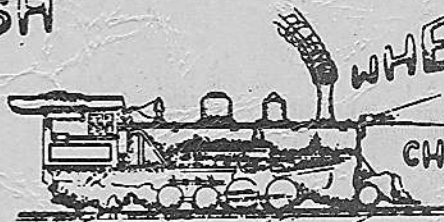
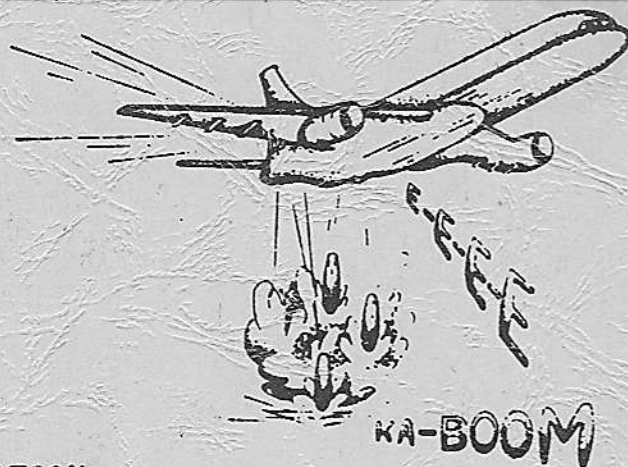


WH-OO-SH



WHE-E-E

CHU-G
CHU-G



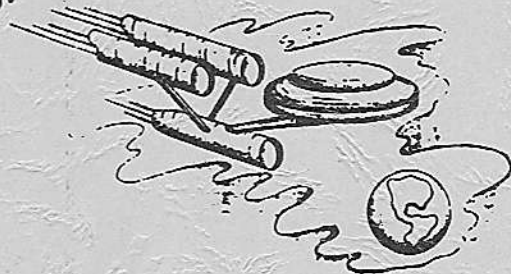
KA-BOOM

COMPLEX SOUND GENERATION

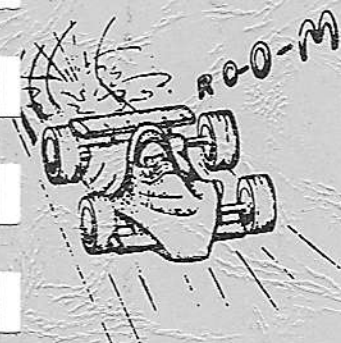
USING THE

SN76477N

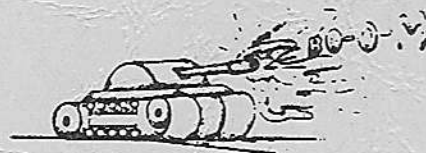
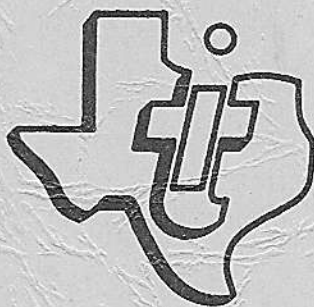
WHOO-SH



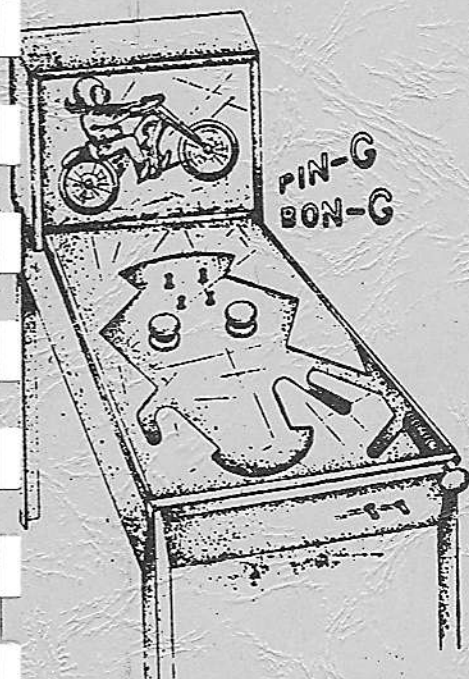
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BOOM



BOOM

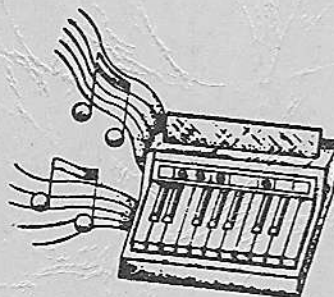


PIN-G
BON-G

TEXAS INSTRUMENTS INCORPORATED
P.O. Box 6325, M/S 812
Dallas, Texas 75222
214-893-5166



BEEP-BE
BEEP-BE



KA-POW
KA-POW



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- II. General Chip Description
- III. Logical Chip Description
- IV. System Design Techniques
- V. Completed Design Examples
- VI. Design Sequence for Developing
Complex Sound
- VII. Conclusion

INTRODUCTION

Accomplishing complex sound with discrete techniques in the past has maintained an advantage only because there has been no other method to produce complex sounds. However these techniques have suffered because of variation in individual discrete components and a cost disadvantage due to complexity. Many custom sound integrated circuits have failed due to no external programming capabilities. If any sound is not accurate, the only way to modify that sound is by changing the internal components of the integrated circuit. Normally this custom IC can only be used in one system, which means a very large quantity of units must be bought to pay for the development costs. Inexpensive MOS microprocessors are being used for some simple tones at this time; however, the cycle time limits their frequency to a maximum of 3K Hz, and they can do neither random noise nor attack/decay. Many of these disadvantages have been overcome by using higher performance microprocessors in conjunction with external components, but this increases costs substantially. With the advances that have taken place in I²L/Bipolar technology in the last couple of years, increased packing densities and lower currents are possible. The purpose of this paper is to present a unique complex sound IC, SN76477, and design techniques that should greatly simplify its implementation. The SN76477 should easily meet the cost/performance requirements of today's complex sound system and easily obtain the desired custom complex sounds from its external programming capabilities.

GENERAL CHIP DESCRIPTION

When most mechanical sounds and sounds that occur in nature are broken down, it is observed that they are composed of one or more of three basic sound functions. These sound functions are (1) a single frequency, (2) varying frequencies, and (3) random noise. The SN76477 has been designed to produce these functions or a combination thereof so that user-defined sounds can be easily constructed. The output can be a continuous wave, or one-shot timing can be selected. Output wave shapes can be tailored with attack times, decay times, amplitude control, and various envelope selections. A basic block diagram is illustrated in Figure 1 below.

- Denotes programming via capacitor
- Denotes programming via resistor
- △ Denotes programming via logic level
- ◇ Denotes programming via analog voltage

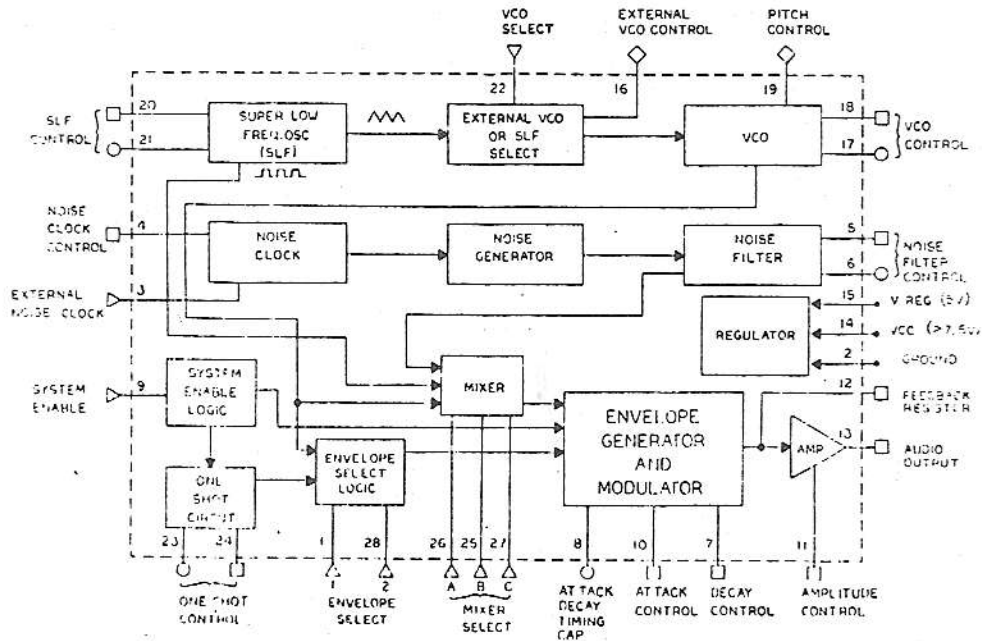


FIGURE 1: SN76477 BLOCK DIAGRAM

The three sound functions, discussed above, are found in the VCO, SLF, and NOISE generator sections. A single frequency can be obtained from the voltage controlled oscillator, VCO, section. The SLF, super low frequency, oscillator can sweep the VCO frequency and is used for other gating purposes. The VCO can also be varied externally. Random frequencies are created in the NOISE generator section. Capability is also provided to filter out various portions of the higher frequencies to obtain low frequency type noise.

The sound functions, thus being generated, are sent to the mixer. External logic level inputs will allow the mixer to select any one sound function or any combination of the SLF, VCO, and NOISE generators. Also, logic inputs are provided to choose between four different envelope types in the envelope select section. Once the envelope is selected and the sound function is chosen in the mixer, the waveshape can be further formed in the 'envelope generator and modulator' section. External components can alter the attack and decay times of the sound signal. The sound waveform is then sent

to an output amplifier section which has an external amplitude control. The output amplifier is designed to interface with external sound modulators or additional audio amplifier stages.

Sound is initiated with a logic level input to the system enable section. The sound waveform can be a continuous type or can be in the form of a one-shot pulse. External components determine the timing for the one-shot function. An internal voltage regulator is provided to increase the operating range of the power supply input.



FIGURE 1: SH6477 BLOCK DIAGRAM

The three sound functions, discussed above, are found in the VCO, SLP, and NOISE generator sections. A single frequency can be obtained from the voltage controlled oscillator, VCO, section. The SLP, supply low frequency oscillator can sweep the VCO frequency and is used for other gating purposes. The VCO can also be varied externally. Random frequencies are created in the NOISE generator section. Capability is also provided to filter out various portions of the higher frequencies to produce low frequency type noise.

The sound functions, thus being generated, are sent to the mixer. External logic level inputs will allow the mixer to select any one sound function or any combination of the SLP, VCO, and NOISE generators. Also, logic inputs are provided to choose between four different envelope types in the envelope select section. Once the envelope is selected and the sound function is chosen in the mixer, the waveform can be further formed in the voltage generator and modulator section. External components can alter the attack and decay times of the sound signal. The sound waveform is then sent

LOGICAL CHIP DESCRIPTION

The SN76477 sound chip is half analog (bipolar) and half digital (I^2L). The analog section consists of the SLF and VCO oscillators, noise filter, attack/decay section, and the operational amplifier. The digital section contains the noise oscillator, noise generator, envelope select, and the mixer.

The SLF is an I/2I oscillator. Its operation is based around a comparator with current sources charging and discharging an external capacitor. A logic diagram of this section is shown in Figure 2a below. One input to the comparator has a voltage reference of 2.5 volts. The external resistor,

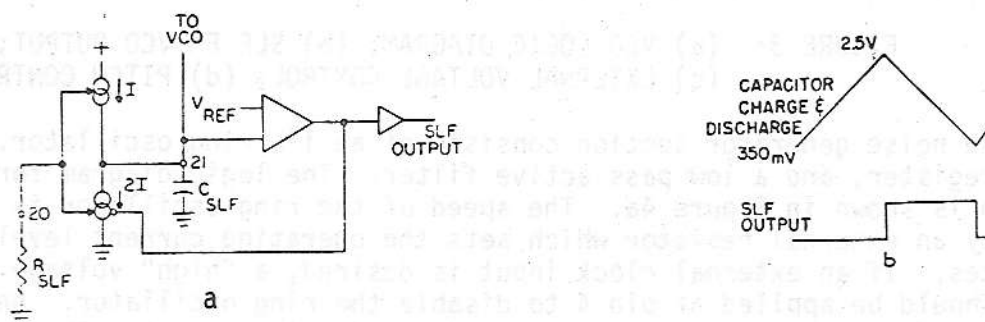


FIGURE 2: (a) SLF LOGIC DIAGRAM; (b) INTERNAL WAVEFORMS

R_{SLF} , determines the value of the current produced in the 'I' current source which charges the external capacitor C_{SLF} . When the capacitor voltage reaches 2.5 volts, the comparator switches, and causes the $2I$ current source to discharge the capacitor. Hysteresis is added to the comparator, which allows the discharge ramp to reach 350 mV before switching off, to allow the 'I' current source to again charge the capacitor. The SLF waveforms are shown in Figure 2b. The resulting waveform on the capacitor is an equal-sided triangle. The comparator output is a square wave with equal ON and OFF times, and is an input to the mixer.

The VCO is the same I/2I oscillator as the SLF, but with some added features. The one comparator input is changed from a reference voltage, as in the SLF, and now has two different possible voltage inputs, as illustrated in Figure 3a. A logic level input on the VCO select pin enables either comparator #2 or comparator #3. When the SLF is selected, the triangular waveform of the SLF capacitor is applied to comparator #2 operating as the VCO. The triangular signal causes the VCO to sweep upward and downward in frequency, and is shown in Figure 3b. However, if external VCO control is selected at pin 22, then comparator #3 is activated. The input to this comparator is an externally applied voltage. The VCO frequency will follow the voltage variations applied to this pin, which can be obtained from either a customer-controlled potentiometer, digital inputs, or any analog waveform. Figure 3c indicates how the VCO varies with a DC voltage level change on the external input. Comparator #1 of the logic diagram of Figure 3a is used as a pitch control. The pitch effects the duty cycle only and has no control over the VCO's frequency rate. A lower voltage on the pitch input results in a smaller duty cycle at the AND gate output, and is illustrated in Figure 3d.

