



HUSH Stereo Noise Reduction System with Adaptive Threshold

SSM2000

FEATURES

- Up to 25 dB of Noise Reduction from Virtually Any Audio Source without Sonic Artifacts
- "Single-Ended" Operation Eliminates Need for Encode-Decode Process
- Adaptive Threshold Dynamically Adjusts to Changing Nominal Signal Levels
- Effectively Decodes Dolby B® Encoded Sources
- Direct VCA Control Port Access for Additional Level Control Functionality
- Logic-Controllable Bypass and Muting
- 100 dB Dynamic Range (Noise Reduction OFF)
- 0.02% Typical THD+N (@ 1 kHz, Noise Reduction OFF)
- +7 V to +18 V Operation
- No Royalty Requirements

APPLICATIONS

- Auto Radio Sound Processing
- Multimedia PC Sound Cards
- Television Sound Processing
- Cassette Tape Players
- AM/FM Receivers
- Telephone & Wireless Links
- Professional Audio

GENERAL DESCRIPTION

The SSM2000 is an advanced audio noise reduction system based on proprietary HUSH® circuitry. HUSH combines a dynamic filter and downward expander to provide a high level of effectiveness without the sonic artifacts normally associated with noise reduction systems. In addition, an Adaptive Threshold circuit detects nominal signal levels and dynamically adjusts both thresholds, thereby providing optimal results regardless of program source. Since it is a single-ended system, HUSH can be used on virtually any audio source, including audio and video tapes, radio and television broadcasts, or any other source with objectionable noise. The SSM2000 can be used with Dolby B encoded sources with excellent results. A key feature is direct access to the Voltage Controlled Amplifier port enabling additional functions such as dc volume control, automatic leveling, compression, etc. with minimal external circuitry.

Dolby B is a registered trademark of Dolby Laboratories, Inc.
HUSH is a registered trademark of Rocktron Corporation.

PIN CONFIGURATION

24-Lead Plastic DIP
24-Lead SOIC

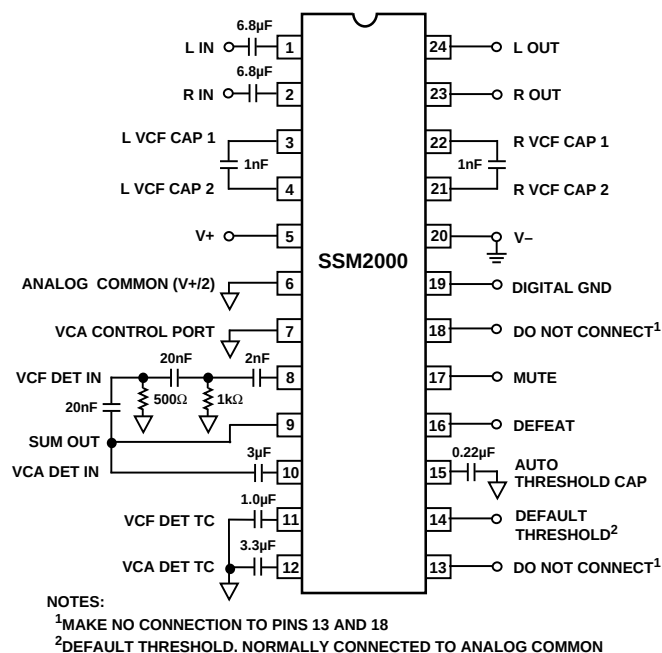
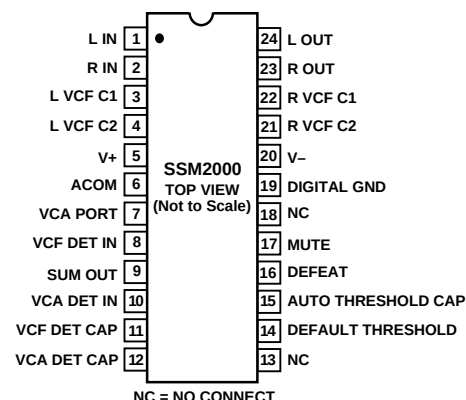


Figure 1. Typical Basic Application

REV. 0

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SSM2000—SPECIFICATIONS

($V_S = +8.5$ V, $ACOM = V_S/2$, $f = 1$ kHz, $R_L = 100$ k Ω , 0 dBu = 0.775 V rms.
 $T_A = +25^\circ\text{C}$, Noise Reduction and Adaptive Threshold enabled (Pin 14 at $V_S/2$), unless otherwise noted.)

Parameter	Symbol	Conditions	SSM2000			Units
			Min	Typ	Max	
AUDIO SIGNAL PATH						
Signal-to-Noise Ratio	SNR	V _{IN} = 0 V, 20 Hz to 20 kHz (Flat)	80	86		dB
Headroom	HR	Clip Point, THD = 1%		4.5		dBu
Dynamic Range		Clipping to Noise Floor		91		dB
Total Harmonic Distortion	THD+N	V _{IN} = 300 mV rms, 2nd & 3rd Harmonics ¹		0.02	0.04	%
Effective Noise Reduction		20 kHz Bandwidth (Flat)				
		Downward Expander Section		15		dB
		Dynamic Filter Section		10		dB
Input Impedance	Z _{IN}	Pins 1 and 2	6	8		kΩ
Output Impedance, Dynamic	Z _{OUT}	Pins 23 and 24		7		Ω
Capacitive Load		No Oscillation		300		pF
Channel Separation		f = 1 kHz, V _{IN} = 300 mV rms		60		dB
Mute Output		V _{IN} = 300 mV rms		−85		dB
Gain Matching, L & R Channels		VCA at A _V = 0 dB		±1		dB
Gain Bandwidth	GBW	NR Disabled		37		kHz
DYNAMIC FILTER						
Minimum Bandwidth	BW _{MIN}	VCF C = 0.001 μF		3		kHz
Maximum Bandwidth	BW _{MAX}			37		kHz
VCA CONTROL PORT						
Input Impedance		Pin 7		3.8		kΩ
VCA Voltage Gain Range	A _V	V _{IN} = 300 mV rms (Pin 7 = 2.0 V & 0 V)	−70		+1	dB
Gain Constant			20	22	26	mV/dB
Control Feedthrough		Pin 7		1	10	mV
POWER SUPPLY						
Voltage Range	V _S		+7.0		18	V
Supply Current	I _{SY}			7.5	11	mA
Power Supply Rejection	PSRR+			70		dB
VCA, VCF DETECTOR						
Input Impedance	R _{IN}	Pins 8 and 10	4.0	5.4	7.0	kΩ

NOTES

¹NR in defeat mode.

Specifications subject to change without notice.

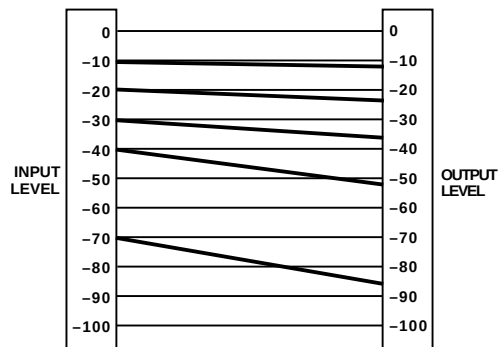


Figure 2. Downward Expander Attenuation Characteristic (In dBt; 0 dBt = Threshold)

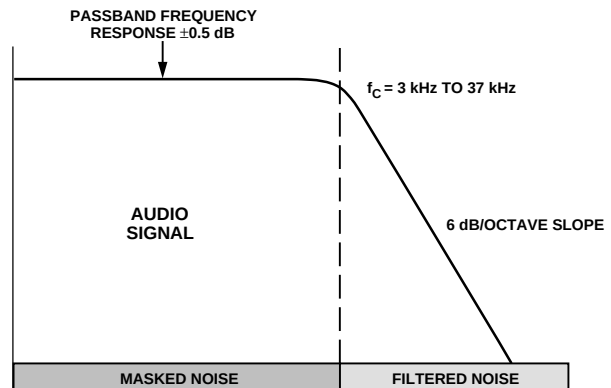


Figure 3. Dynamic Filter Characteristic (For $C_F = 0.001$ μF Defeat Mode)

