is ganged by using control circuits shown in Figures 8 or 9, a voltage controlled pan or centre-off mix can be implemented.

Stereo panning can be accomplished by using two Figure 17 circuits and controlling one with the inverted control signals of the other. This will produce an effect where the left and right sound sources will change sides with an equal monaural mix in the centre. With two more Figure 17 circuits this concept can be extended to quadraphonic systems for interesting and special rotating sound effects.

Figure 18 is a control circuit for an automated mixer-fader using Figure 17. With the digital input high, only the $V_{SA}$ input appears at the output under exponential control of $V_1$. When the logic goes low the $V_{SA}$ level decays to zero and the $V_{SB}$ level attacks to a level controlled by $V_2$ with a time constant of ½R1C. The transition between the two sound sources is smooth and pleasant to the ear.

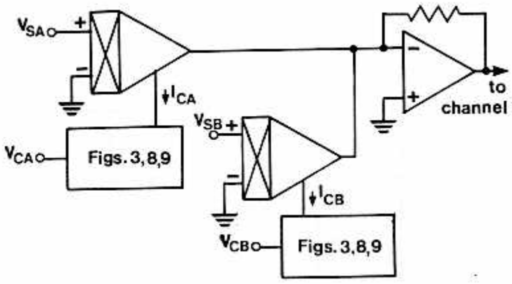


Figure 17

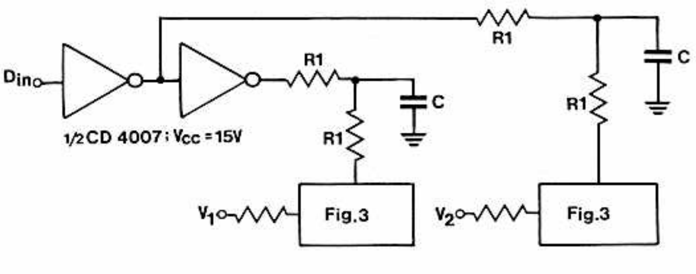
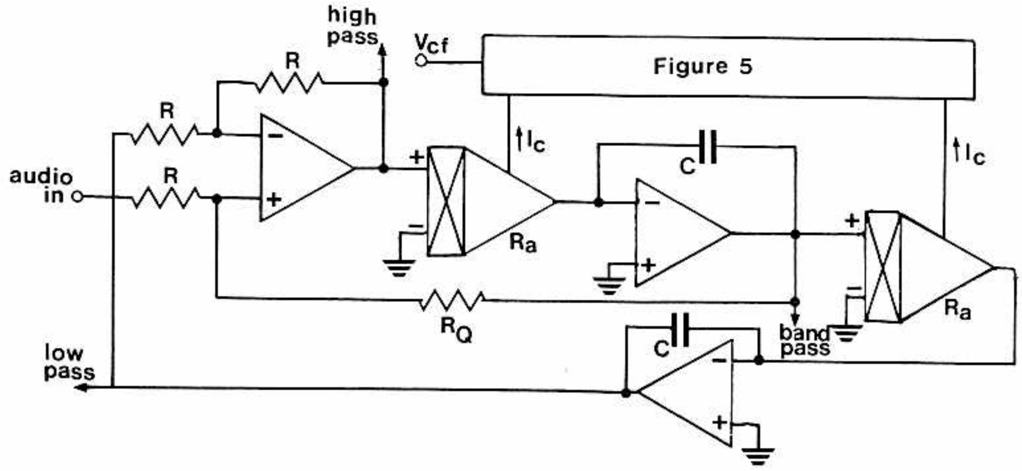


Figure 18

VOLTAGE CONTROLLED FILTERS AND EQUALISERS. Using the circuit in Figure 19 a voltage controlled filter with a 10,000:1 control range can be implemented. The low and high pass outputs have 12dB/octave roll-offs and the bandpass output has 6dB/octave skirts. Such circuits can be placed in series to produce more complex filters. In this application a dual VCA can be thought of as a pair of matched voltage controlled resistors. The $R_a$ in the design equation for the cut-off frequency given next to the figure is 28k when the control current in both halves of the device is 500 μA. At 50 μA control current, the value of the $R_a$ will increase by a factor of 10 and so forth. For control ranges of 1,000:1 or greater, low input bias op amps should be used in the control circuit and signal section of the filter. BIFET type op amps perform well offering low input bias, low noise and wide power bandwidth. If antilog control is used, the greatest control accuracy for a 10,000:1 range is obtained for control currents of 500 μA to 50nA. VCA's used in an output mixer with fixed or voltage controlled filters can implement a remote controlled or automated equaliser.