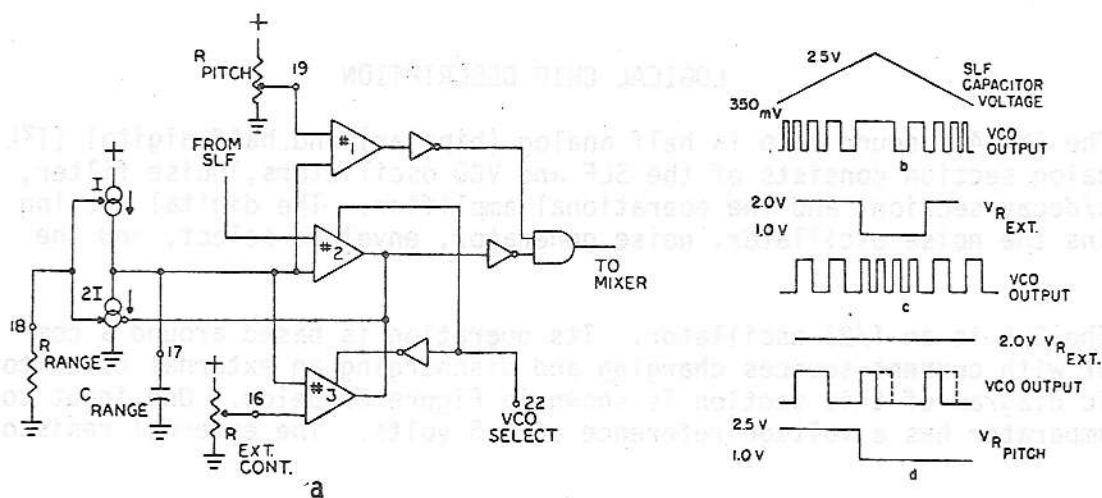


FIGURE 3: (a) VCO LOGIC DIAGRAM; (b) SLF FM VCO OUTPUT;
(c) EXTERNAL VOLTAGE CONTROL; (d) PITCH CONTROL

The noise generator section consists of an I²L ring oscillator, I²L shift register, and a low pass active filter. The logic diagram for this section is shown in Figure 4a. The speed of the ring oscillator is determined by an external resistor which sets the operating current level for the I²L gates. If an external clock input is desired, a "high" voltage level (V_{cc}) should be applied at pin 4 to disable the ring oscillator. An external clock frequency can now be connected to the pin 3 input. Thus either internal or external input frequencies can clock the I²L shift register that produces the pseudo-random noise. The reference for the I/2I current sources is set by the external resistor R_{NF}. When the output of the shift register is low, the 2I current source is turned OFF, and the capacitor is charged by the 'I' current source. Random frequency pulses are obtained from the I²L shift register, and as the output goes to a high level, the 2I current source is enabled. The capacitor is then discharged causing a high to low ramp of voltage. A comparator samples the voltage on the capacitor and compares it to a fixed 2.5 volt reference. Hysteresis in the comparator allows the output to go high when the capacitor voltage is above 2.5 volts, and causes it to go low when the voltage is below 450 mV. An illustration of these waveforms is given in Figure 4b.

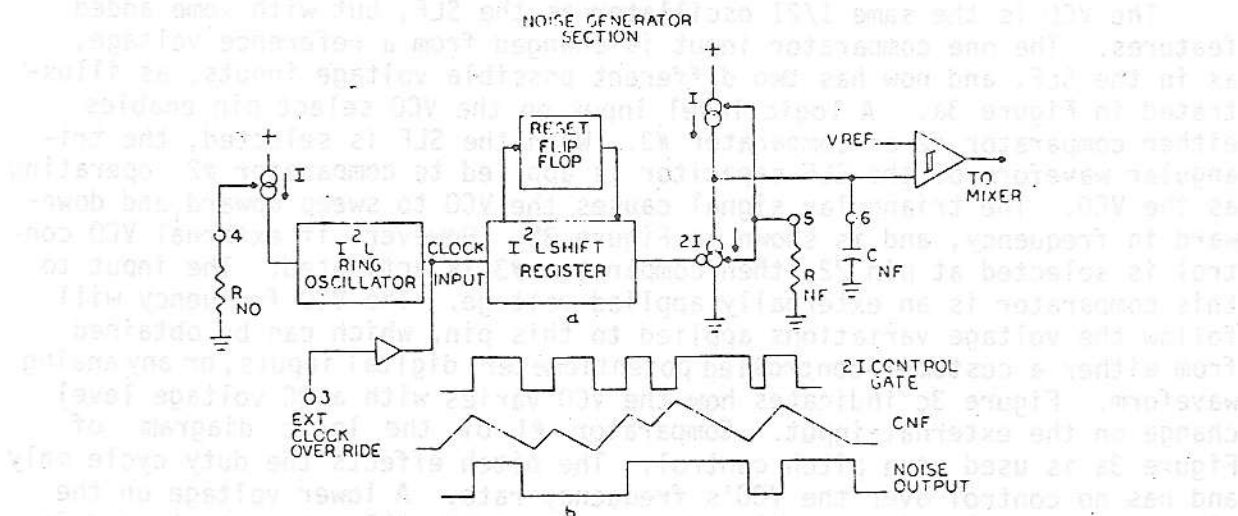


FIGURE 4: (a) NOISE GENERATOR LOGIC DIAGRAM; (b) INTERNAL WAVEFORMS

The mixer is a typical NAND gate multiplexer using I²L logic gates. It operates as a selectable 3-to-1 multiplexer, as shown in Figure 5 below. Depending on the selection at the mixer inputs, the multiplexer output can contain either VCO, SLF, or NOISE signals or any combination of the three. The mixer output is a logical AND function and does not sum the input signals.

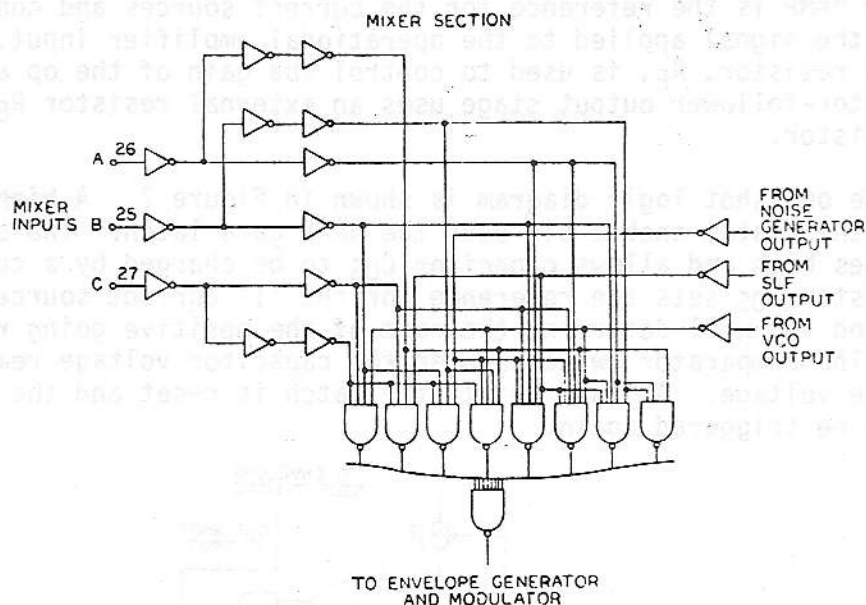


FIGURE 5: MIXER SELECT LOGIC DIAGRAM

The next illustration, Figure 6, covers the envelope select logic section, the envelope generator and modulator, and the operational amplifier. The envelope waveshape is determined by logic level inputs to the envelope select pins 1 and 28. The resistor R_A sets the reference for a current source

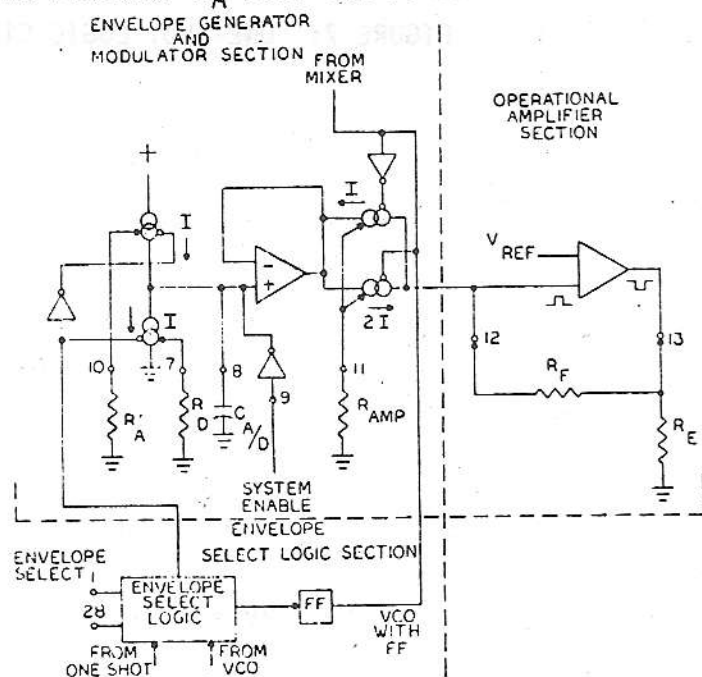


FIGURE 6: ENVELOPE SELECT LOGIC, ENVELOPE GENERATOR AND MODULATOR, AND OPERATIONAL AMPLIFIER LOGIC DIAGRAM

that charges the attack/decay capacitor. When the 'envelope select' output switches at the end of the sound signal period, it enables the current source referenced by the resistor R_D . This current source will ramp the sound output down and is the decay timing function. When the system enable input goes high, the capacitor $C_{A/D}$ is held low causing the output to be disabled. The system is enabled with a low voltage at the pin 9 input and allows the envelope generator to modulate the mixer output using the $I/2I$ current sources. Resistor R_{AMP} is the reference for the current sources and controls the amplitude of the signal applied to the operational amplifier input. An external feedback resistor, R_F , is used to control the gain of the op amp section. The emitter-follower output stage uses an external resistor R_E for the emitter load resistor.

The one-shot logic diagram is shown in Figure 7. A high to low transition of the system enable pin sets the NAND gate latch. The output of the latch goes high and allows capacitor C_{OS} to be charged by a current source. The resistor R_{OS} sets the reference for the 'I' current source. Both values of R_{OS} and C_{OS} will determine the rate of the positive going ramp on the capacitor. The comparator switches when the capacitor voltage reaches the 2.5 volt reference voltage. At this point, the latch is reset and the one-shot function may be triggered again.

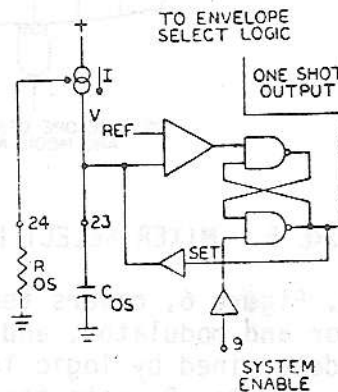


FIGURE 7: ONE-SHOT LOGIC CIRCUIT

SYSTEM DESIGN TECHNIQUES

SYSTEM ENABLE

The system enable, pin 9, controls whether the sound output of the IC is ON or OFF. This pin is also used to set the one-shot latch in the device. If the envelope select logic pins (1 and 28) are chosen for continuous sound operation, then the system enable pin will determine if the generated sound is enabled to the output section of the chip. If the system enable pin is taken to a logical "1" state (2.5 to 15 volts), then the sound output is disabled. When pin 9 is taken to a logical "0", however, the generated sound is enabled to the final output stage and a continuous sound will be heard as long as the pin is held low (0 to .8 volts). These logic states are shown in Table 1. A mechanical switch or a logic control line can be

Pin 9	OUTPUT
0	ENABLED
1	INHIBITED

TABLE 1: SYSTEM ENABLE LOGIC

used to switch between these two modes. The pin 9 input has an internal pull down resistor (15K) and will hold the input low producing a continuous sound at the output. The internal input circuitry is shown in Figure 8. The pin must be driven high to disable the sound. A typical logic control method is to connect pin 9 directly to the output of a MOS, CMOS, or bipolar microprocessor chip.

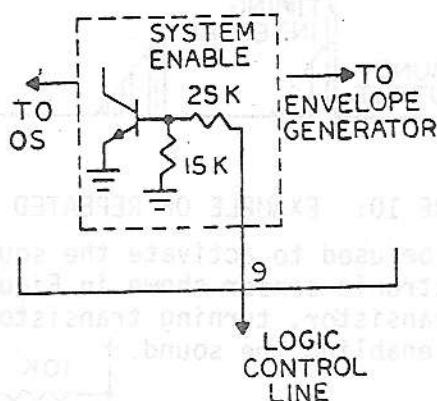


FIGURE 8: SYSTEM ENABLE INTERNAL INPUT CIRCUITRY

When the envelope select logic pins (1 and 28) are chosen for one-shot operation, the system enable pin serves an additional function. On the high to low transition of pin 9, the one-shot latch is set and the one-shot timing function begins. The sound output of the device will continue until the one-shot time has ended (plus any decay time) or until the system enable pin is taken to a logical "1" state, whichever occurs first. Therefore if the entire

one-shot time is required, plus any decay time, then the system enable must be held low for the entire duration, as shown in figure 9. An internal latch is reset when the one-shot timing function ends, to allow the one-shot to be

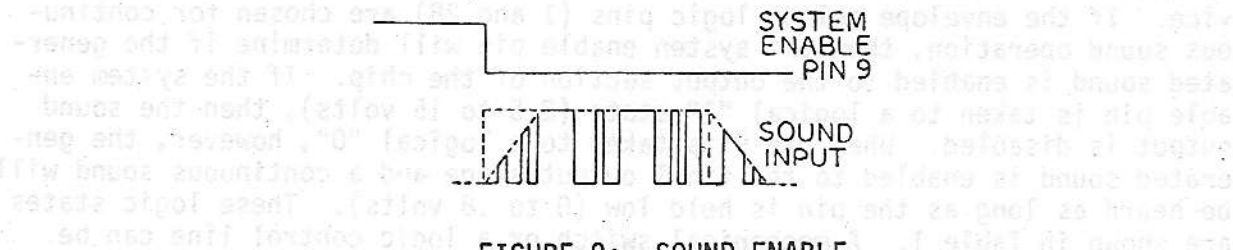


FIGURE 9: SOUND ENABLE

fired again on the next high to low transition of the system enable. If it is desired to interrupt the one-shot time and have the sound disabled, then pin 9 should be taken high at that instant. However in this case, if the one-shot is to be fired again, then the previous one-shot timing must have ended to allow the one-shot latch to be reset. When repeated one-shot functions are needed, a pulse should be used on pin 9 to start the one-shot timing function again on the high to low transition. This pulse should be at least 50 microseconds in length. An example is shown in figure 10. It is important that the high to low transition have a fall time of less than 100 microseconds to insure the one-shot latch has been set.