PIN DESCRIPTION

Pin #	Name	Function and Explanation	Pin #	Name	Function and Explanation
1	L IN	Left Audio Input.	13	NC	Make No Connection to this Pin.
2	R IN	Right Audio Input.	14	DEFAULT THRESHOLD	Default Threshold Adjustment Port. Allows reduction of noise reduction action if signal source is relatively clean such as CD sources. Normally connected to Analog Common. -1.2 V is recommended for CDs; -2 V completely defeats noise reduction.
3	L VCF C1	Left VCF Filter Cap Port.	15	AUTO THRESHOLD CAP	Automatic Threshold Detector Capacitor Port.
4	L VCF C2	Left VCF Filter Cap Port.	16	DEFEAT	Logic High: Defeats Noise Reduction. Logic Low: Normal Action. Connect to Ground if not used.
5	V+	Positive Supply.	17	MUTE	Logic High: Mute. Logic Low: Normal Action. Connect to Ground if not used.
6	ACOM	Analog Common Voltage. Internal Circuit Ground Point. Must be held to a voltage approximately halfway between V+ and V-. Should be a clean low impedance voltage source capable of at least 4 mA, such as from a buffer driven off a supply-splitting voltage divider.	18	NC	Make no connection to this pin.
7	VCA PORT	Input to VCA Control Port. Allows external adjustment of attenuation with a +22 mV/dB slope. Zero volts relative to ACOM gives zero additional attenuation. Should be connected to ACOM if function not required.	19	DIGITAL GND	Digital Logic Reference (Logic Zero).
8	VCF DET IN	Input to VCF Detector.	20	V-	Negative Supply.
9	SUM OUT	Combined Left Plus Right Output.	21	R VCF C2	Right VCF Capacitor Port.
10	VCA DET IN	Input to VCA Detector.	22	R VCF C1	Right VCF Capacitor Port.
11	VCF DET CAP	Voltage Controlled Filter. Time Constant Capacitor Port.	23	R OUT	Right Audio Output.
12	VCA DET CAP	Voltage Controlled Amplifier. Time Constant Capacitor Port.	24	L OUT	Left Audio Output.

ABSOLUTE MAXIMUM RATINGS

Supply Voltage	+18 V
Audio Input Voltage	Supply Voltage(s)
Control Port Voltage (Pin 7)	Positive Supply
Default Override (Pin 14)	V+
Defeat (Pin 16)	V+
Mute Override (Pin 17)	V+
Operating Temperature Range	-40°C to +85°C
Storage Temperature Range	-65°C to +150°C
Junction Temperature (T _J)	+150°C
Lead Temperature (Soldering, 60 sec)	+300°C

ESD RATINGS

883 (Human Body) Model	2.5 kV
EIAJ Model	300 V

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the SSM2000 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
SSM2000P	-40°C to +85°C	24-Pin Plastic DIP	N-24
SSM2000S	-40°C to +85°C	24-Pin SOIC	SOL-24

PACKAGE INFORMATION

Package Type	θ_{JA}^1	θ_{JC}	Units
24-Pin Plastic DIP (P)	54	27	°C/W
24-Pin SOIC (S)	72	24	°C/W

NOTE

¹ θ_{JA} is specified for the worst case conditions, i.e., θ_{JA} is specified for device in socket for P-DIP packages; θ_{JA} is specified for device soldered onto a circuit board for surface mount packages..



SSM2000

APPLICATIONS

This applications example (Figure 4) demonstrates some of the additional functions that can be easily implemented through use of the VCA Control Port (Pin 7). These functions can be selected to operate simultaneously with the basic HUSH noise reduction function. The VCA detector output provides a signal which can be further processed using one quad op amp (OP482) to provide these various additional useful functions.

The circuit shown in the figure below achieves: (1) Compression, (2) Volume Leveling, (3) DC Volume Adjustment.

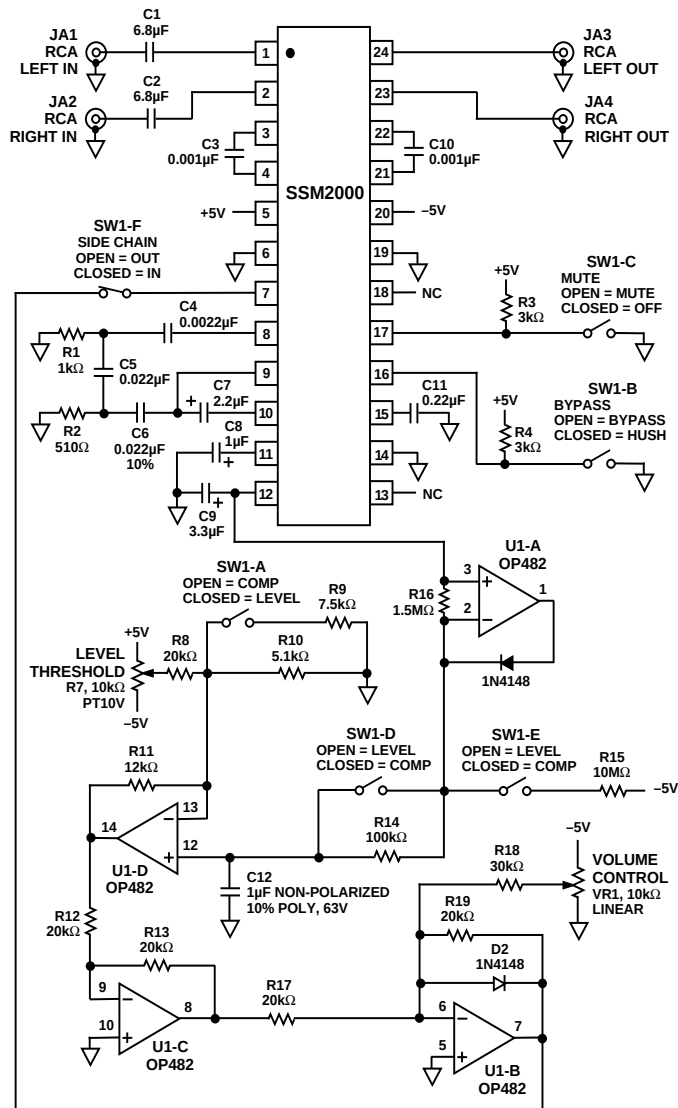


Figure 4. Typical Dual Supply Application and Test Circuit

SIMPLIFIED THEORY OF OPERATION

The input audio signals are processed to extract information concerning the frequency distribution and amplitude of both the desired signals and the undesired noise. Left and right audio signals are passed through voltage controlled (low-pass) filter, and then through a voltage controlled amplifiers. Both the filters and amplifiers are low distortion, and add negligible noise of their own. The VCF has a user-definable cutoff range that is usually set from 1 kHz to 35 kHz. It can be set to cover other ranges as required by the application. The VCA can be adjusted from a loss to a gain, adding to the SSM2000's versatility. In accordance with proprietary patented algorithms, control signals are derived and applied to both the VCF and VCA, resulting in up to 25 dB noise suppression with the minimum loss of desired signals.

