SOUND SEMICONDUCTOR®

SSI2144

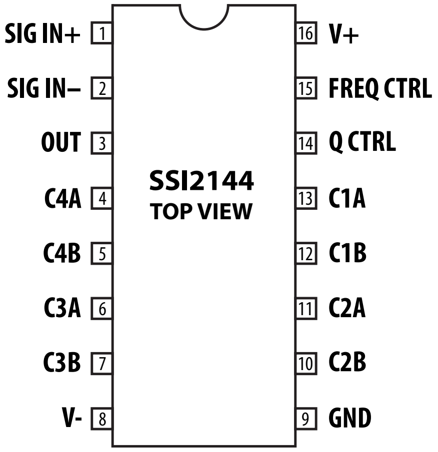
FATKEYS™ FOUR-POLE VOLTAGE CONTROLLED FILTER

The SSI2144 reprises the SSM2044 of legacy chipmaker Solid State Micro Technology, which many believe to be the best-sounding analog synthesis filter IC ever produced. Based on Dave Rossum's patented classic improved ladder topology, the SSI2144 allows rich tonal characteristics that showcase the very best attributes of subtractive synthesis.

The SSI2144 uses the same internal circuit as the SSM2044 but incorporates improvements by the original designer and takes advantage of modern process technology. Features include a minimum 10,000 to 1 sweep range, on-chip control of resonance, differential inputs, high control rejection, and minimized external components. The SSI2144 will operate on supplies as low as ±4V, and improvements include lower noise, significantly better control feedthrough, and more consistent unit-to-unit performance of the resonance control. Pin connections were revised for PCB layout ease. Most importantly, the SSI2144 preserves the coveted sonic character of the SSM2044.

FEATURES

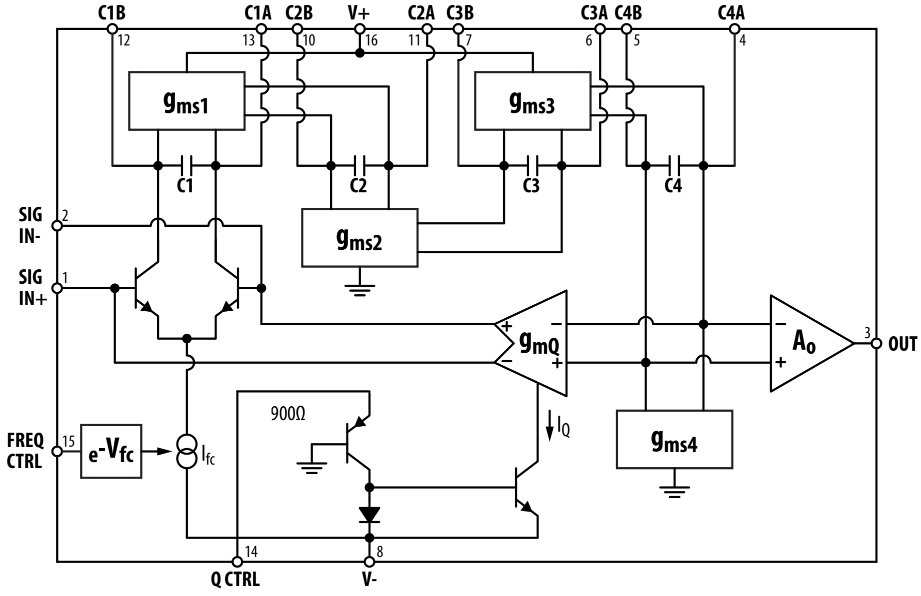
- **Classic Analog Synthesis Timbre**
- **On-Chip Resonance Circuit Improved for More Consistent Control and Performance**
- **±4V to ±16V Operation**
- **Pin Connections Optimized for PCB Layout**
- **Differential Inputs**
- **Large Sweep Range - Typical 20,000 to 1**
- **Low Feedthrough on Both Control Ports**
- **16-Pin SSOP Package with Minimal External Components**



PIN CONNECTIONS

16-LEAD SSOP

(JEDEC MO-137-AB)