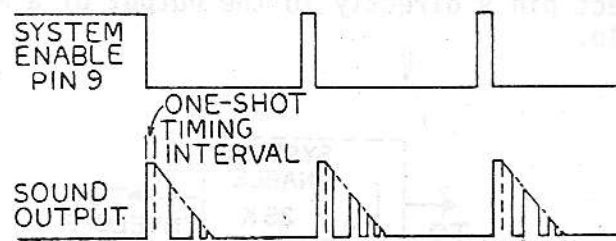


FIGURE 10: EXAMPLE OF REPEATED ONE-SHOT FIRING

Many methods may be used to activate the sound enable input. One such method is the optoelectronic sensor shown in Figure 11. The light source activates the photo-transistor, turning transistor 2N2222 ON, lowering the voltage at pin 9, and enabling the sound.

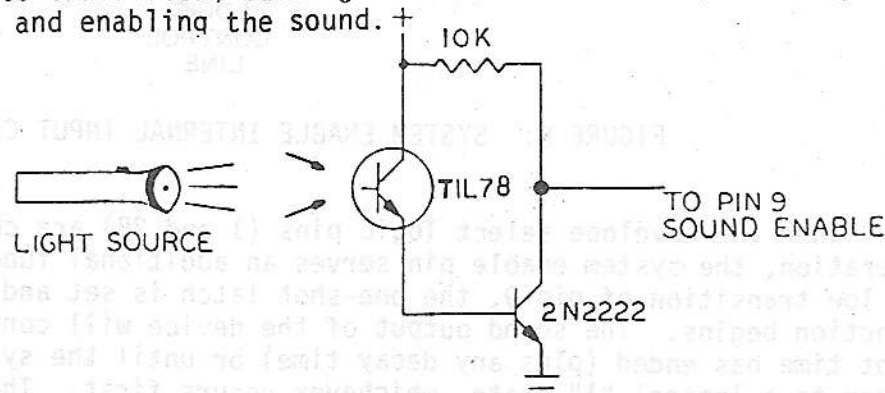


FIGURE 11: OPTOELECTRONIC SOUND ENABLE

MIXER SELECT

The mixer select inputs determine which of the generated sound functions that will be enabled to the envelope generator and modulator section. The mixer can be programmed to send either VCO, SLF, or noise individually; or the mixer can logically AND one or more of these generated sound functions. Refer to the mixer select logic, Table 2.

MIXER SELECT			MIXER OUTPUT
C (PIN 27)	B (PIN 25)	A (PIN 26)	
0	0	0	VCO
0	0	1	SLF
0	1	0	NOISE
0	1	1	VCO/NOISE
1	0	0	SLF/NOISE
1	0	1	SLF/VCO/NOISE
1	1	0	SLF/VCO
1	1	1	INHIBIT

TABLE 2: MIXER SELECT LOGIC

It must be emphasized that the AND function is a logical AND operation and not simultaneous sounds, which will be discussed later. Figure 12 represents an example where the SLF/Noise function is logically ANDed together. (This would sound similar to a steam engine locomotive or a prop-plane, with the SLF determining the repetition rate.)

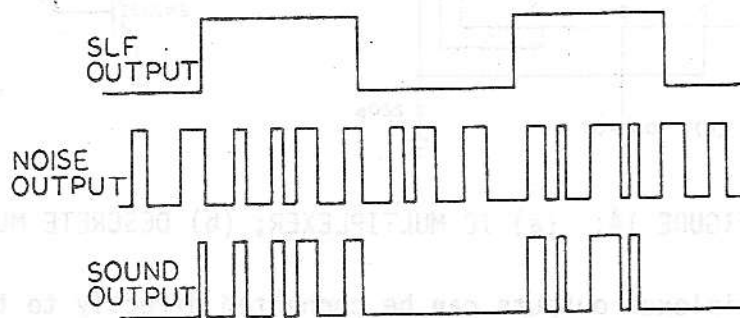


FIGURE 12: MIXER SELECT SLF/NOISE

Each mixer line requires 2.5-15 volts for a logic "1" state and 0-0.8 volts for a logic "0" state. With an open pin the input will be at a low, logic "0" level. The inputs can be driven from CMOS or TTL logic outputs. An illustration of the internal circuitry is shown in Figure 13.

In many cases multiple sounds occurring at the same time are desired. A few such cases could be a steam engine and a whistle, two simultaneous race cars, musical tones along with a snare drum beat, car engine and a

LOGIC CONTROL
LINE OR LINES

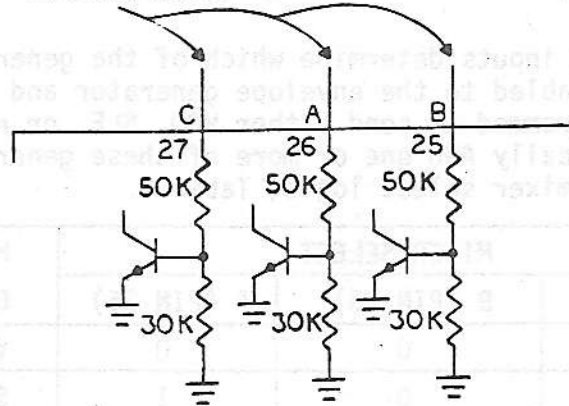


FIGURE 13: MIXER SELECT INTERNAL INPUT CIRCUITRY

police siren, simultaneous car engine and horn, and etc. To obtain two sounds occurring simultaneously, an external multiplexer is required. The multiplexer is an oscillator or frequency generator that can switch the mixer select lines at a rapid rate so that the two different sound functions appear to occur at the same time. Two examples of simple external multiplexers are shown in Figures 14a and 14b.

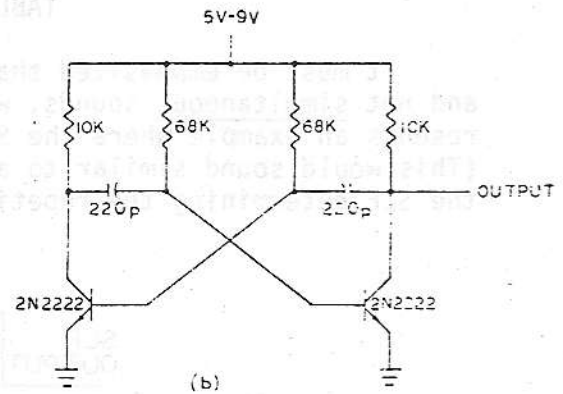
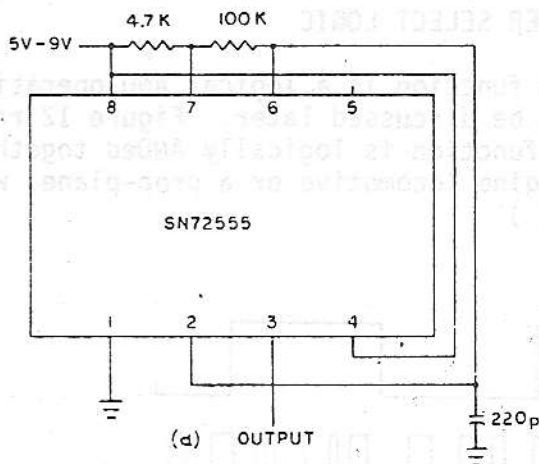
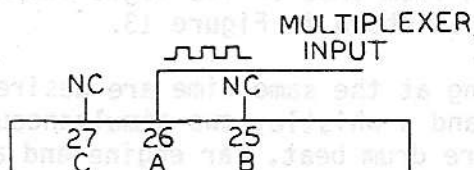


FIGURE 14: (a) IC MULTIPLEXER; (b) DISCRETE MULTIPLEXER

The multiplexer outputs can be connected directly to the inputs of the mixer select line or lines that have to be toggled. A multiplexer with a 50% duty cycle should be used to obtain equal amplitudes for both sound functions. The frequency of the multiplexer should be above the human hearing range of 20K Hz and not greater than 100K Hz. An example of multiplexing is shown in Figure 15.



MIXER SELECT			MIXER OUTPUT
C	B	A	
0	0	0	VCO
0	0	1	SLF

FIGURE 15: EXAMPLE OF SLF AND VCO MULTIPLEXING

The SLF and VCO tone generators, having their separate sounds multiplexed at such a fast toggle rate, will result in the effect of simultaneous sounds. This could be used for musical notes, bells, pin ball machines, dual race cars, and etc.

ONE SHOT

The one-shot timing function is typically determined by an external resistor-capacitor combination. Figure 16 shows how the external RC is connected to the internal circuitry. The equivalent of the internal circuitry on the

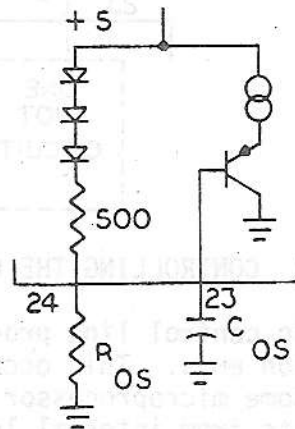


FIGURE 16: ONE-SHOT INTERNAL CIRCUITRY

resistor input pin (pin 24) contains three diodes and a small 500 Ω limit resistor all connected in series to the +5 volt regulated line. For the internal currents to stay within the specification limits (600 μ A) the external resistor connected to this pin should never be smaller than:

$$R_{os} \approx \frac{5V - 3V_D + (500\Omega \times 600\mu A)}{600\mu A} = 4.7K \text{ ohms}$$

As described in the system enable section, the one-shot internal circuitry begins operation when a high to low transition occurs on the pin 9 input. The external capacitor begins to charge at a rate determined by the internal circuitry and the external one-shot resistor, until it reaches a trip point and the one-shot timing function ends, resetting the internal latch. Any following one-shot operations require another high to low transition on the system enable input. If a one-shot timing function is ended early (by taking the system enable pin high), that one-shot timing should be allowed to end, to reset the internal latch, before another one-shot operation is performed. The equation that relates the one-shot time to the external resistor and capacitor values is as follows:

$$TONE-SHOT \approx .8 R_{os} C_{os} \text{ where } T = \text{seconds}$$

$R_{os} = \text{ohms}$
 $C_{os} = \text{farads}$

For some applications, it may be desired to operate the one-shot function at a particular time controlled by a microprocessor or other control

logic. This can easily be accomplished as depicted in Figure 17. One-shot operation begins, as usual, with the high to low transition on the system enable pin (pin 9), also, the microprocessor output to pin 23 should be held at

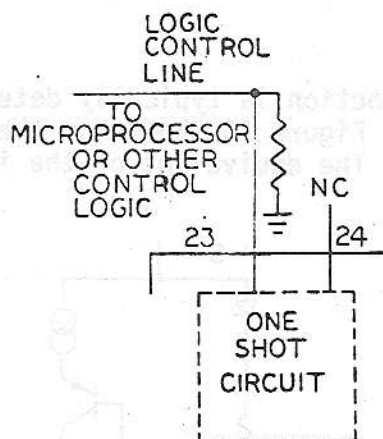


FIGURE 17: CONTROLLING THE ONE SHOT LOGICALLY

a low level. When the logic control line produces a low to high level change on pin 23, one-shot operation ends. This occurs at a trip point level of approximately 2.5 volts. Some microprocessor IC's could have a low level output greater than 2.5 volts from internal leakage currents. A load resistor to ground on the logic control line should solve this problem.

It must be pointed out that the external RC or external microprocessor produces a specific time period. Any attack time (from the attack/decay section) will take up part of this one-shot time. Any decay time is not part of the one-shot time, but is time added on at the end of the one-shot period.

REGULATOR

The internal regulator is a series-pass transistor type with a zener diode reference, as shown in Figure 18. This regulator can be used if the system has a 7.5V to 12.0V power source. Ideally suited for 9V battery operation,

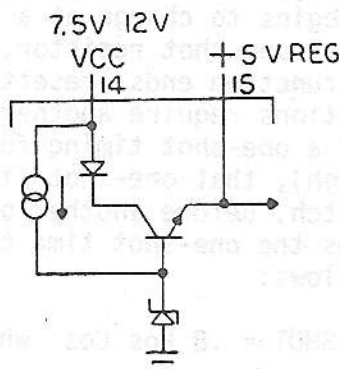


FIGURE 18: INTERNAL VOLTAGE REGULATOR SECTION

ation, it will maintain consistent sound over most of the battery life. The regulator has reverse bias protection to prevent damage to the IC if the battery leads are inadvertently reversed.

The regulator produces +5 volts used to power all the internal circuitry in the chip. The regulated 5 volts is also available at pin 15. Thus, 5 volts from pin 15 can be used to power a small amount of external circuitry if needed. Power can be provided to operate one low power schottky TTL device, if the sound chip's programming resistors are all not at their low end limits. The regulator will source 10mA at 7.5 volts Vcc and remain regulated. The regulator does not have overload protection, and excessive output current should be avoided so that the transistor is not seriously overloaded.

If the system already contains a regulated +5V power supply, it can be used as an input to pin 15. In this case, the regulator is not needed and pin 14 will have no connection to the system.

VOLTAGE CONTROLLED OSCILLATOR

The voltage controlled oscillator (VCO) section will produce a changing frequency as the voltage level input is varied. Figure 19 indicates the equivalent input circuitry of this section.