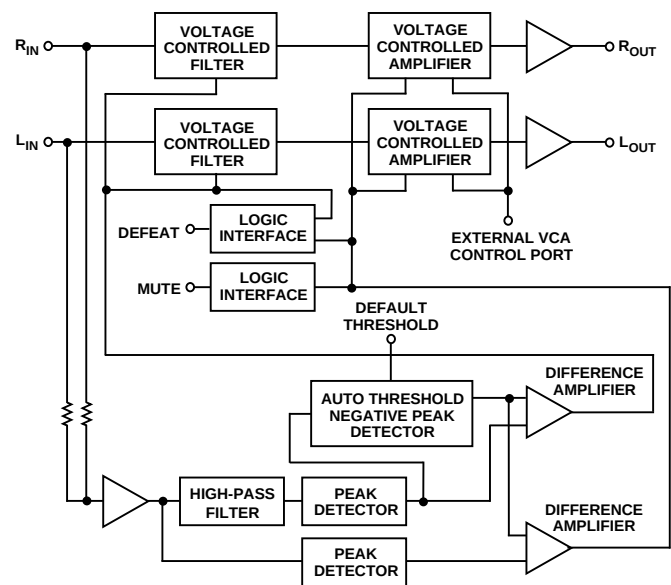


Figure 5. SSM2000 System Block Diagram

Typical Performance Characteristics—SSM2000

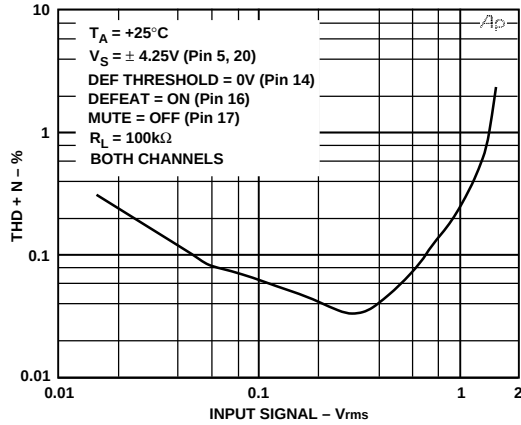


Figure 6. THD+N (%) vs. Input Signal

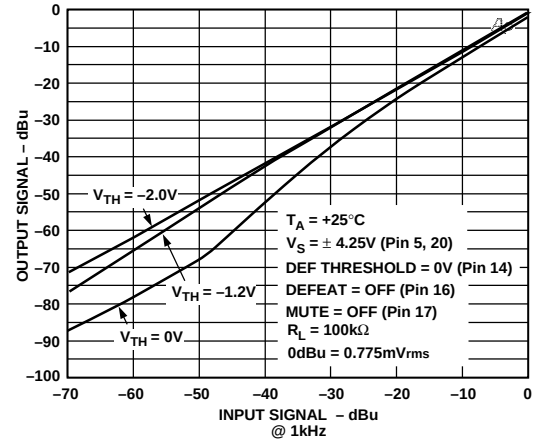


Figure 9. Output vs. Input Characteristics (With Different Adaptive Threshold Voltage, Pin 17)

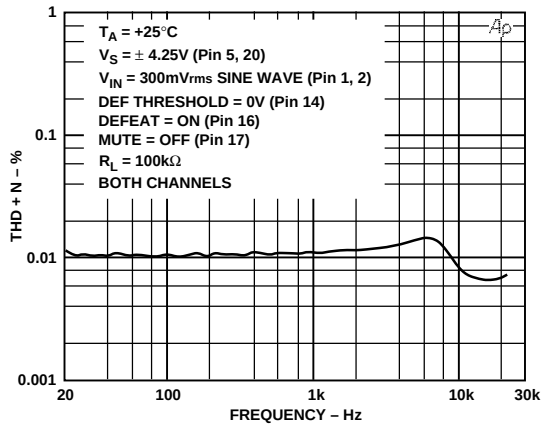


Figure 7. THD+N (%) vs. Frequency

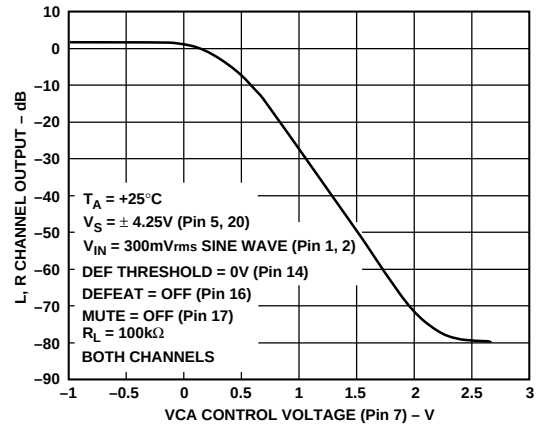


Figure 10a. Channel Output vs. VCA Control Voltage (Pin 7)

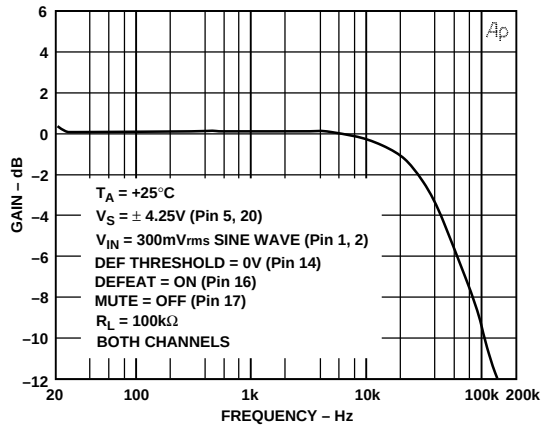


Figure 8. -3 dB Bandwidth

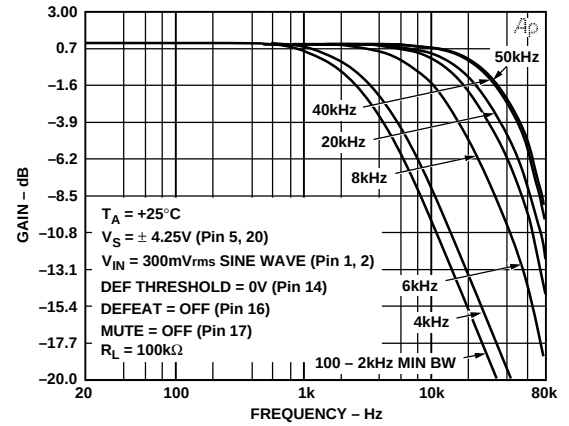


Figure 10b. VFC Characteristics (Simulated Noise Level 90 mV rms with Different Frequency) Applied through a 3-Pole HP filter