FUNCTIONAL BLOCK DIAGRAM

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SPECIFICATIONS (V_S = ±12V, T_A = 25°C; using Figure 1 circuit unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
POWER SUPPLY						
Supply Voltage Range	V_S		±4		±16	V
Supply Current - Positive	I_{CC}	V_{FC} and Q CNTRL at ground	4.0	5.0	6.2	mA
Supply Current - Negative	I_{EE}	V_{FC} and Q CNTRL at ground	4.2	5.2	6.4	mA
FILTER SECTION						
Frequency Sweep Range			10:000:1	20:000:1		
Frequency Control Sensitivity			-20	-19	-18	mV/oct
Frequency Control Input Bias Current				4	10	µA
Frequency Control Input Range	V_{FC}		-120		+150	mV
Frequency Control Feedthrough		$\pm V_{IN}$=GND; $-90mV \leq V_{FC} \leq +90mV$	-36	-50		dB
Frequency Control Offset Voltage		Untrimmed	-10	0	+10	mV
Maximum Available Control Current		V_{FC} = -120mV	500	720	1000	µA
RESONANCE (Q) SECTION						
Q Current Input Range	I_Q		0		1000	µA
Q Current at Oscillation		$-90mV \leq V_{FC} \leq +90mV$	350	400	450	µA
Q Control Feedthrough		$0 < I_Q < 400\mu A$		-40	-20	dB
SIGNAL INPUTS						
Input Bias Current	I_B	Either Input, V_{FC} = 0, I_q = 0		40	150	nA
Differential Input Signal Range	V_{IN}	Clipping		±50		mV
SIGNAL OUTPUT						
Maximum Output Signal Current	I_{OMAX}		±300	±400	±520	µA
Dynamic Range	DR	Noise floor to 1% THD, A Wtd		92		dB
Output Offset	I_{OS}	$V_{IN+} = V_{IN-} = V_{FC} = 0$, $I_Q = 0$		10	55	µA

ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±18V
Storage Temperature Range	-65°C to +150°C
Operating Temperature Range	-40°C to +85°C
Lead Temperature Range (Soldering, 10 sec)	260°C

ORDERING INFORMATION

Part Number	Package Type	Container
SSI2144SS-TU	16-Lead SSOP*, Tube Packing	100
SSI2144SS-RT	16-Lead SSOP*, Tape and Reel	4000

*Compliant to JEDEC MO-137-AB. Please order in full container multiples.

USING THE SSI2144

Signal Inputs

Figure 1 shows typical connection of the SSI2144 as a four-pole lowpass filter in electronic music systems. Differential inputs allow the convenience of directly connecting two oscillators. To prevent cancellation of in-phase signals, a 3dB attenuation of the SIG IN- input is accomplished using the resistor values shown. If only one input is needed, the unused input pin should be connected to ground via a 200Ω resistor.

The SSI2144 differential input signal level is nominally ±20mV and clips at ±50mV. The resistor values in Figure 1 result in ±7V being the nominal input signal level.