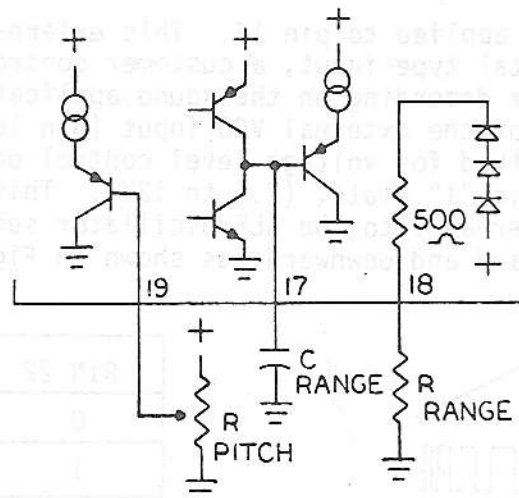


FIGURE 19: VCO INTERNAL CIRCUITRY

The external resistor on pin 18 (R_{RANGE}) sets up a reference current in the VCO which charges and discharges an external capacitor connected to pin 17. Both the resistor and capacitor values will determine the speed at which the capacitor charges and thus control the frequency of the oscillator. This relation is described by the approximate equation as follows:

$$\text{Min VCO Freq} \approx \frac{0.64}{R_{\text{RANGE}} \times C_{\text{RANGE}}} \quad \text{where} \quad \begin{array}{l} \text{Freq} = \text{hertz} \\ R = \text{ohms} \\ C = \text{farads} \end{array}$$

The RC values set up the minimum VCO frequency, occurring when the external VCO control voltage or the SLF input voltage are at high levels, (approximately 2.5 volts or above). As the voltage level input to the VCO is decreased (to 0 volts), the oscillator frequency will increase with an approximate 10:1 ratio determined internally. For example, if the minimum frequency is set at 1K Hz, then the VCO range will be from 1K Hz to 10K Hz. If the minimum frequency was 5K Hz, the range would be 5K Hz to 50K Hz, and so on. To insure that the internal circuitry is limited to safe operating

currents, the VCO range resistor should have a value no lower than 4.7K ohms. As mentioned earlier, the changing voltage level is the controlling factor for the VCO. Two different methods are used as voltage level inputs and are selected by the "VCO select" pin 22, see Figure 20. With the VCO select (pin 22) at a logic "0" state or open, the voltage input to the VCO is controlled

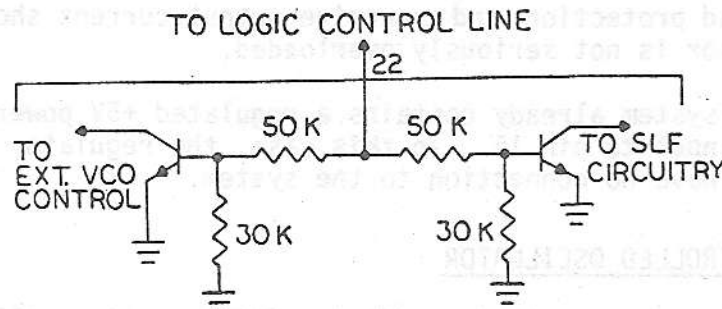
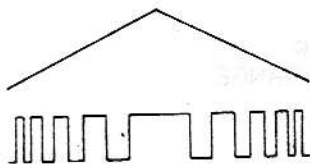


FIGURE 20: VCO SELECT INTERNAL CIRCUITRY

by an external source applied to pin 16. This external source can be any DC voltage level, a digital type input, a customer controlled potentiometer, or any analog waveform depending on the sound application of the VCO. A more detailed explanation of the external VCO input (pin 16) will be discussed later. The second method for voltage level control occurs when the VCO select pin is taken to a logic "1" state, (2.5 to 12V). This connects the VCO voltage control input internally to the SLF oscillator section and is used to sweep the VCO frequency upward and downward, as shown in Figure 21. The VCO select



PIN 22	CONTROL MODE
0	EXTERNAL (PIN 16)
1	INTERNAL (SLF)

FIGURE 21: VCO FM OUTPUT

pin can be controlled by a mechanical switch or logic control line, and the input is TTL and CMOS compatible. The VCO is free running, not locked to the system enable or one-shot functions, and is able to operate from 1 Hz to 20 KHz.

The output is a square wave pulse with a 50% duty cycle. This output pulse section is connected internally to the pitch control section, and from that section to the mixer control. The function of the pitch control is to change the width of the VCO pulse, without affecting the VCO frequency rate. Varying the pitch control input causes the 50% duty cycle to be reduced to approximately 18%. The equivalent input circuitry for pin 19 pitch control is shown in Figure 22. A voltage anywhere between 2.5V and 5.0V will leave the VCO duty cycle unchanged at 50%. Lowering the voltage at pin 19 (to 0 volts) will reduce the duty cycle to about 18% minimum. An equation that relates VCO duty cycle to the voltage input at pin 19 is:

$$\text{VCO Duty Cycle \%} = 50 \times \frac{\text{voltage at pin 16}}{\text{voltage at pin 19}}$$

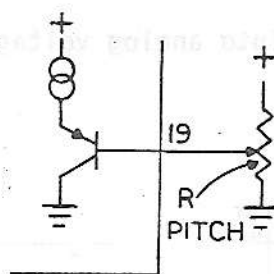


FIGURE 22: PITCH CONTROL INPUT PIN 19

The external VCO control, pin 16, is used to alter the frequency of the VCO to produce the frequency changes needed in the user-defined sound. This voltage can be a DC level, potentiometer input, digital, or analog type input.

A DC voltage level applied to pin 16 will generate a constant frequency in the VCO and thus a constant tone at the output. Changing the voltage level will change the frequency of the tone according to the equation described previously. The DC voltage value should range from 0 to 2.5 volts. If the external voltage goes above 2.5 volts, the output of the VCO section saturates at a high logic level and in turn saturates the output amplifier stage. This may be used as an alternative method to disable the sound output without changing the system enable input. When a potentiometer is used for the control voltage, a limit resistor should be used to keep the maximum voltage range at 2.5 volts. An example of this and the illustration of the equivalent input circuitry is shown in Figure 23 below.

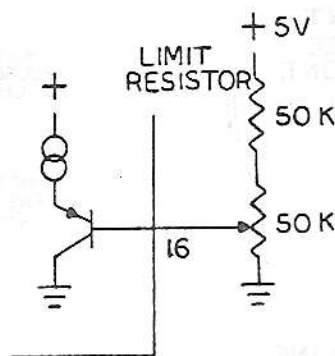


FIGURE 23: INPUT CIRCUITRY TO EXTERNAL VCO CONTROL PIN 16

Some applications may require a few or many different, separate tones. A musical toy organ would be one example. The most simple method to simulate this, using customer control mechanical switches, is shown in Figure 24a. When logic lines from the system are used to control the various tone functions, the typical method used is shown in Figure 24b. Here, the logic line switches from the normally low voltage level to a high voltage at the inverter input. Then the open collector inverter gate pulls the resistor value to approximately ground and changes the voltage level at the pin 16 input. If the inverter gates have totem pole outputs, then a series diode with the cathode at the inverter output should be used, as illustrated in Figure 24c.

Another method to change tones uses a single logic line. In this case, the logic line comes from a controller whose output contains pulse width or frequency variations. A circuit is added to the logic line to transform

the digital data variations into analog voltage variations. This circuit is described in Figure 25.

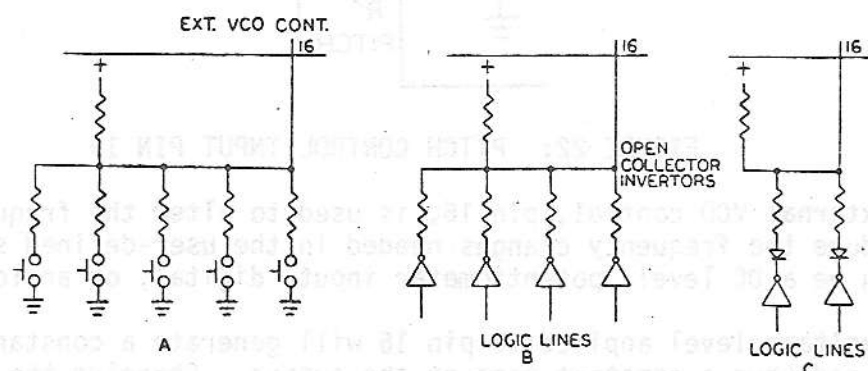


FIGURE 24: EXTERNAL VCO (a) MECHANICAL SWITCHING; (b) OPEN COLLECTOR INVERTOR SWITCHING; (c) TOTEM POLE INVERTOR SWITCHING

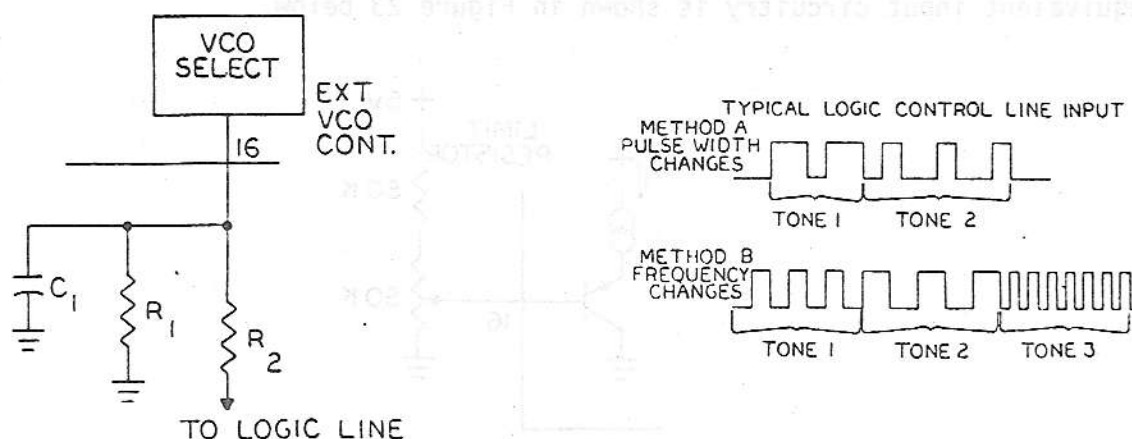


FIGURE 25: PULSE WIDTH OR FREQUENCY VARIATIONS TRANSFORMED TO DC

The R_1 and R_2 resistor divider combination of Figure 25 is designed to keep the input to pin 16 below 2.5 volts. A low pass filter is formed by R_2 and C_1 which must be designed to keep the pin 16 input at an analog type voltage level. This system is ideally suited for music, detecting electrical motor speed variations, remote control race cars, and etc.

Many other voltage level variations can be applied to the pin 16 external VCO control input to obtain a wide variety of VCO changes and the resulting sound outputs. These signals can include sawtooths, sine waves, triangles, pulses, voice waveforms, and any other analog type waveforms. All of which result in a frequency modulated signal at the output.

SLF (SUPER LOW FREQUENCY OSCILLATOR)

The SLF is built like the VCO but it is able to work at lower frequencies. The normal operating range is from 0.1 Hz to 30 Hz, but will also work up to 20K Hz. Typically, the SLF is used for gating purposes in the mixer section or for applying a triangular waveform to the VCO. Figure 26 illustrates the equivalent of the internal input circuitry.

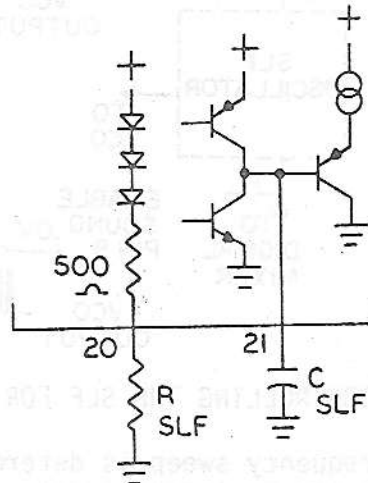


FIGURE 26: SLF INTERNAL CIRCUITRY

To limit the internal circuitry to safe operating currents, R_{SLF} should have a minimum value of 4.7K ohms. The charge and discharge of the capacitor C_{SLF} creates a triangular waveform as in the VCO section. The frequency of this waveform is determined by the following equation:

$$SLF \text{ Freq} \approx \frac{0.64}{R_{SLF} C_{SLF}} \quad \text{Where} \quad \begin{array}{l} \text{Freq} = \text{hertz} \\ R = \text{ohms} \\ C = \text{farads} \end{array}$$

If an exponential type waveform is desired, a resistor may be connected across capacitor C_{SLF} . The output of the SLF section applies a 50% duty cycle square wave to the input of the mixer section. When used in a system, the SLF operating frequency may be changed by series resistors connected between pin 20 and the output of open-collector inverter (or buffer) gates, as described in the VCO section.

The SLF is a free-running oscillator with no control from the one-shot or system enable sections. At times, it is required to control the starting point of the SLF when it is used to vary the voltage in the VCO section. This has been found useful in applications such as whistles, bomb drops, cat meows, missiles, sirens, jet take-offs, etc. When a frequency down sweep is required (for a missile, bomb drop, ricochets, etc.), the circuitry configuration described in Figure 27 shows one such method. The capacitor C_{SLF} is held at a low level with a logic control line. When the sound is required, the logic control line is released at the same time the system enable pin 9 is taken low. The capacitor now starts to charge. The VCO select pin at a logic "1" state will allow the SLF voltage to control the VCO. As the capacitor charges, the VCO will sweep downward in frequency. When the SLF capacitor reaches the peak of the triangular waveform, the system enable pin should be taken to a logic "0" state to end the downward frequency sweep sound out-

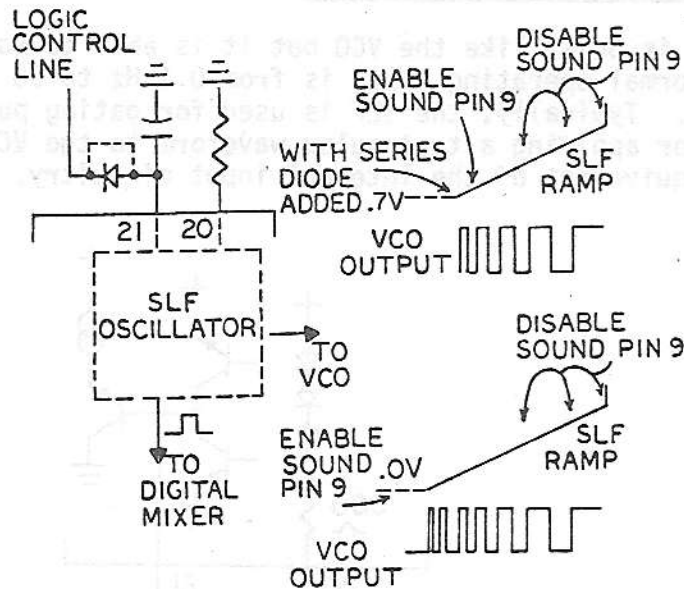


FIGURE 27: CONTROLLING THE SLF FOR FREQUENCY DOWNSWEEP

put. The length of the frequency sweep is determined by the RSLF CSLF timing rate. For longer SLF ramp times, increase the value of RSLF CSLF (CSLF may require $1\mu\text{f}$ to $47\mu\text{f}$ for long durations). Normally the SLF capacitor never discharges below 0.4 volts. Therefore, when the capacitor is released at that low level, the VCO frequency will be extremely high. If this is undesirable, a series diode can be used to bring the release point up, to obtain a much lower starting frequency. Also, if the logic control line is not an open connection when released, a series diode must be used on the control line as shown in Figure 27. The diode is needed for control lines connected to MOS and totem pole TTL logic devices.