SSM2000—Typical Performance Characteristics

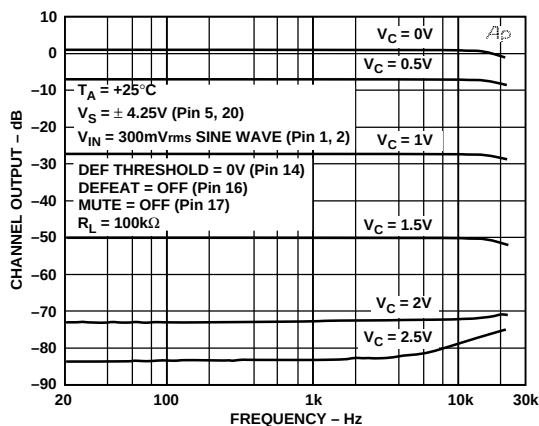


Figure 11. Channel Output vs. Frequency for Different VCA Control Port Voltages

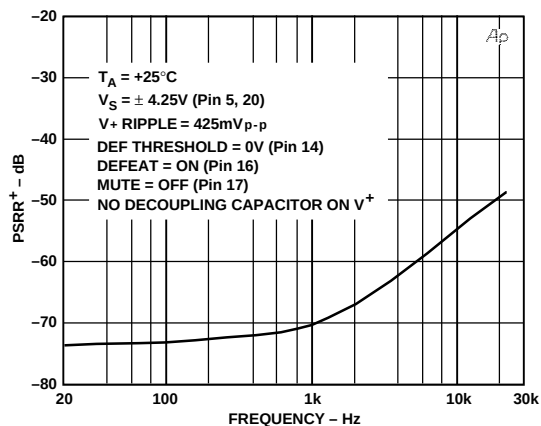


Figure 14. PSRR+ vs. Frequency

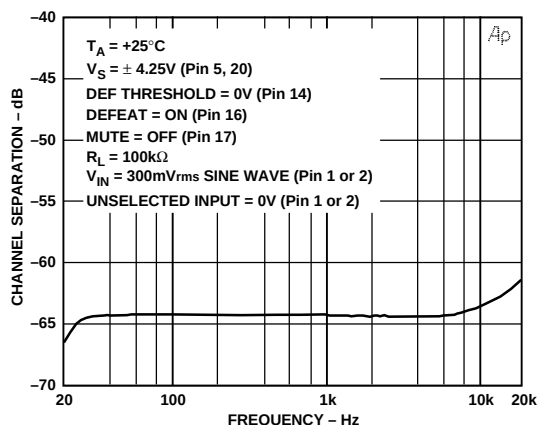


Figure 12. Channel Separation vs. Frequency

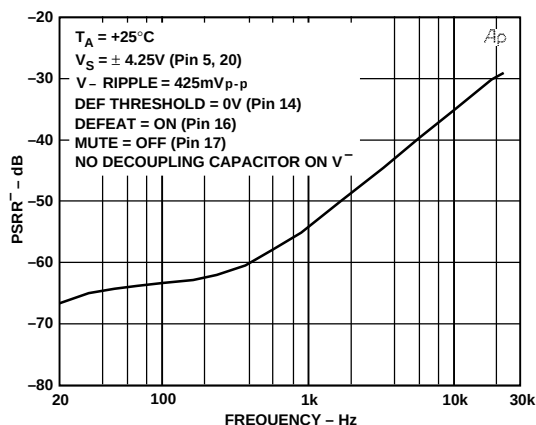


Figure 15. PSRR- vs. Frequency

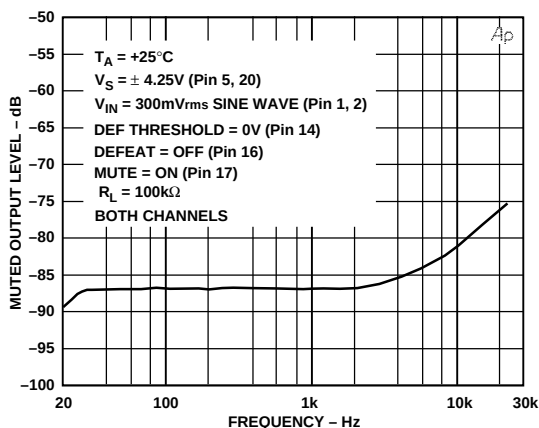


Figure 13. Muted Output Level vs. Frequency

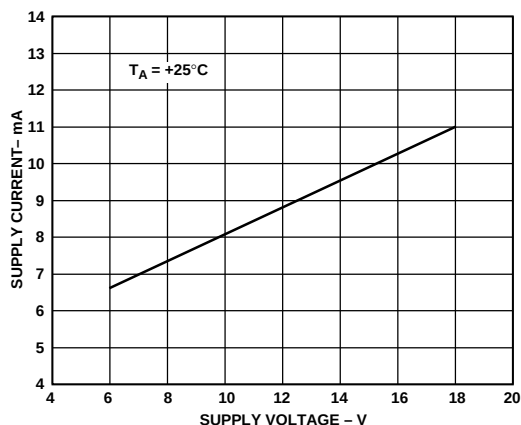


Figure 16. Supply Current vs. Supply Voltage

APPLICATIONS INFORMATION

Introduction

The SSM2000 is a dual channel audio noise reduction IC which reduces noise through a combination of variable filtering and downward expansion in conjunction with a unique adaptive noise threshold detector. These two techniques yield an overall noise reduction of up to 25 dB on AM and FM radio, open reel and cassette tape, CD, Dolby B encoded programming, broadcast studio-transmitter links, telephone lines, and other audio sources without the need for any additional manual adjustment. The HUSH Noise Reduction System as implemented in the SSM2000 has been shown to substantially reduce noise in PC multimedia, intercom systems, teleconferencing systems, mobile communications, automotive audio, home stereos and televisions, and other consumer and professional audio applications while preserving full signal fidelity and transparency.

A brief explanation of the nature of audio signals is useful before discussing the details of the SSM2000's operation. First, audio signals have both amplitude and frequency content. Music and voice are created by changing both the amplitude and frequency of sound waves as shown in Figure 17. Second, the highest audio signal amplitudes typically occur at low frequencies (100 Hz–1 kHz) and taper off exponentially as frequency increases. Third, when an audio signal is recorded, audio noise is also generated. This noise is the white noise "hiss" or waterfall sound that is easily heard on taped material. Audio noise for a given source and bandwidth does not, in general, change with frequency or amplitude. However, noise levels do change between different sources, because of differences in recording equipment, media, and the surrounding environment. Fourth, psychoacoustic effects mask noise that occurs at or near the frequency of the audio signal. Finally, audio noise is usually considered to be most objectionable in the 3 kHz–8 kHz bandwidth region.

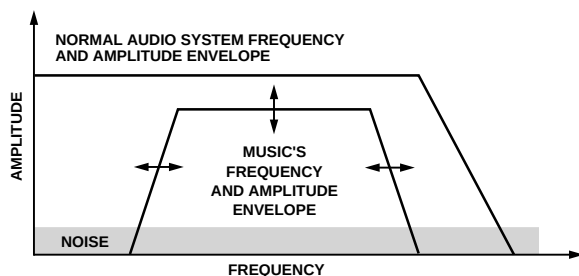


Figure 17. A Frequency-Amplitude Plot of the Audio Envelope

An analog noise reduction system must first distinguish between the desired source material and the undesirable noise. It must then attenuate the noise while leaving the source material unaffected. One approach to noise reduction is to assume that signal below a predetermined amplitude is noise, and to then attenuate the noise by using a Voltage Controlled Amplifier (VCA). A variation of this noise reduction method is found in Dolby B cassette tape systems. This method achieves about 10 dB of improvement in signal-to-noise ratio (SNR). This system incorporates a high-frequency compressor on the recording side, and a high frequency expander during playback. Another noise reduction technique senses and reduces noise by measuring the frequency content of the audio signal and then filters noise that

occurs above the highest signal frequency. This noise reduction method utilizes a Voltage Controlled Filter (VCF) and is the basic method of operation in the DNR® system, which provides about 10 dB of noise reduction. The HUSH system shown in Figure 34 combines elements of both of these techniques to achieve 25 dB of noise reduction, and also has significant improvements.

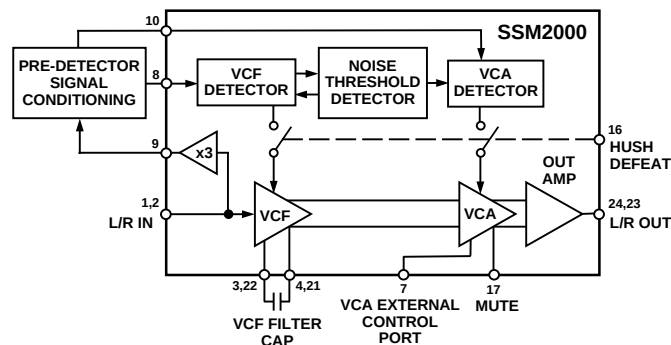


Figure 18. SSM2000 Block Diagram (One Audio Channel Shown)

Recalling that the noise floor changes with different audio sources due to recording equipment, media, and the environment, we realize that fixed threshold approaches cannot yield optimal results. The HUSH Noise Reduction System incorporates an automatic noise threshold detector that senses these changes and adapts the VCA and VCF to become more or less aggressive depending on the amplitude of the noise floor. To determine the amplitude of the noise floor the SSM2000 assumes that the averaged amplitude during short periods of no audio is equal to the noise floor. This assumption works well in audio applications, but does have implications for evaluation and testing that are discussed in the "Evaluating the SSM2000" section.

Variable Low-Pass Filtering

The audio signal is first passed through a single-pole low-pass Voltage Controlled Filter (VCF). Both the Left and Right VCFs are controlled by a detector which places their cutoff frequencies just beyond the highest audio signal frequency. Since the highest audio signal frequency constantly changes, the VCF's cutoff frequency must also change in concert with the audio signal to avoid attenuating desired signal.

For example, with signal levels below the filter threshold (presumed to be mostly noise), the VCF shuts down to about 1 kHz, providing noise reduction in the critical 3 kHz–8 kHz band, as Figure 19 illustrates. The VCF progressively "opens up" as higher frequency amplitudes are detected at the inputs. The VCF's cutoff reaches 20 kHz when the high frequency signal amplitude is 30 dB above the threshold. At this point the VCF is acoustically transparent. The VCF's cutoff frequency range is between 1 kHz to 35 kHz. The minimum range of the VCF is limited to 1 kHz for two reasons: one, to avoid high frequency loss at the leading edge of transients, because the lower the minimum cutoff the longer it takes the VCF to slew "open," and two, noise is most objectionable at mid and high range frequencies. Once again, if the VCF characteristics are to be measured, then please refer to the section on "Evaluating the SSM2000."

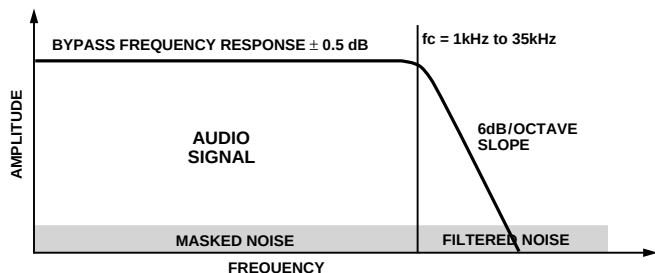


Figure 19. A Frequency Amplitude Plot Illustrating the Noise Reducing Effect of the VCF

The SSM2000 has been designed to minimize control feedthrough. Control feedthrough may cause an audible output as the internal control lines of the VCAs and VCFs are changed rapidly. This feedthrough is the cause of many of the unpleasant artifacts prevalent among noise reduction systems and is often due to parasitic capacitance and mismatches within the IC. This specification is important for the VCA and VCF, but the VCF is the most susceptible because it operates at constant dc gain. The solution incorporated into the SSM2000 to reduce control feedthrough has been to convert from single-ended to full differential at the signal input and convert back again at the output buffer. Because the audio path through the VCA and VCF are fully differential, control feedthrough is determined purely by mismatches with no systematic errors. The slight penalty to be paid for a fully differential system, besides extra complexity, is that the external VCF capacitors (1 nF recommended) now require two pins each instead of one. Careful attention to VCF capacitor matching and layout symmetry reduces control feedthrough to better than 40 dB through the signal path.