By using half of a SSM 2020 in place of $R_Q$ in Figure 19 and taking the output to the inverting input of the high pass op amp stage one can obtain voltage control of Q from less than 0.5 to 250. The audio signal is then taken via the 2020 and Q control can be achieved with control circuits of Figures 3 or 4. This modification has the additional feature that the gain remains constant at maximum pass.

Utilising the 2020 as a pair of voltage controlled resistors to tune a biquad stage also makes possible its application to the realisation of a voltage controlled quadrature oscillator. Sine waves with low distortion (approximately 0.1%) can be achieved.



**DESIGN EQUATIONS:**

$R_a C \omega_0 = 1$

$R_a = 28k$ at $500 \mu A$

$A = 2 - 1/Q$

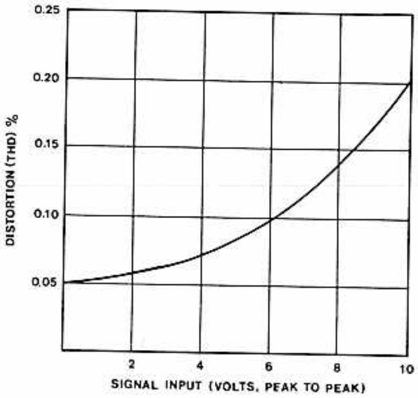
$R_Q = (2Q-1)R$

Figure 19

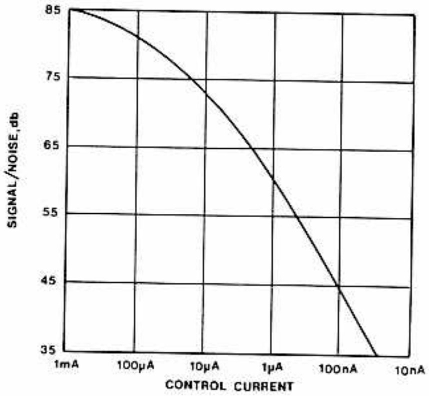
## SPECIFICATIONS: $V_s = \pm 15V$, $I_{c1} = I_{c2} = 500 \mu A$, $T_A = 25°C$, unless otherwise stated.

| Parameters | Min | Typ | Max | Conditions |
|---|---|---|---|---|
| Signal Input Bias $I_b$ | | 500 nA | 2.2 μA | $V_{ee} + 3V \leq V_+, V_- \leq V_{cc} - 3V$ |
| Supply Voltage $V_s$ | ±6 | ±15 | ±18 | |
| Supply Current $I_s$ | | 6 mA | 8 mA | $I_{c1}$ $I_{c2} = 1$ mA |
| Control Current | | | 1 mA | |
| Tranconductance gm | 83 μS | 71 μS | 62 μS | $I_{c1} = I_{c2} = 1$ mA |
| gm match | | ±2% | ±5% | |
| gm Temco | | 100 ppm/°C | | |
| Control Circuit $V_{os}$ | | 1 mV | 3 mV | |
| Output Offset $I_o/I_c$ | | ±2% | ±10% | $V_+ = V_- =$ GND (untrimmed) |
| Control Rejection | | 60 dB | | $0 \leq I_c \leq 1$ mA (trimmed) |
| 450 Ω Resistor | 350 Ω | 450 Ω | 550 Ω | |
| 450 Ω Temp Coef | | +2000 ppm/°C | | |
| Channel Separation | | 100 dB | | F = 1kHz |
| Bandwidth (3 dB) | | 1 MHz | | $I_c = 1$ mA* |
| | | 300kHz | | $I_c = 10$ μA |
| | | 30kHz | | $I_c = 100$ nA |
| Feedthrough: | | | | |
| − Input to Output | | 90 dB | | F = 1kHz, $I_c = 0$ |
| + Input to Output | | 100 dB | | F = 1kHz, $I_c = 0$ |
| Signal/Noise | | 84 dB | | $V_s = 6V_{pp}$, $I_c = 1$ mA |
| Distortion (THD) | | | | |
| VCA (Open Loop) | | 0.1% | | $V_s = 6V_{pp}$, $I_c = 1$ mA |
| VCF (Closed Loop) | | 0.02% | | $V_s = 6V_{pp}$, $I_c = 1$ mA |

*Output at Virtual GND



Distortion vs Signal Input



Signal/Noise vs Control Current (6Vp–p in)

**REFERENCES:** Application Note and Data Sheet published by **Solid State Micro Technology, Santa Clara, U.S.A.**

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# SSM 2040 VOLTAGE CONTROLLED FILTER CIRCUIT

The SSM 2040 is a four section filter whose cut-off frequency can be exponentially voltage controlled over a 10,000 to 1 range. This flexible building block can be used in virtually any active filter design including lowpass, highpass, bandpass and allpass. Roll-off characteristics can be selected to be Butterworth, Bessel, Tchebyscheff, Cauer or any other filter type.