An upward frequency sweep can also be generated, refer to Figure 28 below.

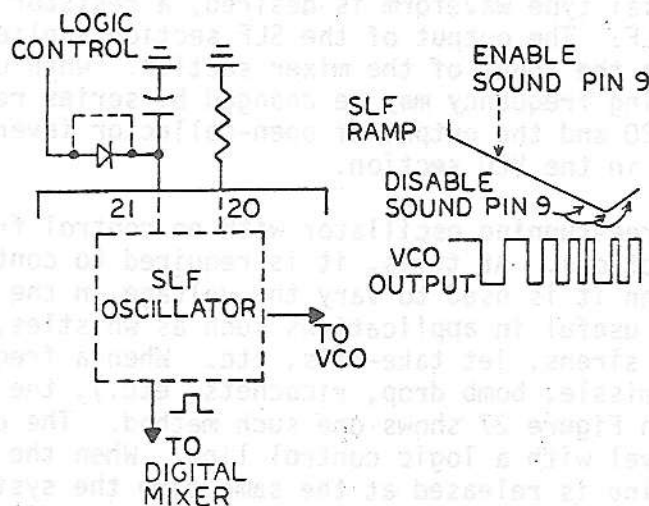


FIGURE 28: CONTROLLING THE SLF FOR UPWARD FREQUENCY SWEEP

The logic control input must initially be held at a high level. When the sound is desired, the system enable pin is taken low and the logic control line is released. This allows the SLF capacitor to discharge with a high to low ramp, and the VCO will sweep upward in frequency. At the end of the frequency sweep the system enable (pin 9) should be taken high to disable the sound output. A series diode is necessary if TTL or MOS logic devices are used. If not included, they would clamp the capacitor at a low level when the gate switched to enable the sound.

If it is desired to use the SLF as a timer, externally, the waveform on the SLF capacitor can be used. A transistor emitter follower, with the base connected to the SLF capacitor, would be used to clock counters, flip flops, etc.

NOISE GENERATOR/FILTER

The 'noise clock' is an internal ring oscillator that supplies clock pulses to the digital 'noise generator' section. The internal input circuitry is shown in Figure 29. An external resistor sets the internal operating currents for the noise clock section. The nominal resistor value for

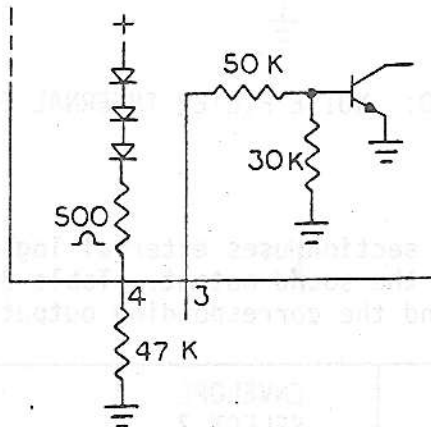


FIGURE 29: NOISE OSCILLATOR/CLOCK-INPUT INTERNAL INPUT CIRCUITRY

pin 4 is 47K ohms. For faster clock rates, a smaller valued resistor may be used. Slower clock rates use a higher valued resistor, but should be limited to a maximum of 100K ohms. At times it may be desired to control the noise generator with an external clock frequency. This may be useful for a slower or more precise clock rate. The external clock input should be applied to pin 3 and then pin 4 should be taken to a 'high' voltage, VCO. The external clock input has a low voltage level between 0 and 0.8 volts. A high logic level is between 2.5 and 12 volts.

The output of the noise generator produces psuedo-random white noise. This output then passes through a filter section. The filter is a variable bandwidth low-pass type. A resistor and capacitor are used to specify the 3db point of the filter's roll-off function and is defined by the following equation:

$$3\text{db Freq} = \frac{1.28}{R \cdot C} \quad \text{Where Freq} = \text{hertz}$$

R = ohms
C = farads

The equivalent input circuitry for pins 5 and 6 of the filter section is shown in Figure 30. For no filter action, a capacitor is not needed and pin 6 can be open; however, pin 5 must have a resistor to ground. If this is done, all the frequency components, both low and high, produced in the noise generator will be sent to the mixer section. When it is desired to filter out the higher frequency components, larger values of R_{NF} and C_{NF} should be used. The minimum value of R_{NF} is 4.7K Ω to limit the noise filter section to safe operating currents.

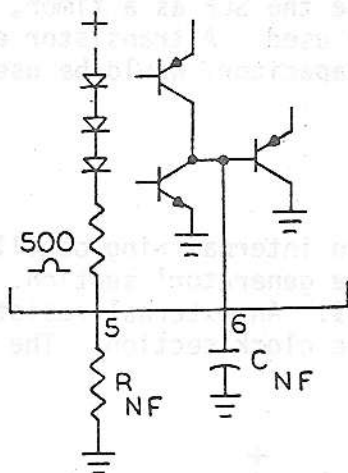


FIGURE 30: NOISE FILTER INTERNAL INPUT CIRCUITRY

ENVELOPE SELECT

The envelope select section uses external logic level inputs to define the type of envelope for the sound output. Table 3 below defines the various logic state inputs and the corresponding outputs. Low voltage level

ENVELOPE SELECT 1	ENVELOPE SELECT 2	OUTPUT
PIN 1	PIN 28	
0	0	VCO
0	1	MIXER ONLY
1	0	ONE-SHOT
1	1	VCO WITH ALTERNATING CYCLES

TABLE 3: ENVELOPE SELECT LOGIC OUTPUT

inputs, for pins 1 and 28, are from 0 to 0.8 volts. A high logic "1" state can be from 2.5 to 15 volts. The equivalent of the input circuitry is shown in Figure 31. Inputs with no connection are at a logic "0" level. The logic control lines may be from mechanical switches, bipolar, or MOS logic devices. When 'mixer only' is selected, the output is not shaped with a modulated envelope, but is the unaltered waveform that has been selected by the mixer inputs. An example of this is described in Figure 32a where noise has been selected as the desired output sound. The noise will be continuous in this mode.

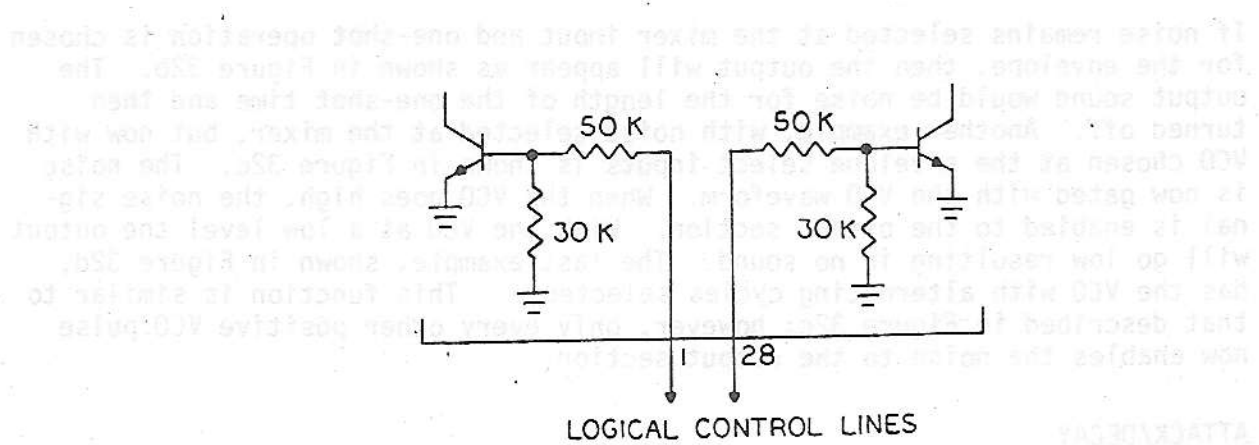


FIGURE 31: ENVELOPE SELECT INTERNAL INPUT CIRCUITRY

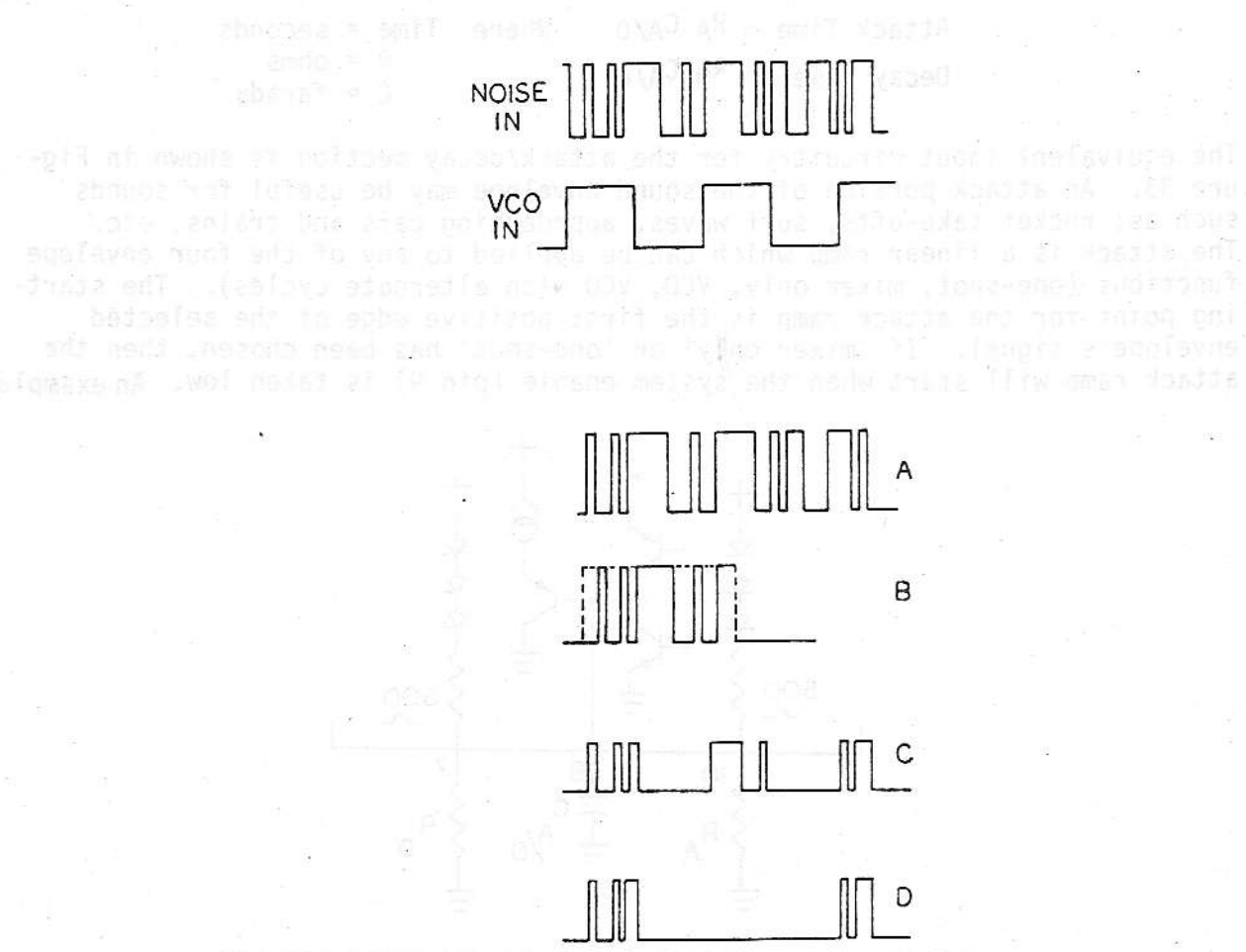


FIGURE 32: EXAMPLE OF THE FOUR SELECTABLE ENVELOPES; (a) MIXER ONLY; (b) ONE-SHOT; (c) VCO; (d) VCO WITH ALTERNATING CYCLES; USING NOISE AS MIXER OUTPUT

If noise remains selected at the mixer input and one-shot operation is chosen for the envelope, then the output will appear as shown in Figure 32b. The output sound would be noise for the length of the one-shot time and then turned off. Another example, with noise selected at the mixer, but now with VCO chosen at the envelope select inputs is shown in Figure 32c. The noise is now gated with the VCO waveform. When the VCO goes high, the noise signal is enabled to the output section. With the VCO at a low level the output will go low resulting in no sound. The last example, shown in Figure 32d, has the VCO with alternating cycles selected. This function is similar to that described in Figure 32c; however, only every other positive VCO pulse now enables the noise to the output section.