Downward Expander

After the audio signal passes through the VCF, it is then differentially sent to the VCA. The VCA is characterized by a downward expander transfer function as shown in Figure 20. Attenuation begins at output levels below the internal threshold at an effective rate of 2.2 dB/decade. Therefore, audible noise is attenuated when source material is not present. Conversely, when audio source levels are at or above the threshold, the VCA is set to unity gain. Because of well documented psychoacoustic effects, it is valid to assume that at high audio amplitudes audio noise is being masked by the audio material. The control information that is required for the downward expander to function properly is provided by the internal VCA detector side-chain circuitry common to both the L and R channels.

Previous downward expander circuits have often used a higher ratio than 2.2 dB/decade to provide impressive noise reduction figures (50 dB or more) in the absence of signal information. However, in most applications, such severe noise gating is totally pointless, and actually exacerbates the effects of VCA control feedthrough, since control feedthrough is not attenuated as the VCA shuts down. For this reason, the maximum VCA attenuation in the SSM2000 is limited to 15 dB. In addition, the “smooth” roll-off of the downward expander eliminates any audible artifacts resulting from this type of noise reduction. In contrast, many noise reduction systems employ gates and comparators that result in dramatic shifts in attenuation. In these types of noise reduction systems noise can be heard switching in and out during periods of low volume audio near that attenuation discontinuity. Telephone systems with noise gating are particularly prone to this type of behavior, because the noise level of

a poor quality connection is very near the gate’s switching level.

The Mute function (Pin 17) can override the VCA controls, as shown in Figure 5. When mute is active (HIGH), it pulls the VCA to maximum attenuation. An 85 dB professional quality mute under worse case conditions can be expected over most of the audible frequency range as shown in Figure 13. Mute overrides both the internal VCA control coming from the VCA Detector and the external VCA control port (Pin 7). The external VCA control port is additive in nature to the internal VCA control signals; therefore, noise reduction and volume control may occur simultaneously in the SSM2000. The VCA control port allows the gain of the VCA to be changed externally at approximately 22 mV/dB, where 150 mV is equal to 0 dB, as shown in Figure 10a.

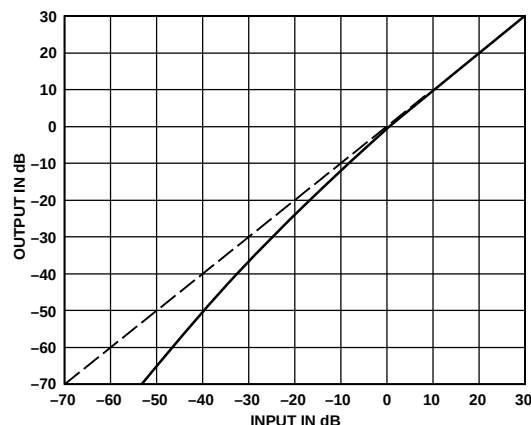


Figure 20. Downward Expander Transfer function

VCF Detector

Both the VCF and VCA detectors are amplitude detectors and identical in every way. The applied input signals to the detectors must be preconditioned for the detector circuitry to give the information that is required by the L and R VCFs and VCAs. Figure 21 is a schematic of the recommended preconditioning filters for use with the VCA and VCF detectors.

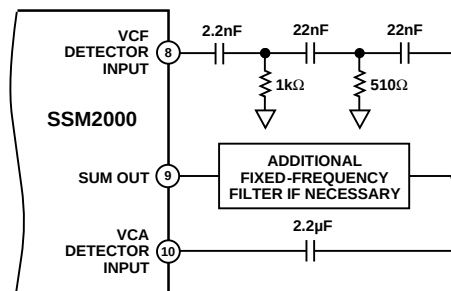


Figure 21. The Recommended Signal Preconditioning Filters for the VCA and VCF Detectors

The VCF detector is fed by $3 \times (L+R)/2$ averaged input signal processed by a three-pole high pass filter with a -15 dB point at 10 kHz. In Figure 22, the response of the VCF’s 3-pole filter is shown. The VCF preconditioning filter performs two functions: first, it eliminates the large amplitude, low frequency audio which would otherwise mask the high frequency signals; and second, it becomes increasingly sensitive throughout most of the VCF’s frequency range of interest (660 Hz to 20 kHz), compensating for the effect of most audio signals which typically decrease in amplitude as frequency increases.

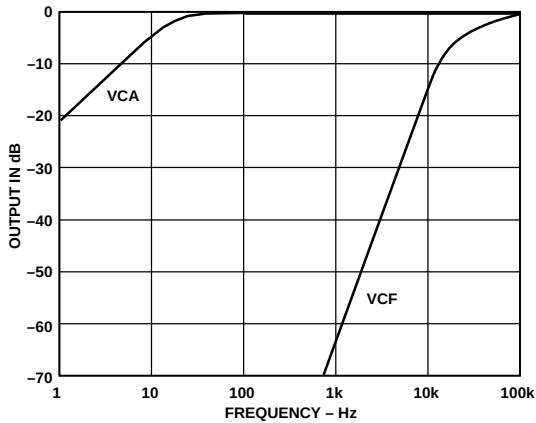


Figure 22. Preconditioning Filter Responses for the VCF
DET IN and VCA DET IN

Once the preconditioned VCF signal is applied to the input of the VCF detector, the $\log(x)$ of the signal is taken. This $\log$ function essentially removes the effect of large signal peaks and smoothes out the response of the VCF control. After the $\log(x)$ is taken the signal is rectified. The signal is rectified for the following two reasons: first, the following peak detector's output will have less ripple, because twice as many peaks are available; and second, the most negative potential of the rectified signal is equivalent to the noise floor. Following the rectifier, the signal is positive peak detected, as shown in Figure 23.

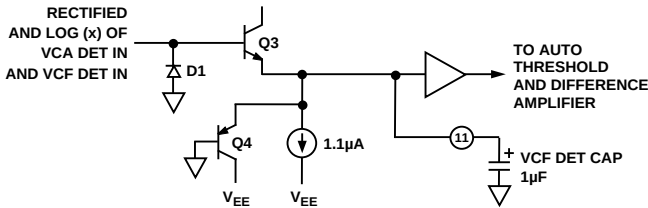


Figure 23. VCA DET IN and VCF DET IN's Positive Peak Detector Circuitry

The attack time of the VCF control is set internally and cannot be decreased, however the release time constant is directly proportional to the value of the capacitor VCF DET CAP. Signals above the potential at Pin 11 cause the emitter diode of Q3 to turn on, thus rapidly charging the VCF DET CAP (Pin 11). When the audio signal has dropped below the potential at VCF

DET CAP, the emitter diode of Q3 is turned off. During this condition, an internal 1.1 μA current source sets the release time by discharging the VCF DET CAP. The release time constant of the VCF Detector is about 10 times faster than the release time constant of the Auto Threshold Detector. This ratio should not be decreased, because the output of the VCF Detector is negative peak detected to arrive at the Auto Threshold level (for more information please refer to the Auto Noise Threshold section). The output of the VCF detector (Pin 11) is multiplied by 13 (A1 of Figure 24) and then the noise threshold is subtracted (A2 of Figure 24) to arrive at the actual control voltage for the L and R VCFs. D1 and Q4 are used to set limits on the output of the detector circuitry to ensure that the detector remains responsive to pulsed high frequency audio.

VCA Detector

The VCF and VCA detectors are identical, therefore refer to the previous section on the VCF detector for detailed information of the internal operation of these detectors. The VCA detector is used to detect the audio-band signal amplitude (20 Hz–20 kHz). Usually the lower frequencies 50 Hz to 2 kHz contain the highest audio amplitudes. Therefore, the VCA's preconditioning filter must allow low frequency signals to be presented to the VCA detector. A single pole filter is used to accomplished this function. This filter is formed by a 2.2 μF capacitor and the 6 k Ω of internal input impedance of Pin 10 as shown in the schematic, Figure 21.