## KEY FEATURES:

- **Exponential frequency control response**
- **4 filter sections in one package**
- **Low noise**
- **Low distortion**
- **Guaranteed control rejection characteristics**
- **10,000 to 1 range**
- **± 15V supplies**

## APPLICATIONS

- **Music synthesisers**
- **Music phase shifters**
- **Parametric equalisers**
- **Tracking filters**
- **Low distortion sine VCO's**
- **Voltage controlled filters:**

| | |
|---|---|
| **Lowpass** | **Biquad** |
| **Bandpass** | **State Variable** |
| **Highpass** | **Sallen & Key** |
| **Allpass** | **Cauer** |
| **Notch** | |

## DEVICE DESCRIPTION AND APPLICATION

The SSM 2040 voltage controlled filter contains four indentical filter stages, all of which are simultaneously controlled by the same exponential function generator as shown in Figure 1. This latter block generates the four control currents according to the equation:—

$$I_c = I_o e^{\frac{qV_{ctl}}{KT}}\ ; \quad q/KT \simeq 1/26\text{mV} @ 25^{\circ}\text{C}\ ; \quad I_o = 10\,\mu\text{A}$$

The temperature dependent term can be corrected by the use of a +3,500ppm/°C compensating resistor (e.g., Tel Labs Q81) as shown in the control circuit (Figure 3).

Characteristics of voltage controlled filters of interest to design engineers include signal/noise ratio, distortion, and control rejection. The equivalent input noise for the 2040 is 0.5 µV r.m.s. at 20Hz–20kHz bandwidth. As the input signal is typically 20mV r.m.s., the signal to noise ratio is close to 90dB. As the 2040 is operating in a closed loop environment, the distortion at full input level is excellent, typically 0.02%. The control rejection specification for the 2040 is typically 0.6mV equivalent at input for a 5 octave sweep from centre in either direction. This is 37dB below signal level, and as control changes are generally slow compared to signal frequencies, this is quite acceptable. Nevertheless control "pop" may be further reduced by adding a capacitor, say 47nF, between the inverting input and the output of the op amp in Figure 3.

The control circuit shown in Figure 3 is a typical control summer used to derive the 1V/octave characteristics used in electronic music applications.