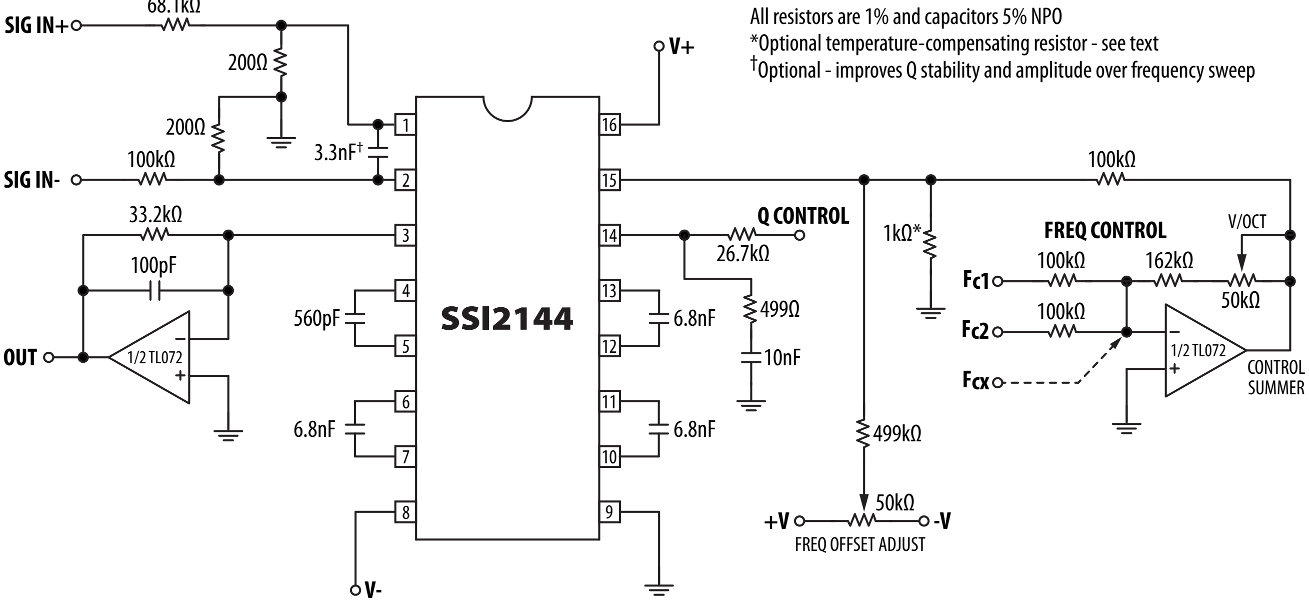
Frequency Control

The Control Summer adds voltages from various sources such as the panel frequency control, ADSR, LFO, etc. Any number of signals can be mixed through resistors to the summing node of the op amp. For best control rejection, the Control Summer and input attenuator should be designed such that maximum swing to the Frequency Control (pin 15) matches extremes of the intended sweep range when the Control Summer is driven to the op amp's full output voltage swing. With values shown in Figure 1, ±90mV at the Frequency Control pin corresponds to a 1000:1 sweep range using ±12V supplies.

A frequency offset adjustment is necessary in polyphonic systems for consistent cutoff fequency across voices, or programmable systems where repeatable performance from a given control voltage is desired.

Resonance (Q) Control

The Q Control (pin 14) is a current input summing node at ground. Minimum resonance occurs at zero current. Oscillation will occur when current into the Q Control reaches approximately 400µA, equating to 10.7V using the resistor value of 26.7kΩ in Figure 1. Figures 2 shows typical squarewave response at various Q current intervals.



NOTES:
All resistors are 1% and capacitors 5% NPO
*Optional temperature-compensating resistor - see text
†Optional - improves Q stability and amplitude over frequency sweep