Adaptive Noise Threshold

The threshold level chosen for both the variable filter and downward expander is of prime importance in differentiating between signal and noise. In an automotive environment for example, the audio sources are generally AM and FM radio, tape, and CD. Setting the noise threshold at a value suitable to improve a noisy FM station could easily wipe out most of the dynamic range of a CD. FM station threshold setting is compounded by the vast variations in signal strength in any given location, and the fact that many FM receivers will revert to monaural operation with a greatly improved signal to noise ratio when signal strengths become weak. It is also unreasonable to expect the driver of an automobile to fiddle with panel controls in order to improve the threshold tracking. The patented adaptive noise threshold in the SSM2000 solves these problems, maintaining the transparency of the noise reduction system under most operation conditions while not introducing cumbersome end-user controls.

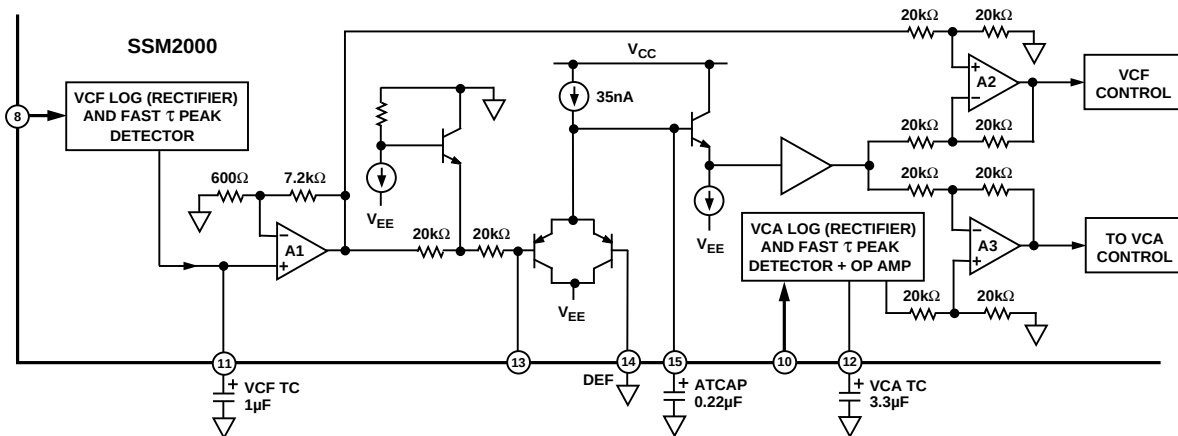


Figure 24. Schematic Diagram of the Adaptive Noise Threshold and Related Circuitry

Noise is most objectionable at high frequencies (3 kHz–8 kHz). Therefore, only the VCF detector output signal is used to determine the adaptive noise threshold. Figures 25a–c, are a series of circuits which illustrate how the noise threshold is derived. It is important to remember that the signal that is applied to the noise threshold detector circuitry has already been rectified and averaged. Hence, the lowest potential over a set period of time corresponds to the noise floor. Node A corresponds to the output of the VCF Detector, and Node B is proportional to the adaptive noise threshold.

Figure 25a illustrates the condition where the potential at Node A is above the maximum possible potential for Node B. The maximum noise threshold is set by the potential placed on Pin 14. If the potential at Node B rises to a diode drop above Pin 14, then Q1's emitter-base diode turns on and clamps Node B. This is represented by the current flow I2. However, if Node B has not yet risen to the maximum noise threshold level, then both Q1 and Q2 are OFF and the 35 nA current source is charging C1 (A.T. CAP). The auto threshold capacitor should be a ceramic or equivalent low leakage capacitor, because the charging current could otherwise be of similar amplitude to the capacitor leakage current.

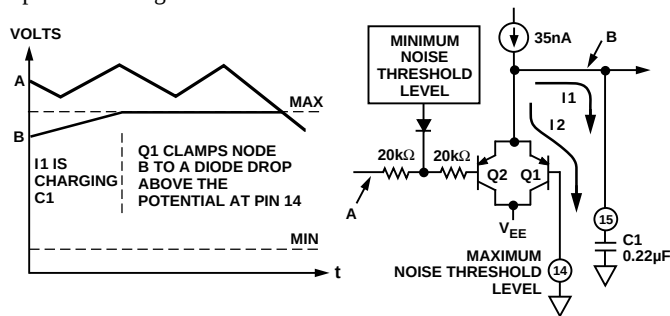


Figure 25a. Condition Where the Actual Noise Threshold Is Above the Maximum Noise Threshold Level Setting (Pin 14)

Figure 25b illustrates the condition where the potential at Node A is between the maximum and minimum potentials for Node B. When Node A falls below Node B, then the emitter-base diode of Q2 turns ON causing Node B to follow Node A. Current I2 illustrates how the discharge current from C1 and the 35 nA current source are directed through Q2. Q2 shuts OFF the moment that Node A rises above Node B. This forces the 35 nA current source to begin charging C1 at a constant rate set by the value of C1 at Pin 15.

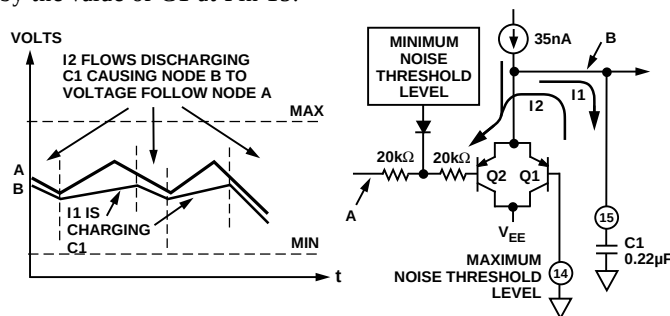


Figure 25b. Condition Where the Noise Level Is Between the Maximum and Minimum Threshold Settings

Figure 25c illustrates the condition where the potential at Node A is below the minimum potential for Node B. In this case the internal minimum noise potential causes a diode to turn ON. This clamps the Node A potential to the minimum noise threshold level. I1 represents the current flow in this condition. In addition, the 35 nA flows through Q2's emitter-base diode as shown by I2.

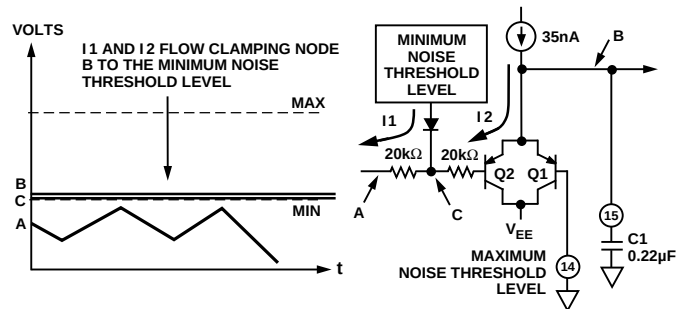


Figure 25c. Condition Where the Noise Level Is Below the Minimum Noise Threshold Level Setting

Simply subtracting the noise threshold from the average VCF HF control signal plus noise threshold and the average VCA control signal plus noise threshold will yield the final VCF and VCA control signal. This operation is accomplished with two internal difference amplifiers.

Figures 26a–b shows the response of the detector that controls the VCF bandwidth and VCA gain respectively. Both L IN and R IN pins receive a 10 kHz tone burst. The lower trace of Figure 26a shows the control voltage to the VCF (Pin 11) and the lower trace of Figure 26b shows the control voltage to the VCA (Pin 12). Note the quick rise and slow fall times. This allows fast adaptation to changed input signal conditions, while avoiding pumping effects and other sonic artifacts.