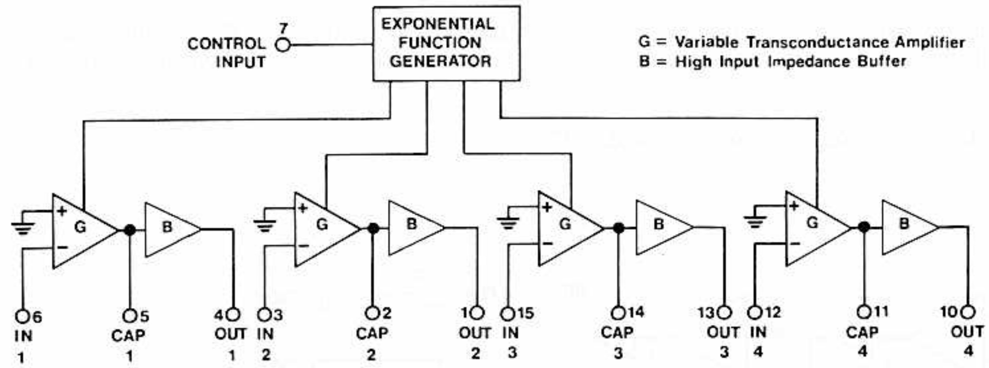


Figure 1 Functional Block Diagram

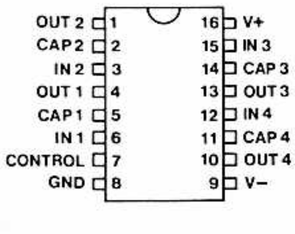


Figure 2 Pin Configuration

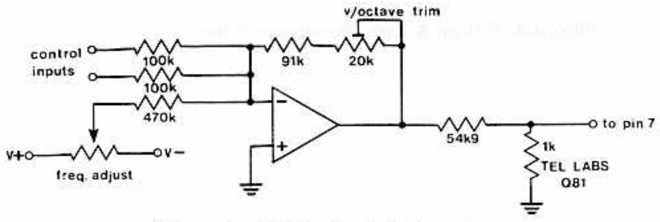


Figure 3 2040 Control Input

The equation describing the variable transconductance amplifier is:—

$$I_o \simeq (V_+ - V_-)G\,; \quad G = I_c/52\text{mV} \ @\ 25^\circ\text{C}$$

The generalised voltage controlled filter connection is shown in Figure 4. The differential equation describing the filter operation is:—

$$\frac{d(V_o - V_{ib})}{dt} = \frac{-G\,R_a\,(R_f V_{ia} + R_i V_o)}{C\,(R_i R_f + R_a R_i + R_a R_f)}$$

Solving this equation for the general filter function we find:—

$$V_o = \frac{V_{ib}(S/\omega_o) - K\,V_{ia}}{1 + (S/\omega_o)}$$

$$\text{where } S = j\omega\,, \quad \omega_o = \frac{G\,R_a R_i}{C(R_a R_i + R_a R_f + R_i R_f)}\,, \qquad K = R_f / R_i$$

From the above general equation, we can derive the three specific single cases. Figures 5 to 7 show the lowpass, highpass, and allpass (phase shift) connections for the single stage, and their equations are:—

LOWPASS REAL POLE: $V_o = -K\,V_i\,/\,(1 + S/\omega_o)$

HIGHPASS REAL POLE: $V_o = V_i(S/\omega_o)\,/\,(1 + S/\omega_o)$

ALLPASS NETWORK: $V_o = V_i(S/\omega_o - 1)\,/\,(S/\omega_o + 1)$

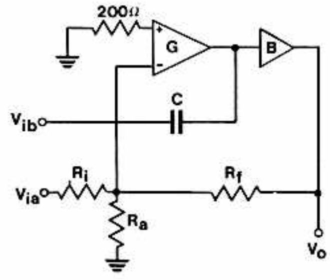


**Figure 4 Generalised 2040 Connection**

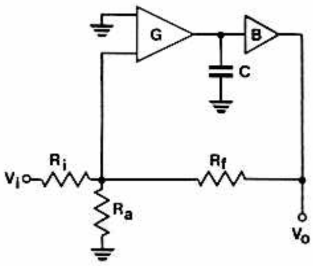


**Figure 5 Lowpass Real Pole**

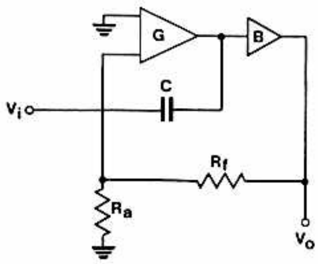


**Figure 6 Highpass Real Pole**

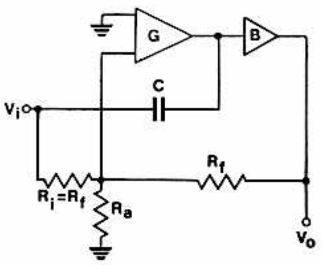


**Figure 7 Allpass**

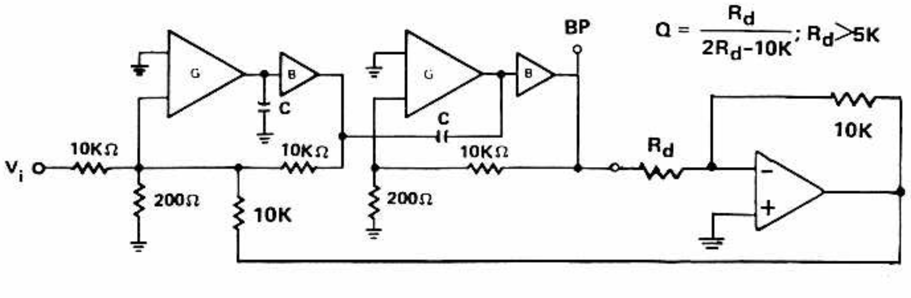
The 2040 is thus a circuit capable of implementing any fourth order filter function in a voltage controlled manner. Figure 9 shows the classical "four-pole" electronic music lowpass filter.