Figure 1: Typical Application Circuit

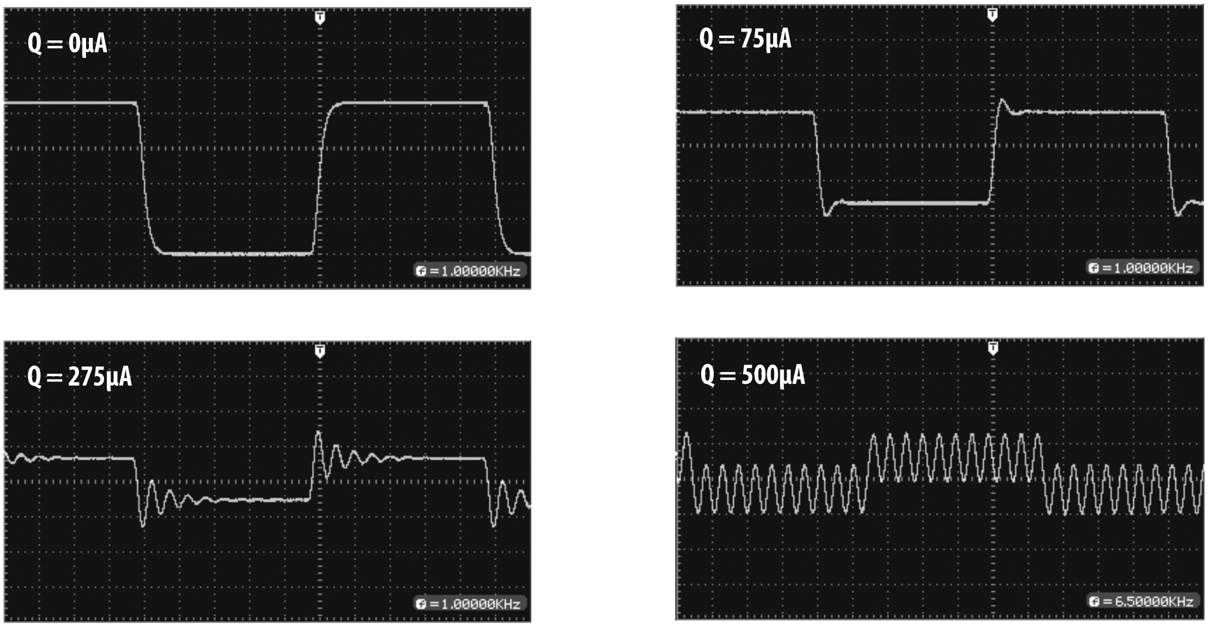


Figure 2: Square Wave Response vs. Q Current

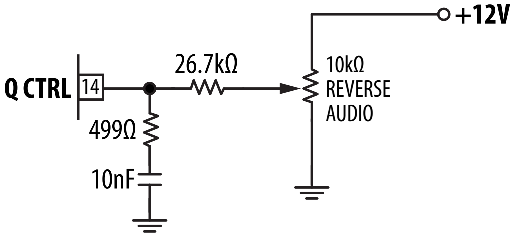


Figure 3: Recommended Q Control Potentiometer Circuit

Due to response of the Q circuit (see "SSI2144 Filter Characteristics" below), ideal potentiometer feel is achieved with a "reverse audio taper" (90% at 50%; i.e. Bourns PDB181 series) configuration as shown in Figure 3.

If accurate musical intervals during oscillation are desired, the V/OCT trim and a temperature compensating resistor (such as the Panasonic ERA-V33J102V) are necessary. If such intervals aren't important, substitute 1% 187kΩ in the Control Summer feedback network and 1% 1kΩ in place of the temperature compensating resistor. The temperature compensating resistor should be physically as close to the SSI2144 as possible to maintain good thermal coupling.

Signal Output

Figure 4 shows direct connection to a current input SSI2164 VCA from the SSI2144's output (pin 3). In this case, no intervening op amp is required. A 10µF cap blocks any DC offset present at Pin 3, so no further offset adjustment is neccesary to maintain the SSI2144's specified control feedthrough. The input to the SSI2144 should also be AC coupled when this circuit is used.

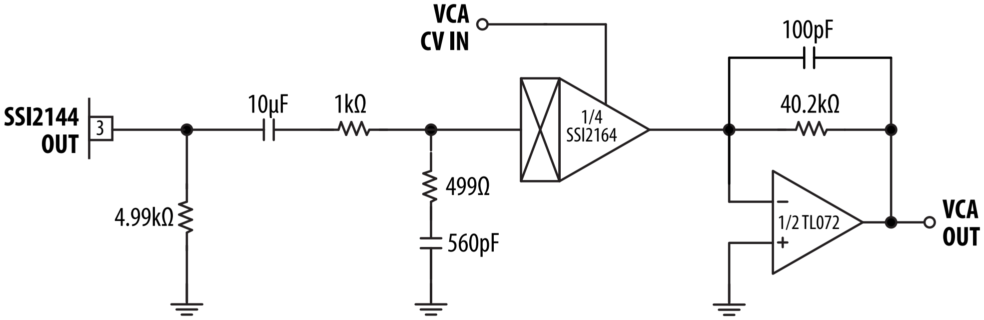


Figure 4: Direct Connection of SSI2144 to a SSI2164 VCA

SSI2144 FILTER CHARACTERISTICS

Figures 5 and 6 show behavior of the SSI2144 filter and Q circuits. In Figure 4, the solid line shows response of the filter with the Q control at ground. In this case, the filter comprises four real poles, each producing 3dB of attenuation at the cutoff frequency. As voltage is applied to the F_C input, cutoff frequency will vary exponentially in response to the control voltage.

The Q circuit provides negative feedback around the filter. As Q control current is increased, gain at DC and frequencies below cutoff are proportionately decreased, and gain at the cutoff frequency is increased as shown in the dotted line of Figure 4. At higher frequencies, an approximate 24dB/octave rolloff will be maintained.