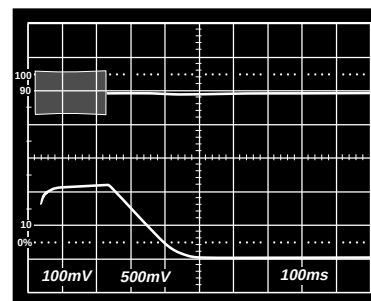


Figure 26a. VCF Control Voltage for a Tone Burst

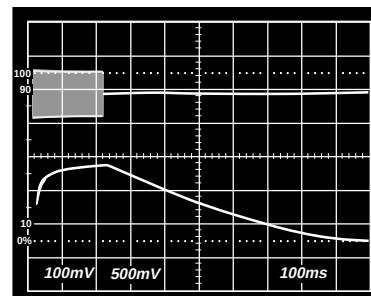


Figure 26b. VCA Control Voltage for a Tone Burst

Signal Chain Position

Figure 27 illustrates a common audio signal path. The SSM2000 is normally placed just before the volume control and power amplifier. The reason the SSM2000 should be placed as far down the signal chain as possible is that noise that is introduced by the previous components will be operated on by the noise reduction system. On the other hand, the SSM2000 works best at the 300 mV rms level and therefore the IC should be placed before any significant volume control. To operate the SSM2000 in a post-volume control position, please refer to the Optional Application Circuits—Using the SSM2000 in a post-volume control application section.

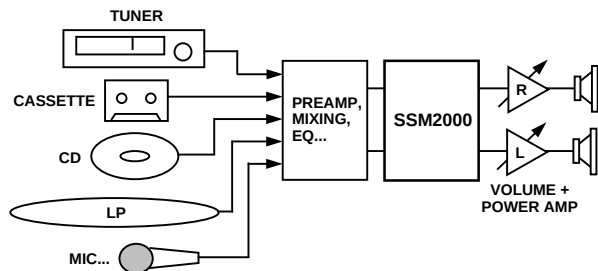


Figure 27. The Position of the SSM2000 in a Common Audio Signal Chain

Powering the SSM2000—Dual Supply

The SSM2000 has a supply voltage range from +7 V to +18 V. A well regulated (< 20 mV of ripple) ± 9 V supply is acceptable, even though this value is exactly equal to the absolute maximum rating of 18 V. The HUSH has been found to be operational down to a supply range of only 4.5 V. However, for guaranteed performance the supplies must be within the specified supply ranges.

The power supplies of choice from a performance perspective are quality linear supplies or batteries, because of their low noise. If a switching supply is required, or the power supply lines are noisy, then adequate filtering of the power supply lines should be provided. It is common to place a power supply filter at the power supply and another at the entry point of power to the audio system, but only one filter is necessary if these two locations are separated by less than a foot or so.

In normal dual supply applications ACOM should be connected to the system ground. If ACOM is not attached to the system ground, then please refer to the section on Powering HUSH—single supply. $V+$ and $V-$ should be connected to their respective power rails. $V+$ and $V-$ will need to be properly decoupled, because the IR drops in the power rails during large signal swings in the HUSH chip can cause additional distortion. As shown in Figure 28a, it is recommended that an aluminum electrolytic bulk storage cap of $1\ \mu\text{F}$ be placed in the vicinity of the HUSH chip and a $0.1\ \mu\text{F}$ ceramic capacitor be placed directly at the HUSH chip. Both power rails should be decoupled this manner.

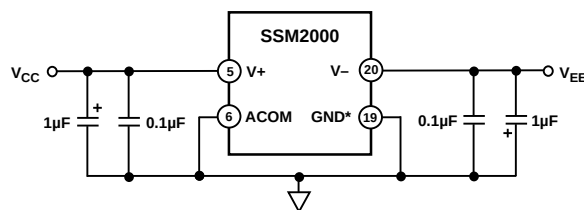


Figure 28a. The Dual Power Rail Connections for the SSM2000

Powering the SSM2000—Single Supply

To operate HUSH in the single supply mode, a false ground potential should be generated and attached to ACOM, as shown in Figure 28b. This false ground is usually set at the midpoint between the power rails. The false ground that will be created for the HUSH chip must be able to both sink and source current up to 10 mA. A low cost OP292 will perform this function very well. Once again, a $1\ \mu\text{F}$ aluminum electrolytic capacitor and a $0.1\ \mu\text{F}$ ceramic capacitor should be used to decouple both the false ground potential and positive supply from the negative supply. It may be helpful to read the preceding section “Powering HUSH—Dual Supply” for information on power supply issues that affect both dual and single supply applications.

Mute (Pin 17) and Bypass (Pin 16) potentials should be referenced to DGND. Other inputs are either capacity coupled or referenced to ACOM.

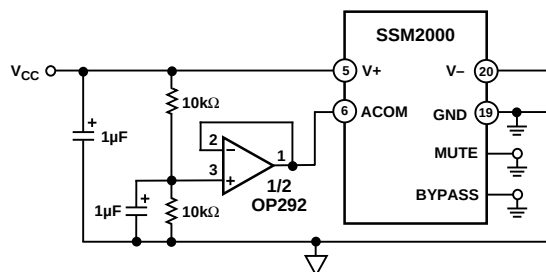


Figure 28b. Powering the SSM2000—Single Supply

DETAILED PIN DESCRIPTIONS

Left Audio IN and Right Audio IN (Pins 1, 2)

L IN and R IN are the inputs for the Left and Right channels. These are each single ended inputs with an input impedance of $10\ \text{k}\Omega$. The input driver for SSM2000 should be able to handle this load level without significant harmonic distortion. These inputs should be ac coupled with at least the minimum capacitor value shown in the example circuits, which is $6.8\ \mu\text{F}$. This sets up a high pass filter with a corner frequency of less than 3 Hz. Choosing a lower value capacitor than $6.8\ \mu\text{F}$ may result in the loss of low frequency audio signal. On the other hand choosing a large value will improve low frequency channel separation.

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VCF Capacitor Port (L Pins 3, 4—R Pins 21, 22)

The capacitors connected to these ports control the low-pass filter range of the VCF. Choosing the recommended value, 1 nF, results in a VCF range where the lowest possible low-pass corner frequency is about 660 Hz. There is a 20 dB/decade decrease in amplitude after the corner frequency regardless of the capacitor value at this port. Raising the value to 10 nF lowers the VCF range by a decade to 66 Hz. This will permanently attenuate the high frequency audio signals regardless of the audio frequency spectrum applied to the input of HUSH. In other words, for VCF capacitor values higher than 1 nF, high frequency loss will occur. On the other hand, lowering the value of the VCF capacitor to 0.1 nF will result in a VCF range of 10 kHz to 100 kHz. Of course, most of this range is outside of audible frequencies and is therefore not very useful.

V+ (Pin 5)

V+ is the supply pin. Please refer to the sections “Powering the SSM2000—Dual Supply” and “Powering the SSM2000—Single Supply” for more information.

ACOM (Pin 6)

ACOM is the internal ground reference for the audio circuitry. In single supply applications this pin is normally connected to a low impedance potential that is one half the positive supply. “Powering the SSM2000—Dual Supply” and “Powering the SSM2000—Single Supply” for more information.

VCA Control Port (Pin 7)

As shown in Figure 5, this port connects into the VCA circuitry. The purpose of this port is to allow external control of the VCA amplitude setting or volume in addition to the normal internal VCA detector control. Every 22 mV applied to the port results in a 1 dB decrease in amplitude, with 0 dB corresponding to about 150 mV. Figure 10 illustrates the transfer characteristic of the VCA control port.

VCF Level Control Input Port (Pin 8)

This pin is the input to the VCF control and noise threshold detection circuitry. A three-pole filter is recommended between the SUM OUT (Pin 9) and VCF IN (Pin 8).

SUM OUT (Pin 9)

SUM OUT is the buffered combination of the Left and Right inputs. Figure 29 shows the internal configuration of SUM OUT. It is this combined Left and Right audio signal that will be used by the VCF and VCA detectors to determine audio amplitude and frequency content.

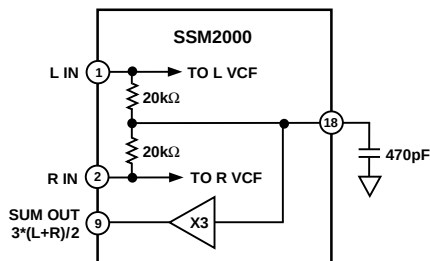


Figure 29. The Internal Circuit for SUM OUT

VCA Level Control Input Port (Pin 10)

This pin is the input to the VCA detector, which outputs a voltage that will control the VCA in the audio signal path. A single-pole filter is recommended between the SUM OUT (Pin 9) and VCA IN (Pin 10).