Using additional feedback allows one to synthesise pole pairs with resonance. Figure 8 shows a Sallen & Key bandpass filter with transfer function.

$$V_o = -V_i\,(S/\omega_o)\,/\,(S^2/\omega_o^2 + (2 - R_d/10\text{K}\Omega)(S/\omega_o) + 1)$$

Using feedback around two allpass stages creates a notch filter and can be used to synthesise a Cauer (elliptical) filter. Likewise feedback around multiple allpass stages gives the electronic music "phase shifter", shown in Figure 10. Its transfer function is:—

$$V_o = V_i\,(S^4/\omega_o^4 + 6S^2/\omega_o^2 + 1)/(S/\omega_o + 1)^4$$



$$Q = \frac{R_d}{2R_d - 10K}\,; \ R_d > 5K$$

**Figure 8 Sallen & Key Bandpass Filter**

These few examples illustrate the versatility of the 2040 in synthesising filter networks and even a fourth order state variable filter may be realised.

Design hints for the SSM 2040 are as follows: —

a. The output pins (OUT 1 to OUT 4) are only capable of swinging ± 1V, and sinking 500 μA DC. Hence a 10k feedback resistor and load will give good performance.

b. THE OUTPUTS ARE NOT SHORT CIRCUIT PROTECTED. OUT, CAP OR IN pins must be not shorted to either supply although connections to ground can be tolerated for several seconds.

c. C values should be kept above 1000pF to ensure stability at all control settings.

d. The 200 ohm attenuating resistor is chosen for optimum control rejection. Other values can be used with some degradation of this parameter.