When feedback exceeds 12dB, loop gain at cutoff exceeds unity and the filter oscillates with a pure sinewave at the cutoff frequency. This waveform can therefore become a very useful tone source in electronic music systems.

The SSI2144's Q control circuit has been improved over the SSM2044. It accurately applies the current supplied to the Q input summing node (which is maintained at a ground potential) to the feedback amplifier, eliminating process dependent variations in the gain of the Q control circuit.

Figure 5 shows resonance, measured as the height of the resonant peak above the low frequency gain, as a function of Q Control current. Note that the slope is more flat at lower current, then increases rapidly as oscillation is approached. To compensate for this variation in slope, the "reverse audio" taper potentiometer circuit in Figure 3 above is recommended. Figure 7 shows the corrected response; the rightmost portion of the rotation represents the region of oscillation.

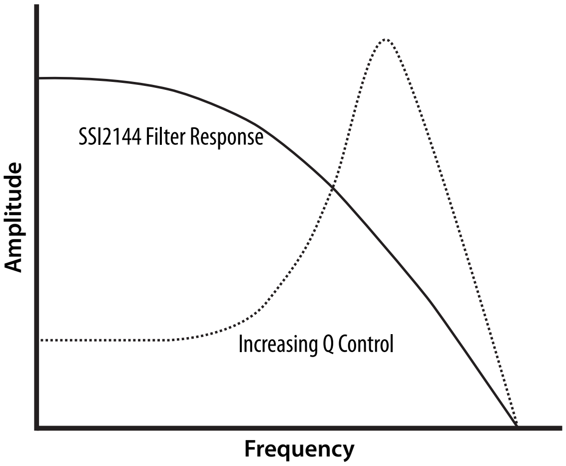


Figure 5: Filter and Q Response

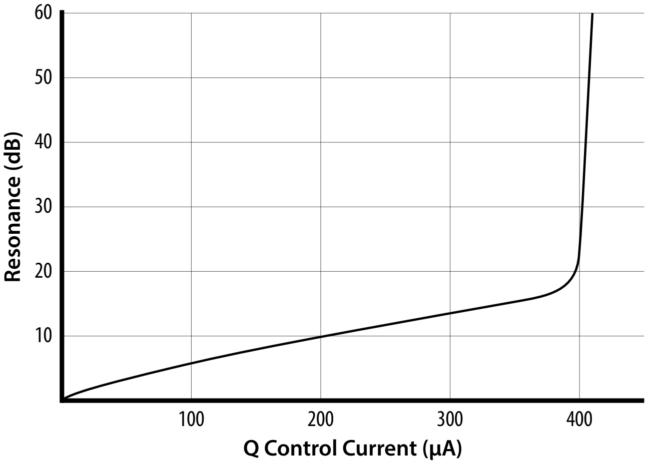


Figure 6: Resonance Peak Height vs. Q Current

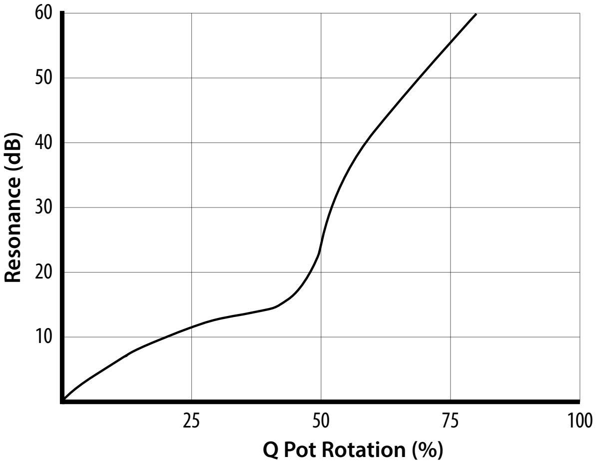


Figure 7: Q Response Using "Reverse Audio" Pot

APPLICATION INFORMATION

SUB-AUDIO FREQUENCY CUTOFF CONSIDERATIONS

In most fixed signal-path synthesizers, cutoff frequency is limited to the audio range. Modular systems, however, may allow sub-audio cutoffs.