ATTACK/DECAY

The resistor R_A sets an internal current which charges capacitor $C_{A/D}$ to produce the attack part of the sound envelope. The capacitor $C_{A/D}$ is also shared by the decay section and the discharge rate is determined by a current set by resistor R_D . The approximate timing is given by the following equations:

$$\begin{aligned} \text{Attack Time} &\approx R_A C_{A/D} & \text{Where Time} &= \text{seconds} \\ \text{Decay Time} &\approx R_D C_{A/D} & R &= \text{ohms} \\ & & C &= \text{farads} \end{aligned}$$

The equivalent input circuitry for the attack/decay section is shown in Figure 33. An attack portion of the sound envelope may be useful for sounds such as; rocket take-offs, surf waves, approaching cars and trains, etc. The attack is a linear ramp which can be applied to any of the four envelope functions (one-shot, mixer only, VCO, VCO with alternate cycles). The starting point for the attack ramp is the first positive edge of the selected envelope's signal. If 'mixer only' or 'one-shot' has been chosen, then the attack ramp will start when the system enable (pin 9) is taken low. An example

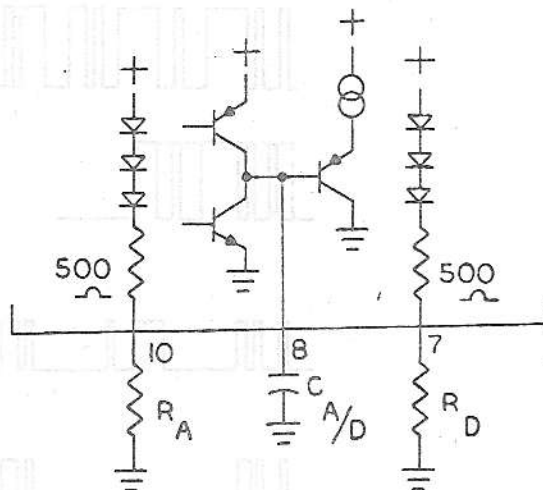


FIGURE 33: INTERNAL INPUT ATTACK/DECAY CIRCUIT

is shown in Figure 34a and 34b. However, if VCO or VCO with alternating cycles is selected, the attack ramps up on each positive edge (or every other positive edge) of the VCO's frequency, as shown in Figure 34c and 34d. In all cases, the attack rate must be chosen correctly. If the attack rate is

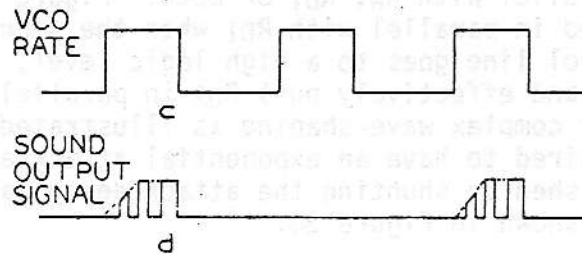


FIGURE 34: EXAMPLES OF ATTACK; (a) NO ATTACK WITH SYSTEM ENABLE; (b) ATTACK ADDED WITH SYSTEM ENABLE; (c) VCO RATE; (d) ATTACK ADDED WITH 'VCO WITH ALTERNATING CYCLES'

too long, the amplitude of the output might never have time to reach an audio level before the envelope has ended. When the attack function is not desired, the resistor R_A is still required.

The decay section ramps the sound amplitude down as the sound ends and has many uses. Some examples are explosions, gun shots, etc. The decay is triggered from a high to low transition on three of the four possible envelopes. These envelopes are the one-shot, VCO, and VCO with alternating cycles.

The 'mixer only' function is not used here and the decay has no effect. An example of an output decay with one-shot selected is depicted in Figure 35a. A small valued attack resistor has been used to obtain an almost instantaneous rise time. Figure 35b and 35c illustrates an output decay when VCO is the desired envelope. Attack/decay examples, where both ramps are operating,

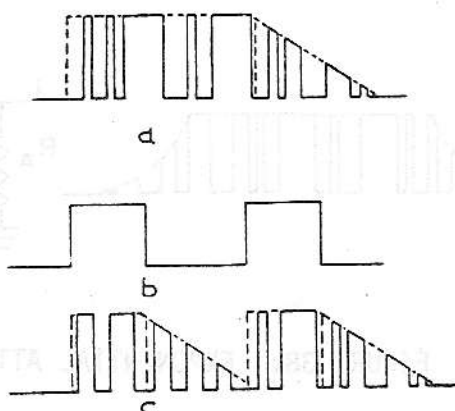


FIGURE 35: EXAMPLES OF DECAY; (a) WITH ONE-SHOT; (b) VCO RATE; (c) DECAY WITH VCO

are shown in Figure 36, below. The attack/decay may be made more complex by external circuitry. At a preset time, a logic control line can switch a

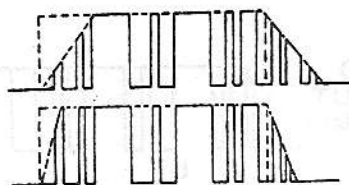
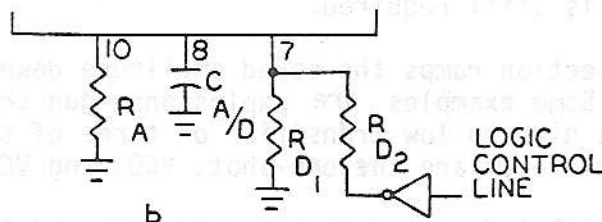


FIGURE 36: EXAMPLES OF ATTACK AND DECAY

resistor in parallel with R_A , R_D , or both. Figure 37b shows a case where R_{D2} is connected in parallel with R_{D1} when the second ramp is desired. When the logic control line goes to a high logic level, the open-collector inverter gate goes low, and effectively puts R_{D2} in parallel with R_{D1} . This technique can be used for complex wave-shaping as illustrated in Figure 37a. At times it might be desired to have an exponential attack and decay waveform. This can be accomplished by shunting the attack/decay capacitor $C_{A/D}$ with a resistor R_{EXP} as shown in Figure 38.



a



b

FIGURE 37: COMPLEX WAVE SHAPING; (a) COMPLEX WAVEFORM; (b) EXTERNAL COMPLEX WAVE SHAPING LOGIC

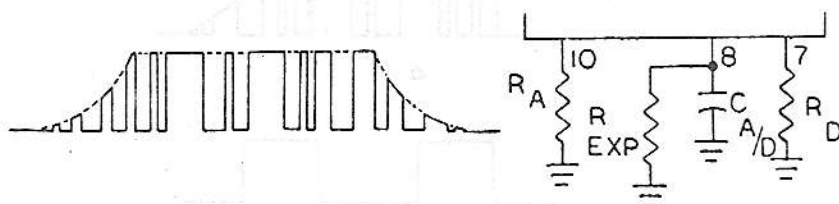


FIGURE 38: EXPONENTIAL ATTACK/DECAY

OUTPUT AMPLIFIER

The output amplifier is a gain section designed to interface with external sound modulators or additional amplifier stages. The output is an operational amplifier operating as a summer and inverter, as illustrated in Figure 39. The output is an emitter follower without a load resistor. Therefore, pin 13 should have a pull-down resistor, R_E , with a value ranging from 2.7K to 10K ohms. Figure 40 shows the equivalent of the input circuitry for the amplifier section.

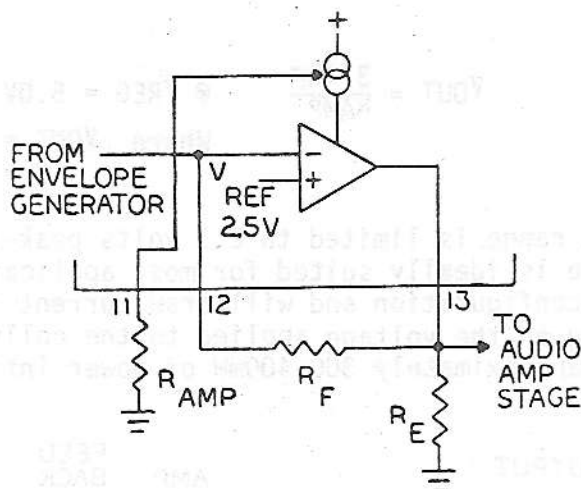


FIGURE 39: OPERATIONAL AMPLIFIER

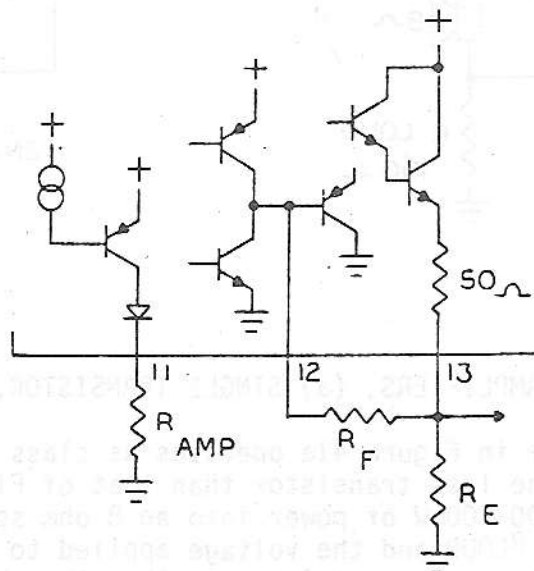


FIGURE 40: OPERATIONAL AMPLIFIER INTERNAL INPUT CIRCUITRY

The resistor value R_{AMP} sets the operating currents for the operational amplifier's internal circuitry and is the main adjustment to control the amplifier's output amplitude. The value of this resistor is normally between

47K and 220K ohms. Any lower resistance will typically begin to saturate the operational amplifier and is especially noticeable on the decay portion of the sound envelope.

The feedback resistor, R_F , is used to compensate for external variations and also any chip-to-chip variations. This is accomplished by connecting the feedback resistor between the last amplifier stage and the input pin 12, as shown in Figure 41a and 41b. In both cases the feedback resistor is connected to the last stage at a point where the signal is in phase with the operational amplifier's output. The peak output voltage is determined by the following equation:

$$V_{OUT} \approx \frac{3.4R_F}{R_{AMP}} \quad @ V_{REG} = 5.0V$$

Where V_{OUT} = volts
 R = ohms

The dynamic output range is limited to 2.5 volts peak-to-peak before clipping occurs. Figure 41b is ideally suited for most applications. The amplifier is in a push-pull configuration and will draw current only when a signal is present. Depending on the voltage applied to the collector of Q_1 , this circuit will provide approximately 300-400mW of power into an 8 ohm speaker.

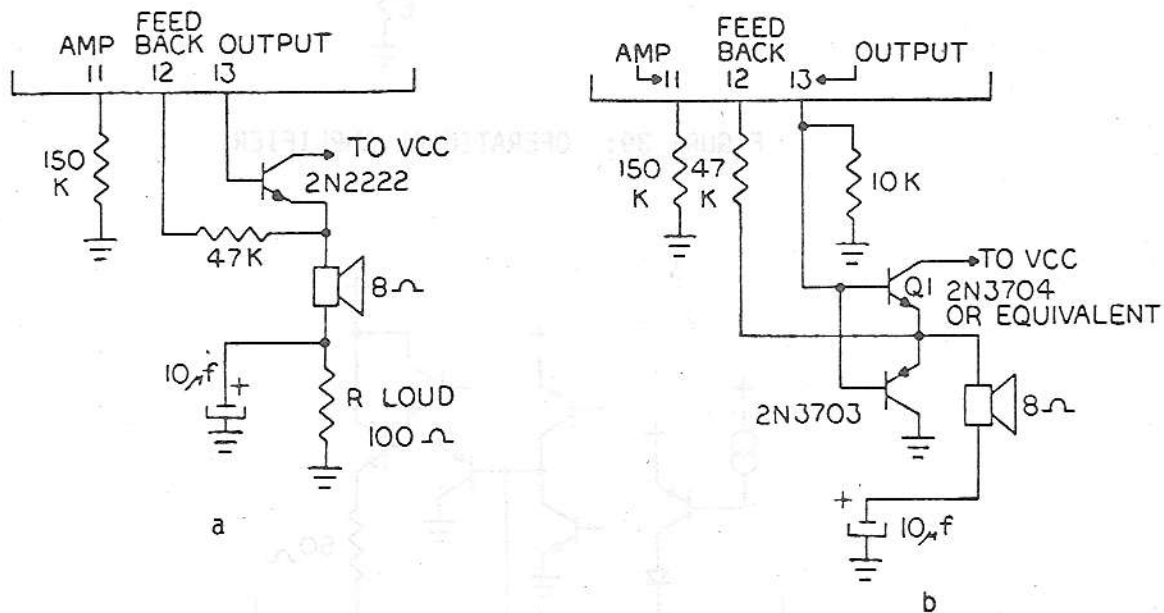


FIGURE 41: AUDIO AMPLIFIERS; (a) SINGLE TRANSISTOR; (b) COMPLEMENTARY SYMMETRY

The output amplifier in Figure 41a operates as class A and draws continuous current, but uses one less transistor than that of Figure 41b. The circuit can deliver about 100-200mW of power into an 8 ohm speaker depending on the resistance value of R_{LOAD} and the voltage applied to the collector of transistor Q_1 . For higher power requirements than the above two circuits, a simple 0.5w-5w audio amplifier could be used instead.

If the amplitude of the sound output is to be varied for particular sounds, the resistance R_{AMP} can be varied by logic control lines. This can be done, as described in previous sections, by using the logic control line to switch a logic gate that will put a resistor in parallel with R_{AMP} .

Special filtering can be added to the output of the amplifier or can be included in the feedback section of the operational amplifier. Since the output of the amplifier always contains square waves, filtering will change the timbre (harmonic content) of the output signal.

Other external sounds may be added to the input of the amplifier at pin 12. This input can be made either directly or through a series resistor. An example of an input configuration to add a person's voice to the system is shown in Figure 42. This could be used to sing along or talk along with the sounds being generated by the chip.