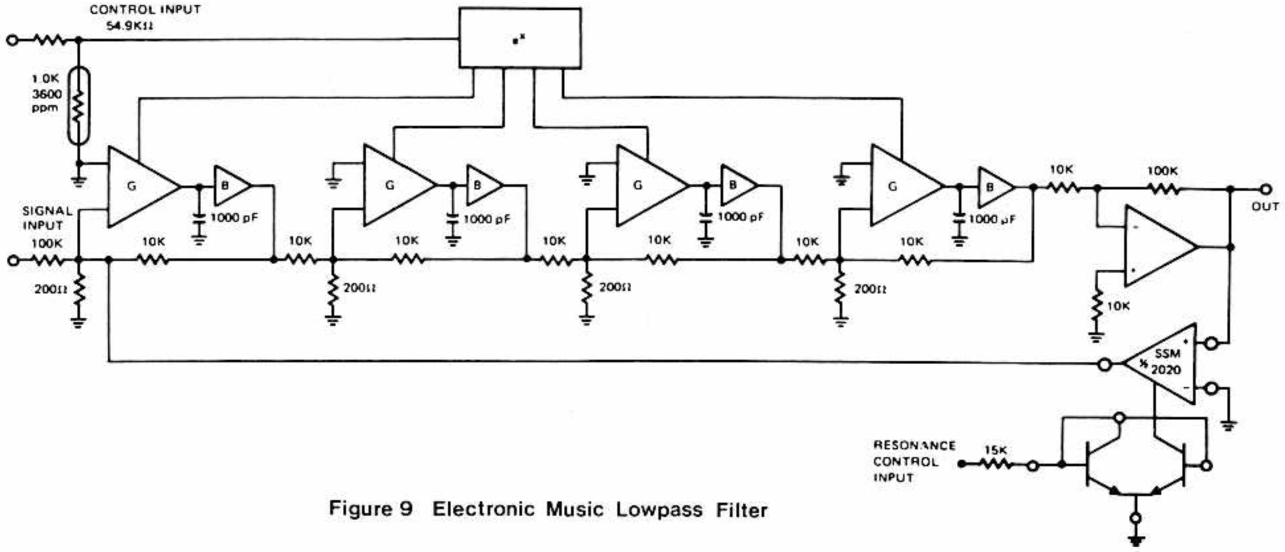


Figure 9 Electronic Music Lowpass Filter

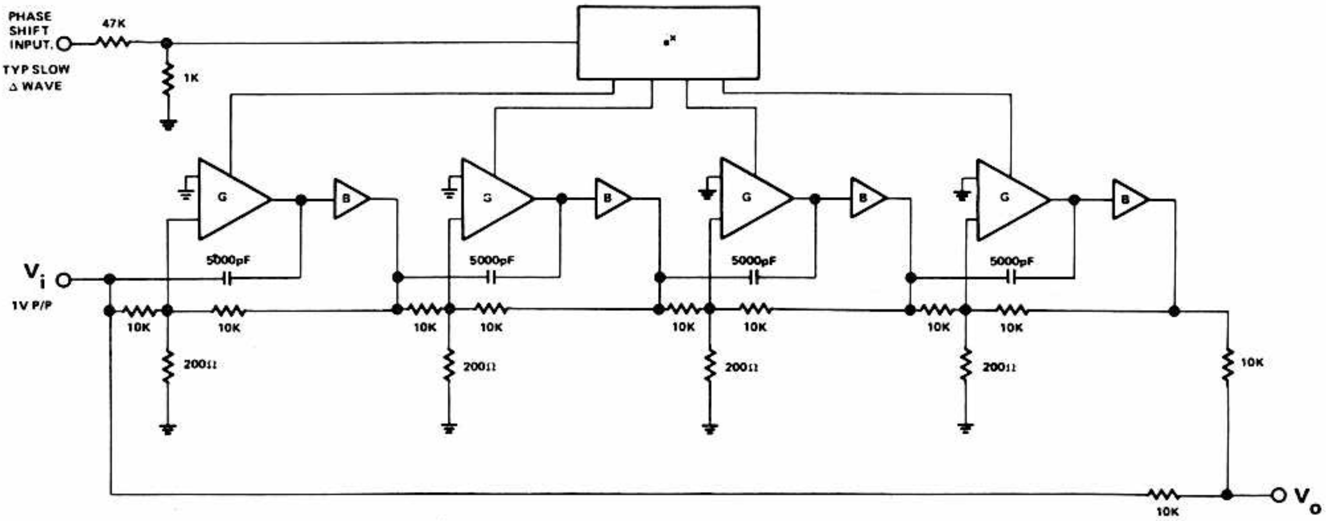


Figure 10 Electronic Music Phase Shifter

## SPECIFICATIONS: $V_s = \pm 15V$, $T_A = 25^oC$

| Specification | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Functional Range | | 10,000:1 | | | |
| Input Offset, each cell | | | 2 | 5 | mV |
| Input Offset, 4 cells in series | Vcntl = 0mV, −90mV | | 0.6 | 3 | mV |
| | Vcntl = 0mV, +90mV | | 0.6 | 3 | mV |
| Transconductance | Vcntl = 0 | 1/10K | 1/5K | 1/3K | mhos |
| Equiv. Input Noise, each cell | 20Hz−20kHz, Vcntl = −90mV | | 0.5 | | μV RMS |
| Distortion (THD), Ein = 30mVpp | F = 1kHz, Vcntl = −90mV | | 0.1 | | % |
| Tempco of Transconductance | Vcntl = 0 | | +0.5 | | %/°C |
| Control Sensitivity | | | −18 | | mV/oct |
| Tempco of Control Sensitivity | | | 0.33 | | %/°C |
| Power Supply Current | Vcntl = 0 | 2 | 4 | 7 | mA |
| Buffer Slew Rate | | | 2 | | V/μsec |

**REFERENCES:** Application Note and Data Sheet published by **Solid State Micro Technology, Santa Clara, U.S.A.**

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# SSM 2050 VOLTAGE CONTROLLED TRANSIENT GENERATOR

The SSM 2050 is a self contained ADSR type electronic music transient generator requiring a minimum of external parts. Attack, initial decay and final decay have an exponential response to an applied voltage and a minimum range of 2 msecs. to 20 secs. is attainable for each function. Sustain is linearly voltage controllable from 0 to 100%. The device has independent gate and trigger inputs for maximum flexibility.

## KEY FEATURES:

- **Exponential time control response**
- **10,000: 1 time control range**
- **Full ADSR response**
- **Independent gate and trigger allowing ADSR or AD response, or re-triggering**
- **Minimum external components**
- **±15V supplies**

## APPLICATIONS:

- **Music synthesisers**
- **Organs**
- **Rhythm synthesisers**
- **Sound effects generators**
- **Electronic games**

## DEVICE DESCRIPTION AND APPLICATION

The 2050 Voltage Controlled Transient Generator (also called envelope, ADSR or contour generator) implements a well-known electronic music function in a voltage controlled manner. The usual function of a transient generator is illustrated in Figure 1. Classically, the transient generator has been implemented by charging and discharging a capacitor with electronically switched panel controls. In contrast, the 2050 uses a voltage controlled resistor internally to generate the nominally exponential slopes.