The SSI2144 – and its predecessor SSM2044 – can exhibit undesirable behavior when voltage at the Frequency Control (Pin 15) exceeds approximately 175mV. Current in the ladder becomes smaller than the output amplifier's bias current, causing the common-mode voltage of the output stage to suddenly drop. Under these conditions, the filter no longer passes any signal and the output transitions to an unrelated fixed voltage.

Normal operation resumes once the control voltage is reduced to approximately 135mV, and may be accompanied by an audible "thump." Note that actual control voltage levels at which these transitions occur may vary slightly from part-to-part or batch-to-batch.

A network attached to both C4 pins provides a simple solution. Place a pair of matched low leakage diodes (or diode-connected transistors, as shown) with cathodes connected to C4A and C4B (Pins 4 and 5). Tie the anodes together and to a diode connected to ground, and bias this point with a resistor to the negative supply. The bias current magnitude is relatively unimportant. This circuit will prevent the output stage common-mode voltage from dropping, allowing the filter to gracefully degrade in performance at extremely low cutoff frequencies. See Figure 8.

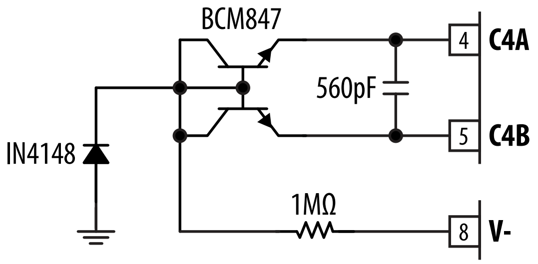


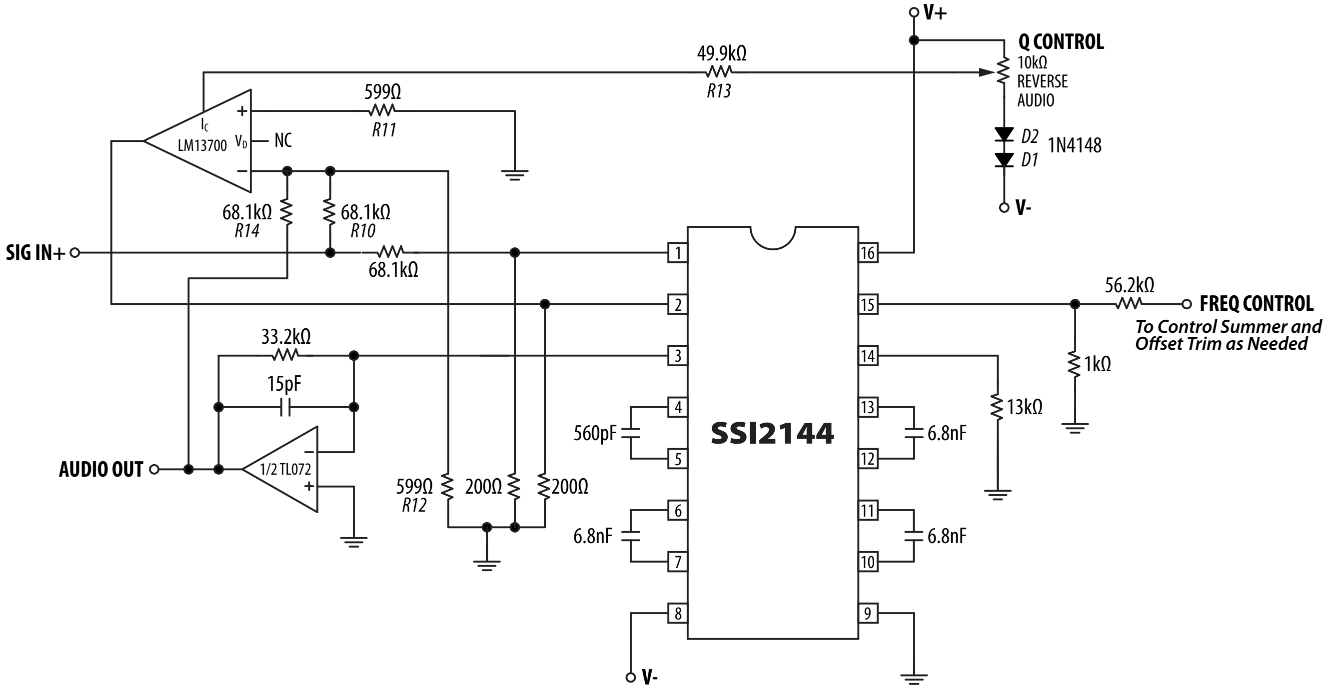
Figure 8: Sub-Audio Filter Cutoff Application Circuit