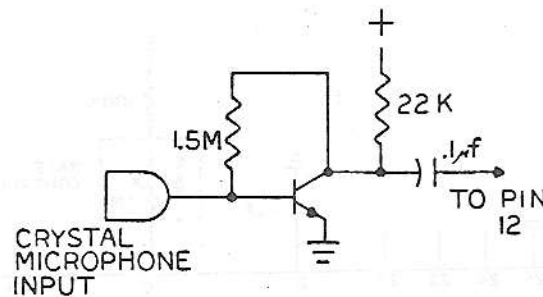


FIGURE 42: ADDING VOICE

STEAM TRAIN/PROP PLANE

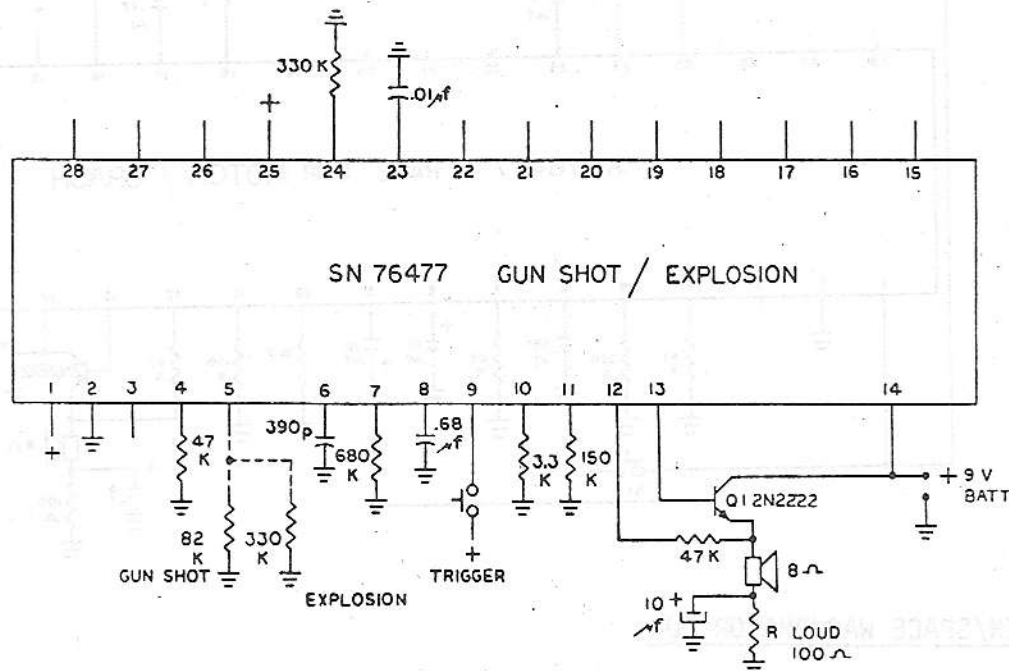
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The VCO generates the race car's motor sound with the REV rate adjusted by the 100K ohm potentiometer. When switch S1 is closed, a momentary pulse is applied to the system enable input and initiates the one-shot. The switch also selects noise as the mixer's output, which generates the crash sound. As the one-shot interval ends, the output amplitude will start to decrease indicating the decay section in operation.

For a more complex system, the mixer can be multiplexed between the SLF and VCO functions. This could be used when two simultaneous race car sounds are needed. The necessary RC components would have to be added to the SLF section.

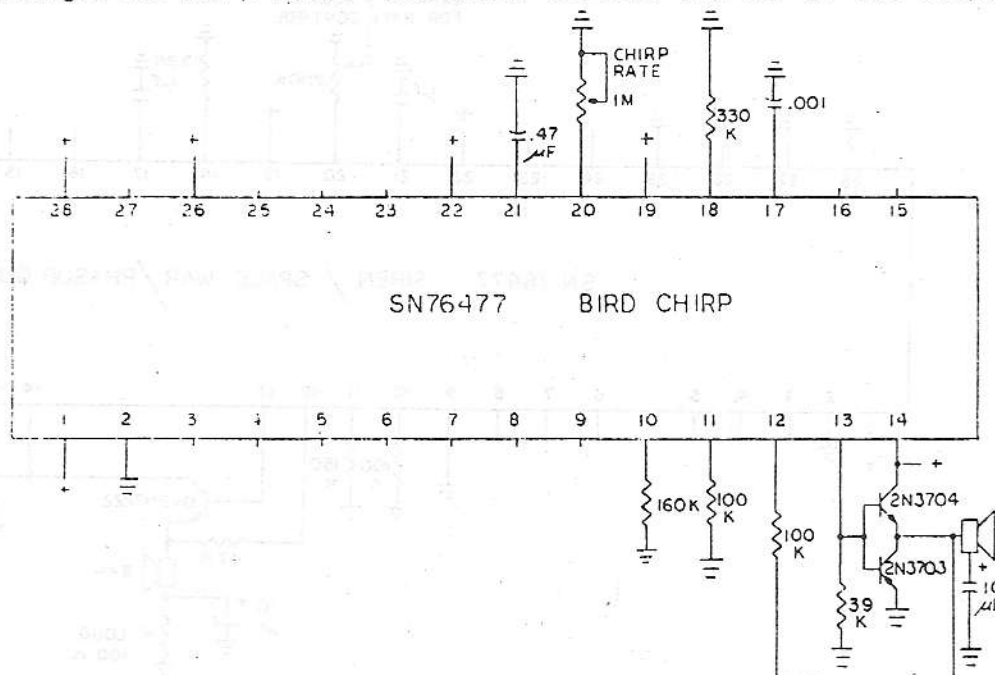
GUN SHOT/EXPLOSION

Both the gun shot and the explosion use the one-shot as the envelope. Noise is selected as the output of the mixer. The one-shot resistor and the decay resistor determine the length of the sound. The noise filter resistor is changed for both sounds. Some high frequencies are needed for the gun shot sound. However, the explosion should contain all low frequencies.



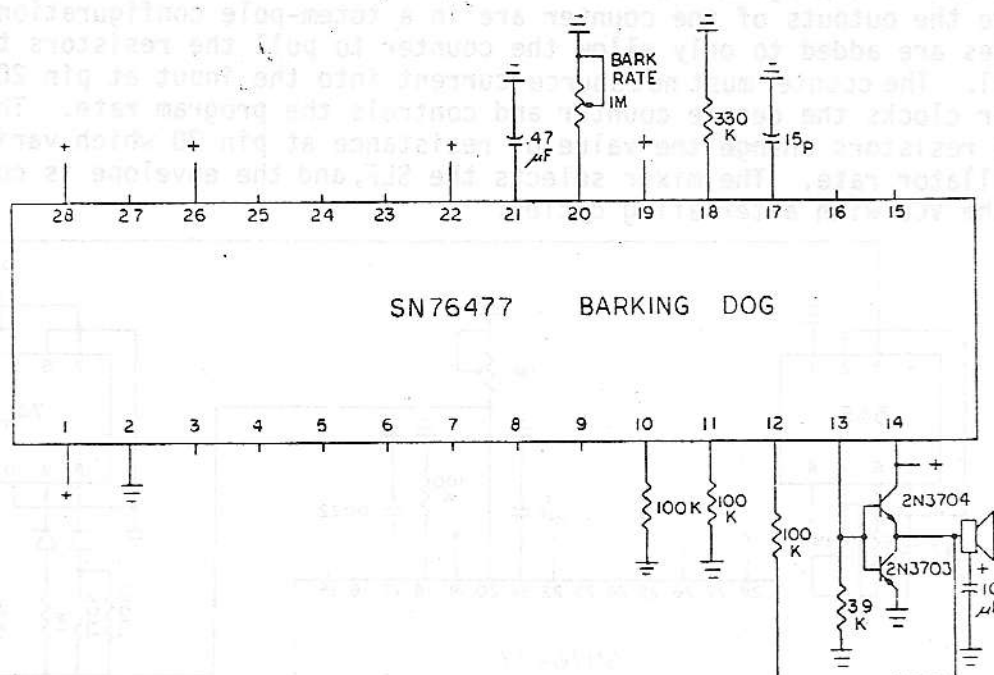
BIRD CHIRP

The bird chirp uses the VCO with alternating cycles for the envelope select function. The SLF frequency modulates the VCO section. Varying the SLF resistor changes the chirp rate. The mixer selects the SLF as the output.



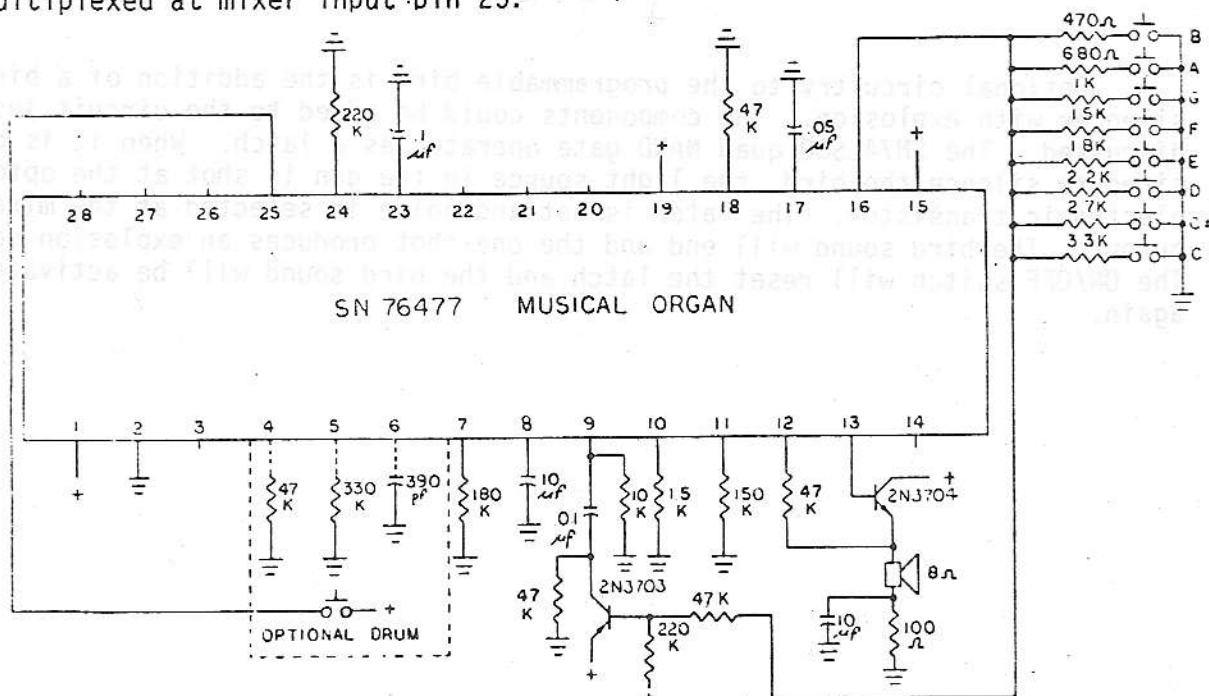
BARKING DOG

The barking dog schematic is identical to the chirping bird circuit with the exception of the VCO capacitor. The capacitor at pin 17 is changed to 15p farads to increase the frequency of the VCO.



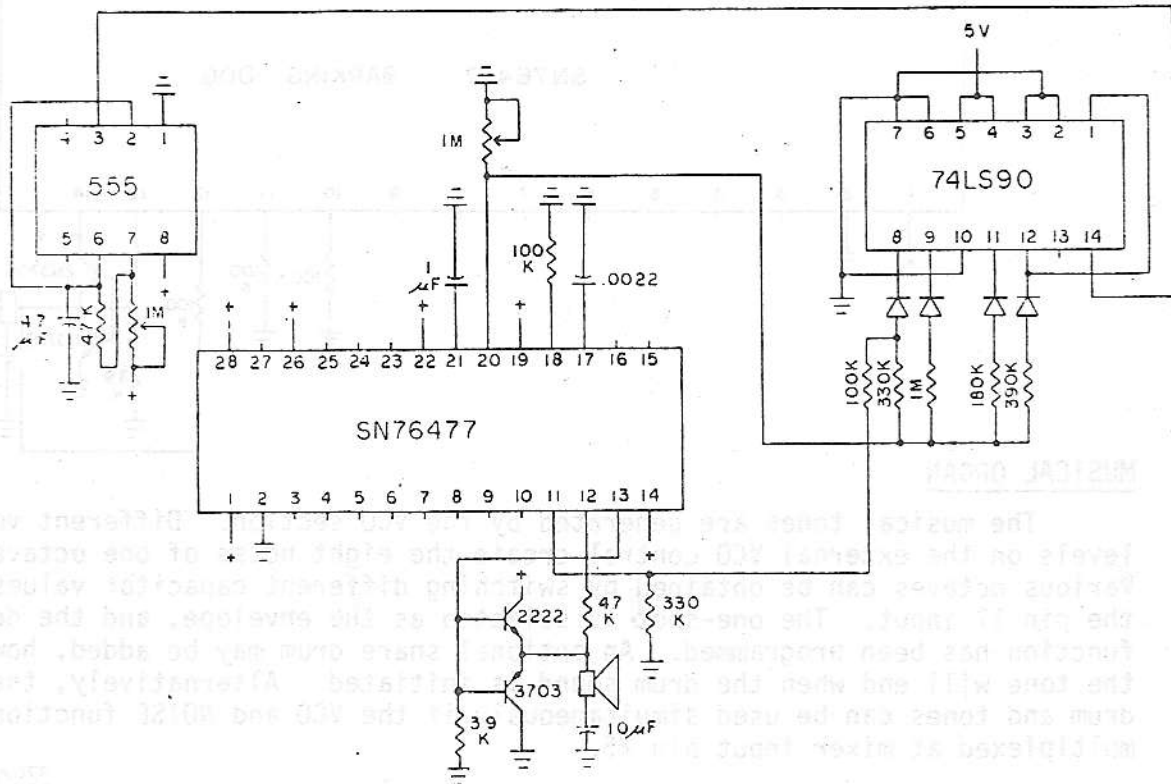
MUSICAL ORGAN

The musical tones are generated by the VCO section. Different voltage levels on the external VCO control create the eight notes of one octave. Various octaves can be obtained by switching different capacitor values at the pin 17 input. The one-shot is selected as the envelope, and the decay function has been programmed. An optional snare drum may be added, however, the tone will end when the drum sound is initiated. Alternatively, the snare drum and tones can be used simultaneously if the VCO and NOISE functions are multiplexed at mixer input pin 25.