The block diagram of the 2050 in Figure 2 shows the internal logic defining the states. An attack flip-flop (AF/F) is set by the TRIGGER pulse and reset by either NOT GATE or the attack comparator determining that the output has reached +10V. Then the three states are defined: ATTACK=GATE AND AF/F, INITIAL DECAY=GATE AND NOT AF/F, FINAL DECAY=NOT GATE. Each state is characterised by a nominally exponential approach to a characteristic voltage; these are +13V, SUSTAIN VOLTAGE, and 0V for attack, initial decay and final decay respectively.

The logic inputs of the 2050 are protected against high voltages by using a lateral PNP structure. The specification for these inputs is 750 µA or 1.5V, which is the minimum current and voltage required to trigger the 2050. The optimum logic interfaces to meet these requirements are given in Figure 4.

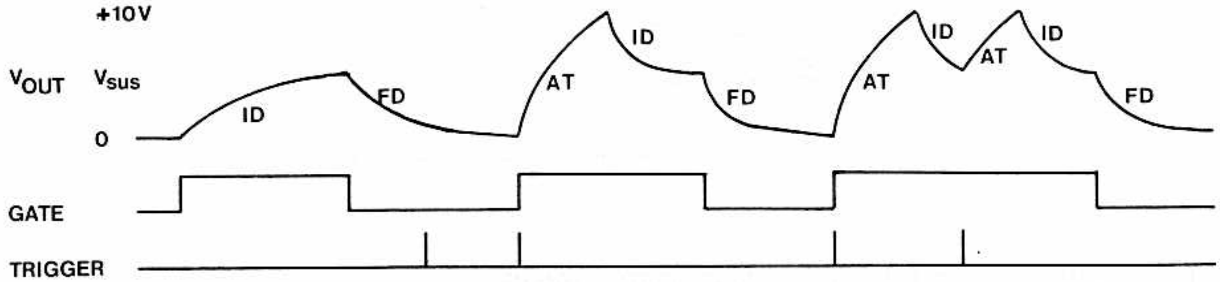

Figure 1 Gate and Trigger Functions

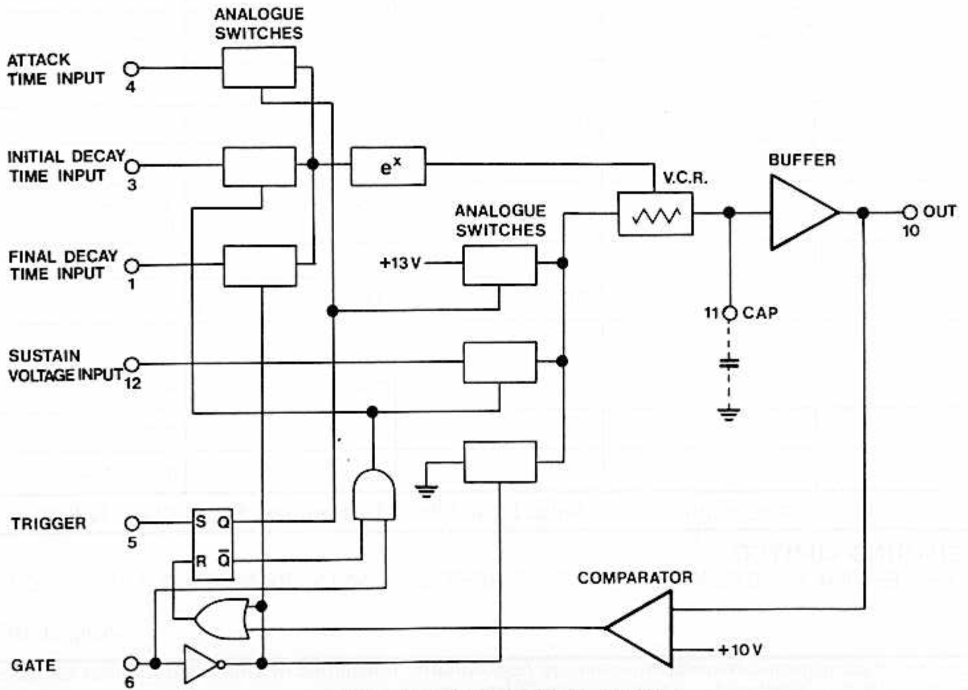

Figure 2 Functional Block Diagram

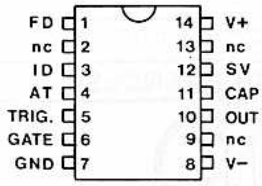

Figure 3 Pin Configuration

A few design compromises were necessary to integrate the voltage controlled transient generator. The voltage controlled resistor is not perfectly linear hence the approaches are only nominally exponential, although the deviation is less than ±5%. Also, there is a control rejection specification determining the maximum possible change in the output voltage approached in the final decay mode (ideally 0V); this is typically 30mV for a time constant change 2.5 decades either way from nominal.