CIRCUMVENTING Q CONTROL PASSBAND ATTENUATION

As described in the preceeding "Filter Characteristics" section, both the SSM2044 and the SSI2144 demonstrate increasing attenuation of the passband as Q is increased. Many synthesizer enthusiasts consider this to be part of its signature sound, but in some applications the designer may wish to mitigate the characteristic.

Figures 8 and 9 show alternate solutions. Both schemes route input and output signals to the input of an external "Q VCA" that uses one-half of an LM13700 Transconductance Amplifier, with its I_C (bias) pin becoming the Q control, replacing the internal Q VCA of the SSI2144. As Q is increased, the filter input signal is proportionately increased to offset DC gain reduction from negative feedback. As a result, DC gain is held constant. In essence the negative feedback at DC will be zero regardless of Q VCA gain, preventing any DC gain change. The TL071's inverting output is summed with the non-inverted signal input and applied to the Q VCA input yielding zero negative feedback signal at DC.

Figure 9 uses one-half of a non-linearized LM13700 as the Q VCA. The values of R10, R11, R12, and R14 are chosen to accurately mimic the SSI2144's internal Q amplifier. Consequently, a control current of approximately 375µA to the I_C input of the LM13700 results in oscillation. With the values shown, the DC gain of the filter remains contant at approximately unity over the Q control range. Increasing R10's value will proportionally reduce DC gain at high Q currents; omitting it will cause the circuit behave virtually identical to the SSI2144. This circuit is recommended if the vintage 'SSM2044' sound is desired.



To Control Summer and Offset Trim as Needed

Figure 9: Non-Linearized "Q VCA"

Figure 10 takes advantage of the LM13700's linearizing diodes which allows R11 to be set to zero. Other values are chosen such that a 1mA control current to the Ic input of the LM13700 gives oscillation and maintains constant DC gain over the Q range. As with Figure 8, increasing R10 will proportionately reduce DC gain at high Q currents. Use this circuit to minimize distortion in the Q VCA.

In both cases, the designer must supply the Q control as a current to the LM13700's I_C input pin. The circuits shown use the same "Reverse Audio" taper pot previously recommended, and assume ±12V supplies. Diodes D1 and D2 (any general purpose signal diode will do) provide thermal compensation for the variation in input voltage at the I_C pin, and therfore should be physically close to the LM13700. Designers familiar with the LM13700 may choose to use other schemes to supply I_C.