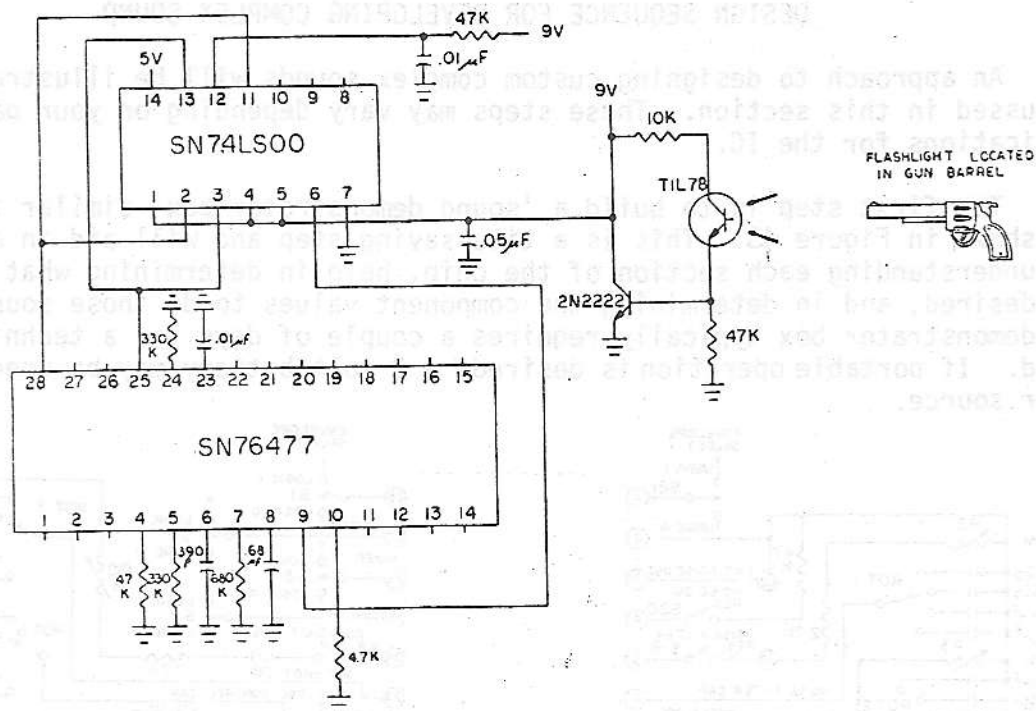


PROGRAMMABLE BIRD/OPTIONAL BIRD SILENCER WITH EXPLOSION

The programmable bird circuitry is programmed by the resistor combination on the SLF pin 20. The SLF is selected to frequency modulate the VCO section. The programming resistors are activated by a 74LS90 decade counter. Since the outputs of the counter are in a totem-pole configuration, series diodes are added to only allow the counter to pull the resistors to a low level. The counter must not source current into the input at pin 20. A 555 timer clocks the decade counter and controls the program rate. The programming resistors change the value of resistance at pin 20 which varies the SLF oscillator rate. The mixer selects the SLF, and the envelope is controlled by the VCO with alternating cycles.



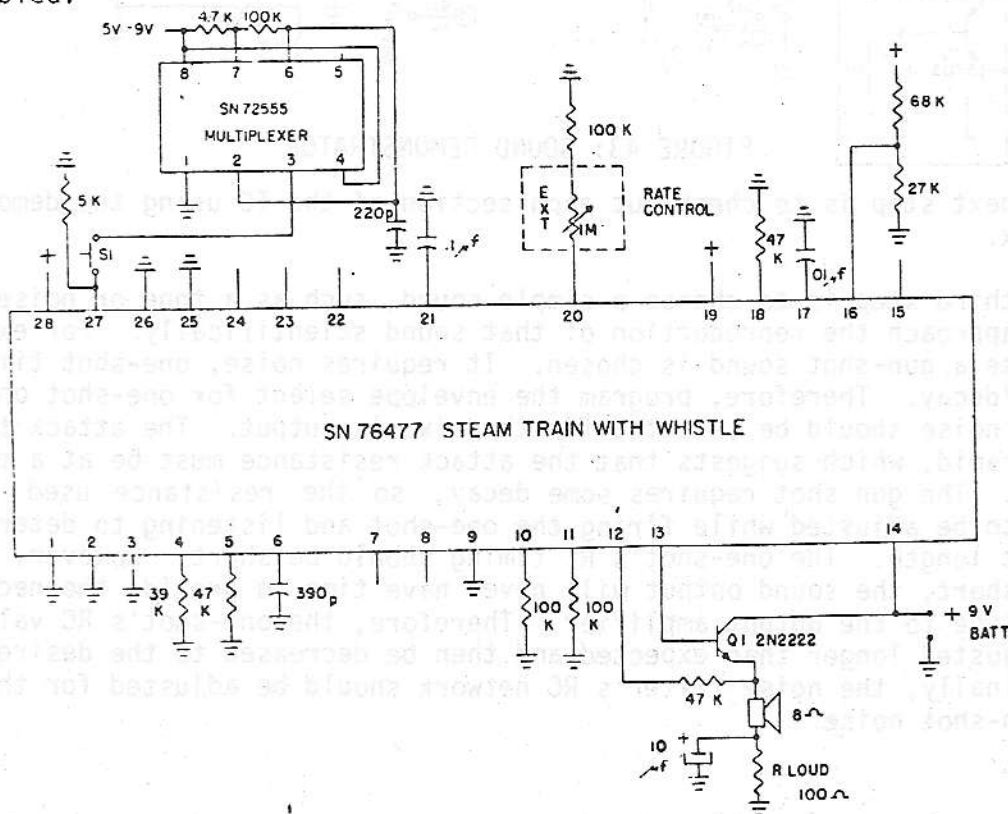
Optional circuitry to the programmable bird is the addition of a bird silencer with explosion. The components could be added to the circuit just discussed. The SN74LS00 quad NAND gate operates as a latch. When it is desired to silence the bird, the light source in the gun is shot at the optoelectronic transistor. The latch is set and noise is selected at the mixer output. The bird sound will end and the one-shot produces an explosion sound. The ON/OFF switch will reset the latch and the bird sound will be activated again.



OPTIONAL BIRD SILENCER WITH EXPLOSION

STEAM TRAIN WITH WHISTLE

An alternative to the steam train/prop plane schematic, given at the beginning of this section, is shown in the illustration below. With the addition of the external multiplexer, the steam train sound and the whistle sound can now occur simultaneously. The whistle is generated by the VCO. The VCO and SLF/Noise mixer input pins are multiplexed when the switch is enabled.



DESIGN SEQUENCE FOR DEVELOPING COMPLEX SOUND

An approach to designing custom complex sounds will be illustrated and discussed in this section. These steps may vary depending on your particular applications for the IC.

The first step is to build a 'sound demonstrator box' similar to the one shown in Figure 43. This is a time-saving step and will aid in analyzing and understanding each section of the chip, help in determining what sounds are desired, and in determining the component values to do those sounds. The demonstrator box typically requires a couple of days for a technician to build. If portable operation is desired, a 9 volt battery may be used for a power source.

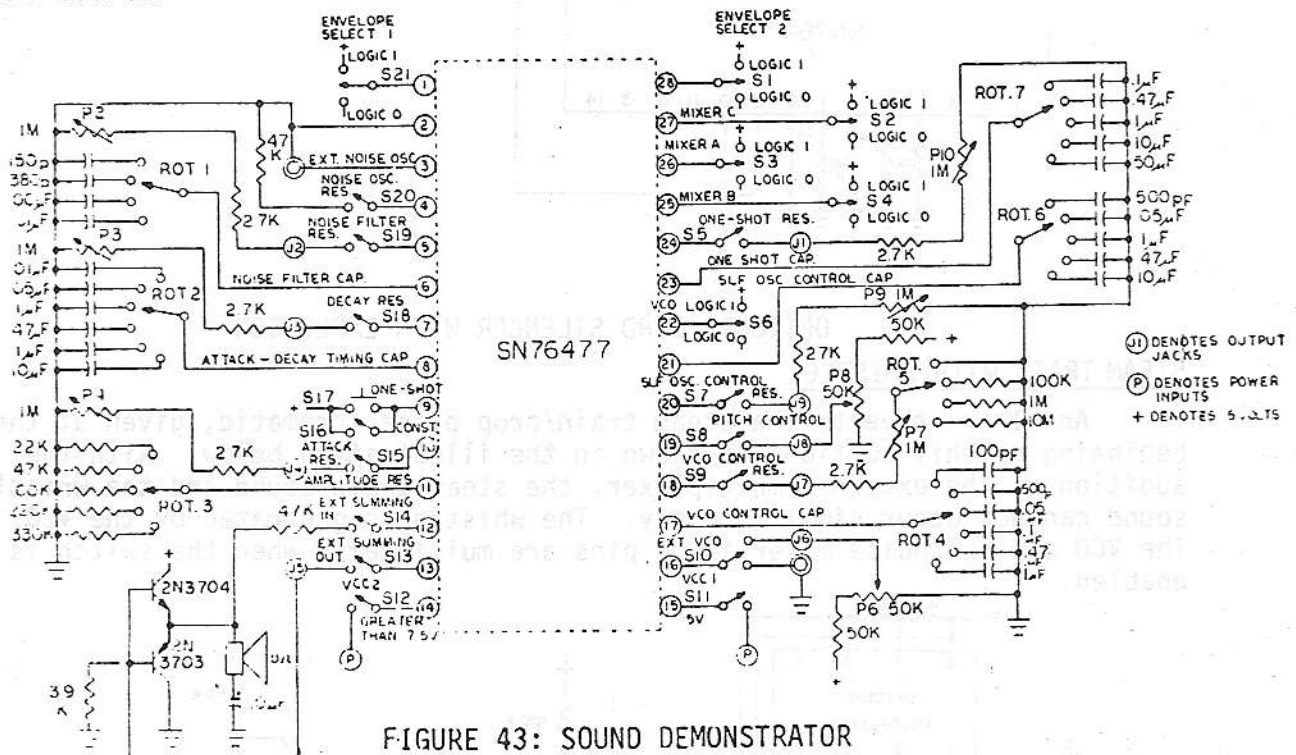


FIGURE 43: SOUND DEMONSTRATOR

The next step is to check out each section of the IC using the demonstrator box.

The third step is to choose a simple sound, such as a tone or noise only, and approach the reproduction of that sound scientifically. For example, suppose a gun-shot sound is chosen. It requires noise, one-shot timing, and attack/decay. Therefore, program the envelope select for one-shot operation, and noise should be selected for the mixer's output. The attack time should be rapid, which suggests that the attack resistance must be at a minimum value. The gun shot requires some decay, so the resistance used will have to be adjusted while firing the one-shot and listening to determine the correct length. The one-shot's RC timing should be short. However, if it is too short, the sound output will never have time to provide the necessary amplitude to the output amplifier. Therefore, the one-shot's RC values must be adjusted longer than expected and then be decreased to the desired length. Finally, the noise filter's RC network should be adjusted for the desired gun-shot noise.

Step four requires logging the component values and logic levels used in your sound for future reference. Table 4 shows a sound logging table including values for the gun shot example. This step is very important since it will keep a log of interesting sounds and prevent the wasted time of trying to repeat an identical sound you have produced in the past. All component values can be determined from the demonstrator box. Use an ohm meter to measure required resistor values by connecting it to a particular sound section's resistor jack and opening the switch that is in series with the IC. The capacitor values are determined from the tables on your demonstrator box.

COMPLEX SOUND LOG

	GUNSHOT						
RESISTORS							
DECAY	680K						
ATTACK	4.7K						
AMPLITUDE	150K						
ONE SHOT	330K						
VCO	-						
FILTER	82K						
SLF	-						
PITCH	-						
VCO EXT	---						
LOGIC CONTROL							
ENV 1	1						
ENV 2	0						
MIXER A	0						
MIXER B	1						
MIXER C	0						
VCO SELECT	-						
CAPACITORS							
ONE SHOT	.01						
SLF	-						
VCO	-						
FILTER	390p						
ATTACK/ DECAY	.68						

TABLE 4: COMPLEX SOUND LOG

Step five is to draw the schematic needed to generate this particular sound. If copies of the IC's pinout are made, similar to the one shown in Figure 44, your time is devoted only to drawing in the necessary external component values.

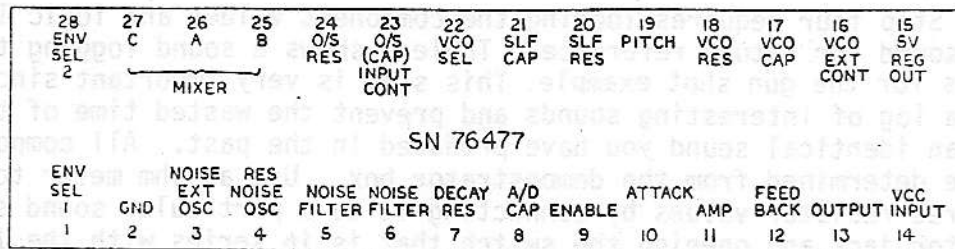


FIGURE 44: IC PINOUT

Step six requires a breadboard of the circuit. Then make any necessary adjustments to the component values.

Step seven is used when several sounds that you have developed (through steps three to five) need to be combined. Compare each individual sound schematic produced in step five. Select all common components on each circuit and draw this on another IC pinout copy. Then determine if any differing values may be compromised to the same value as that used in another sound. For example, if a gun shot was determined to have a certain set of RC one-shot values and a ricochet had another set, then could there be a compromise between the two which would make one set common to both. Decide on the type of switching logic you will need to switch between sounds, and any component additions and add to this drawing.

In step eight, this preliminary system should be breadboarded. Then each sound should be adjusted until that sound is satisfactory.

The final step, step nine, is usually repeated several times. This step is the cost reduction phase. The completed system should be analyzed and revised for optimum cost/performance.

CONCLUSION

A simple, complex-sound system can be developed with the SN76477 integrated circuit. The programming and development of custom complex sounds can be easily preformed with minimal engineering time. The SN76477 has been designed for ultimate flexibility in user-defined sounds, and has many applications. Some industrial examples are: alarms, buzzers, indicators, feedback controls, simulators, etc. Consumer entertainment products might use sounds such as bells, chimes, gunshots, explosions, musical notes, ricochets, drums, phasors, etc. Examples of sounds for home products could include microwave oven tones, smoke detector alarms, sirens, clocks, etc.

As you can see, the range of SN76477 applications is immense. We hope we've shown in this paper how easy it is for you to have that unique sound which makes your product the leader in your market.