The attack, initial decay, and final decay inputs of the 2050 have a sensitivity of 60mV/decade and an input impedance of 3,100 ohms ±25%. The latter tolerance is due to variations of chip resistors although the resistance for the three inputs on any given chip are matched to about 1%. Hence in polyphonic systems, where matched 2050's are to be used, they must be selected for similar control impedance and this is readily measured with a low current ohmmeter as the resistance between Pin 1 and Pin 7. Additionally, the initial time constants on the chip can vary ±50% and since the tolerance of the external 100nF capacitor may be poor a trim for initial time constant is useful. Again, the time constants within the chip are well matched and so a single trim, as shown in Figure 5, will suffice.

Figure 5 illustrates a typical polyphonic synthesiser application requiring minimum parts count and the 100k resistors give it a 2V/decade sensitivity. It will be appreciated however that with a few extra components the voltage controlled characteristics of the 2050 make it simple to obtain more realistic sounds, e.g., a change of envelope shape proportional to the keyboard voltage so allowing variations in amplitude or harmonics with pitch; via a VCA or VCF respectively. Furthermore, unusual envelopes may be created by applying feedback or using control voltages from waveform generators.

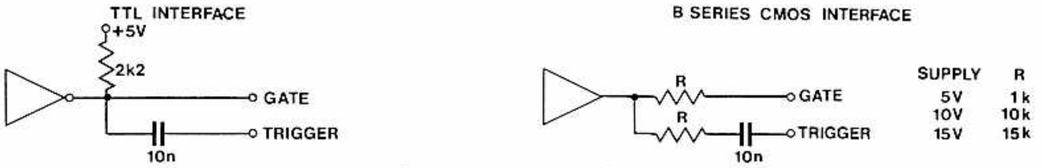

**Figure 4 Interface Circuits**

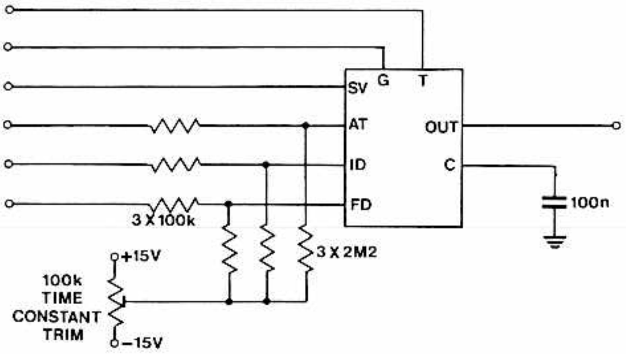

**Figure 5 Typical Polyphonic Synthesiser V.C.T.G.**

## SPECIFICATIONS: $V_S = \pm 15V$, $T_A = 25°C$, CAP = 100nF

| Parameter | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Time Range | 2-20000 | 1-100000 | | msec |
| Offset, Gate=off | ± 250 | ± 50 | | mV |
| Time Constants $V_{IN} = 0$ | 50 | 100 | 200 | msec |
| Offset $V_{SUS}$-$V_{OUT}$ Gate = ON | −1 | 0 | + 1 | V |
| Gate & Trig On Voltage<br>Current $V_{IN} = 1.5V$ | | 1.0<br>500 | 1.5<br>750 | V<br>µA |
| Output Noise | | 0.5 | | mV RMS |
| $V_{attack}$ | 10 | 10.5 | 11 | V |
| Final Decay Control Rejection<br>$V_{OUT}$: $V_{cntl} = 0 - -120mV$<br>$V_{cntl} = 0 - +120mV$ | | 30<br>30 | 150<br>150 | mV<br>mV |
| Control Input Impedance | 2.3 | 3.1 | 3.9 | kohm |
| Control Input Sensitivity | | +18 | | mV/octave |

**REFERENCES:** Application Note and Data Sheet published by **Solid State Micro Technology, Santa Clara, U.S.A.**

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