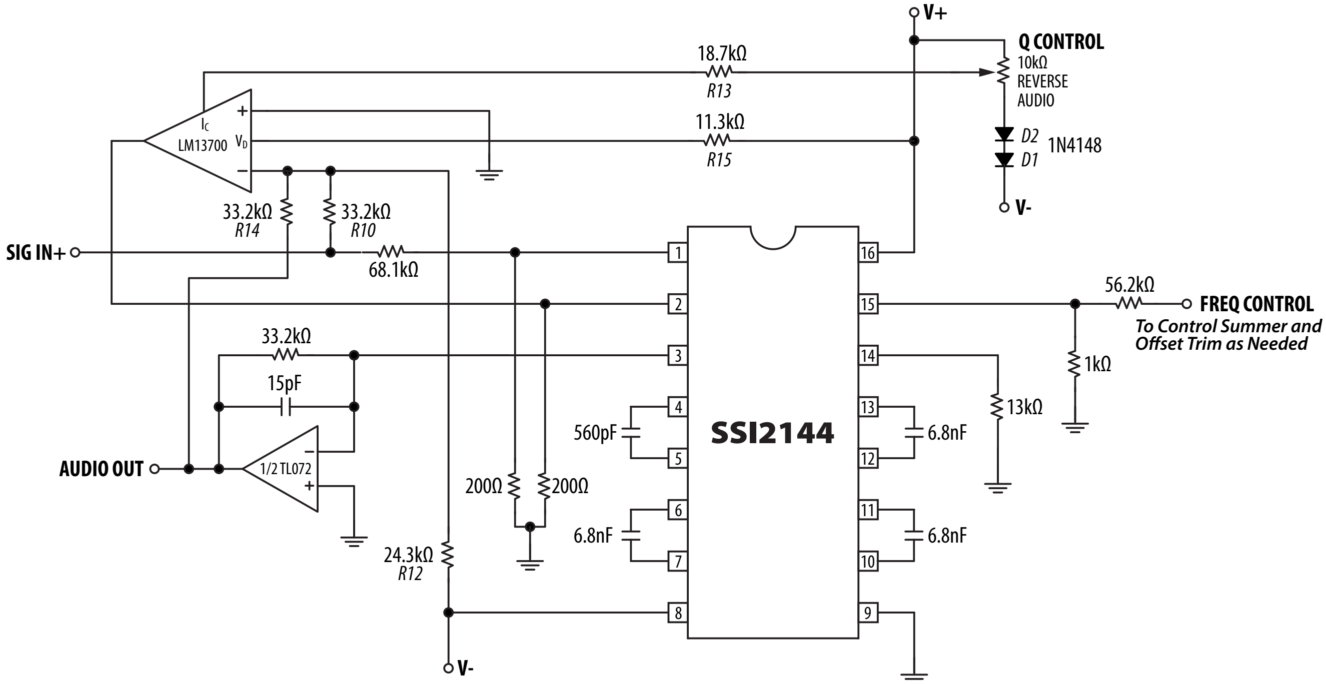
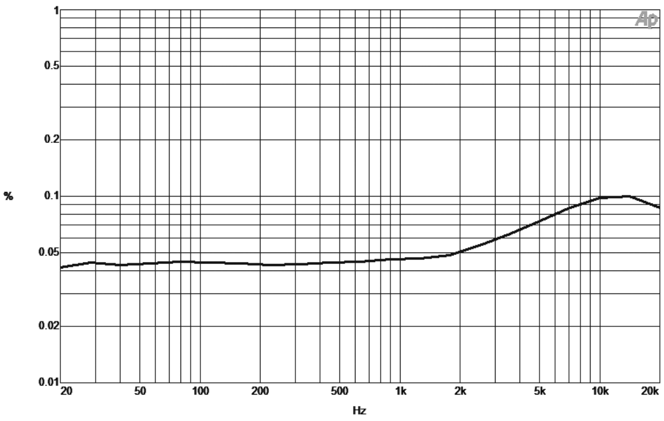


Figure 10: Linearized "Q VCA"

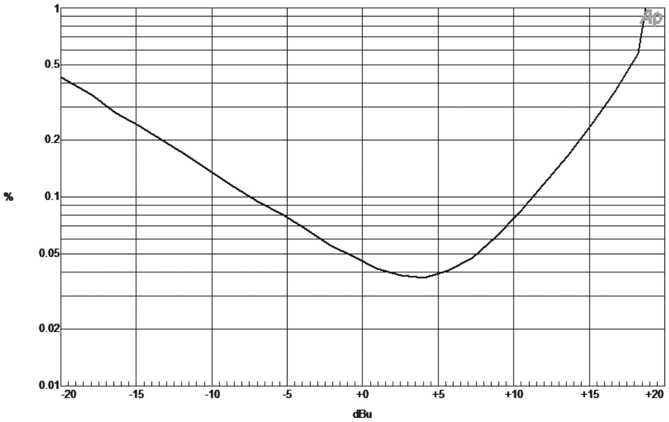
TYPICAL PERFORMANCE GRAPHS

Figure 1 Application Circuit at V_S = ±12V, f = 1kHz unless otherwise noted



THD+N vs. Frequency

V_{IN} = +5dBu, 22Hz - 80kHz Filter



THD+N vs. Amplitude

f = 1kHz , <10Hz - 22kHz Filter

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