VCF Time Constant (Pin 11)

A 1 μ F capacitor is normally connected to this point. The purpose of which is to control the rate of change of the VCF's low pass corner frequency. Raising the value of this capacitor from the recommended 1 μ F will tend to increase “breathing” (noise and high frequency signal that slowly fades in and out). Lowering the value of this capacitor from the recommended 1 μ F will tend to increase “pumping” (noise that noticeably cuts in and out). The final capacitor values are, of course, subjective and should be chosen based on one's own evaluation within the system environment.

VCA Time Constant (Pin 12)

The function of this pin is similar to the VCF TC pin. Once again, a 3.3 μ F capacitor is placed on this pin, which controls the rate of change of the VCA's amplitude. Higher value capacitors will result in “breathing” and lower values will cause “pumping.”

DO NOT CONNECT/Adaptive Noise Threshold Override (Pin 13)

Connecting this pin to any low-impedance potential including ground will disable the adaptive noise threshold. Pin 13's internal connection is shown in Figure 24. It is possible to set up an artificial noise threshold using this pin.

Default Noise Threshold (Pin 14)

This pin sets up the maximum noise threshold possible. As can be seen in Figure 25a–c, the emitter voltage of Q1 can be no higher than a diode drop above the potential set at Pin 14. A maximum noise threshold level prevents HUSH from attempting to filter audio signal in the presence of very high noise. The minimum noise threshold detection level has already been set internally by Q3. By setting the lower limit, HUSH is prevented from attenuating already very low levels of noise which would reduce the responsiveness of HUSH.

Auto Threshold CAP (Pin 15)

The recommended 0.22 μ F capacitor connected to this pin controls the rate of change of the adaptive noise threshold level. As shown in Figures 25a–c, if Q1 and Q2 are turned OFF, then a 35 nA constant current source begins to charge the Auto Threshold CAP. This rising potential across the AT CAP represents the detected noise level. Because the capacitor's charging current only 35 nA, a low-leakage ceramic or equivalent capacitor is required to hold the charge.

DEFEAT (Pin 16)

Applying a +5 V volt signal to this pin will defeat the HUSH noise reduction system. Potentials applied to this pin should be reference to GND. Standard TTL levels are recommended when using DEFEAT. Activating DEFEAT causes the VCF detector and VCA detector to send their maximum control signal levels to the VCF and VCA respectively. If DEFEAT is being controlled by noisy digital logic lines, then use adequate filtering to avoid digital noise interfering with audio signals present in the SSM2000.

Mute (Pin 17)

Applying a +5 V voltage signal to this pin will mute the SSM2000. Potentials applied to this pin should be reference to GND. Standard TTL levels are recommended when using MUTE. Activating MUTE causes maximum attenuation in the VCA on both the L and R channels. If MUTE is being controlled by noisy digital logic lines, then use adequate filtering to avoid digital noise interfering with audio signals present in the SSM2000.

DO NOT CONNECT/Detector Bandwidth Limit (Pin 18)

Pin 18 is connected internally to both the left and right channels though 20 k Ω resistors, as shown in Figure 29. This node allows access to the input of the $\times 3$ gain buffer, whose output is SUM OUT (Pin 9). Do not connect this node to ground or another potential. Connecting a 470 pF capacitor to this pin will limit the range of the input signal that runs through the VCF and VCA detectors to 35 kHz. This is an inexpensive way to remove fixed-frequency tones of frequencies of greater than 35 kHz. Please refer the Precautions, Limitations, and Observations section under Pre-filtering Out-of-Audio Band Noise for more information.

GND (Pin 19)

GND is normally connected to V– in single-supply applications and ACOM in dual-supply applications. Please read the MUTE and DEFEAT sections for more information.

V– (Pin 20)

This pin should be connected to the most negative power potential, typically chassis ground in single-supply applications and the negative power rail in dual-supply applications.

R OUT and L OUT (Pin 23 and Pin 24)

The outputs of HUSH are buffered and can therefore drive moderate loads. For loads (e.g., speakers or headphones) which exceed 2 k Ω or 300 pF additional buffering may be necessary.

OPTIONAL APPLICATION CIRCUITS

The SSM2000 has been designed to facilitate numerous additional functions by adding a modest amount of external circuitry. The direct access to the VCA gain control port plus access to the amplitude and frequency detectors allow construction of valuable systems features such as:

- DC Volume Control—one dc level controls both audio channels without routing audio signals to the front panel.
- Automatic Volume Leveling—constrains long term average volume levels to within a few dB, avoiding constant resetting of volume as one tuner through various stations or switches from radio to tape, etc.

- Compression—reduces dynamic range to improve audibility of softer sounds in noisy environments such as when playing CDs in cars.
- Volume vs. Road Speed—a speedometer signal can be used to increase audio levels as road speed increases.
- Compression vs. Road Speed—see above.

Automatic Leveling

Automatic leveling is similar to compression, however instead of attempting to attenuate all large amplitude audio signals, the leveling circuit attenuates audio signal when the overall signal amplitude has increased for a considerable amount of time, >1 sec. Attenuating loud TV commercials whose average volume levels are significantly above the program material is an application where this feature is particularly useful. The circuit shown in Figure 30 is an example of HUSH automatic leveling.

Automatic leveling is a signal amplitude operation, therefore, the input of the circuit is derived from Pin 12, VCA TC. This input voltage is gained and level shifted. The volume control is “counter intuitive,” because the higher the gain the lower the resulting volume, as the VCA control port attenuates when positive voltage is applied. The level threshold potentiometer sets the volume level, which is a gain range of 1.5 dB to –80 dB. After the op amp, the signal passes through a positive peak detector, and is averaged by a long time constant RC. The signal is now representative of the long term average amplitude of the original audio that is applied to the L/R input of the SSM2000. This signal is then passed to the VCA control port.

Audio Compression

Audio compression can be thought of as fast automatic leveling. The purpose of audio compression is to attenuate larger amplitude signals, such that signals above the adaptive threshold will be scaled by 0.2 dB/dB, while the signals below the externally set level threshold will remain essentially unchanged. A shorter time constant and slight gain change are the only differences between the audio compression circuit and the automatic leveling circuit. Figure 30 illustrates the audio compression circuit. The OP275 is an excellent audio amplifier and is suggested for this application when the power supply rails are greater than or equal to ± 5 V. For applications where the power supplies are separated by less than 10 V, then a single-supply op amp like the OP279 is recommended.

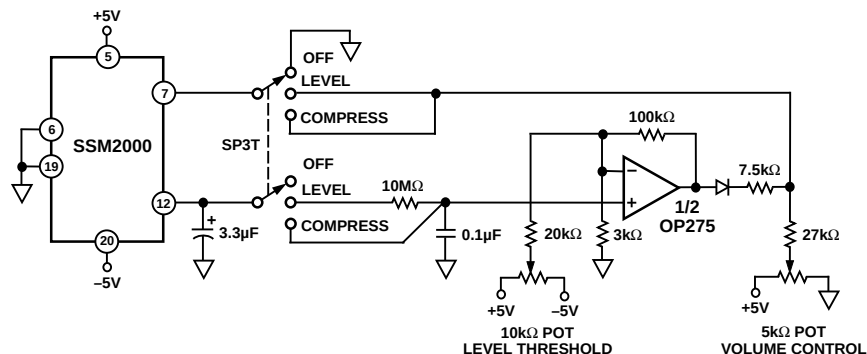


Figure 30. An Automatic Leveling/Compression Circuit

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Volume Control vs. Road Speed

In automotive applications the external volume control port (Pin 7) can also be used to increase the volume as road noise increases. The digital speedometer information available in most vehicles may be filtered or D/A converted and sent to the SSM2000 to control the volume. Figure 31 illustrates a SSM2000 audio volume control system using digital speedometer data.

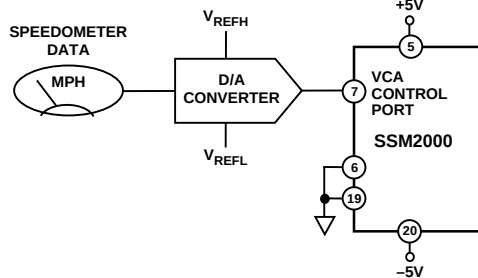


Figure 31. Volume Control vs. Road Speed Block Diagram

Using the SSM2000 in a Post-Volume Control Application

The SSM2000 is capable of operation for limited reasonable changes in input levels, because of the internal adaptive noise threshold detector. However, this detector is limited in range for optimal performance and therefore external circuitry is required if the prevolume control line level is to be changed by more than -20 dB. Figure 32 illustrates a circuit that alters the range of the noise threshold.

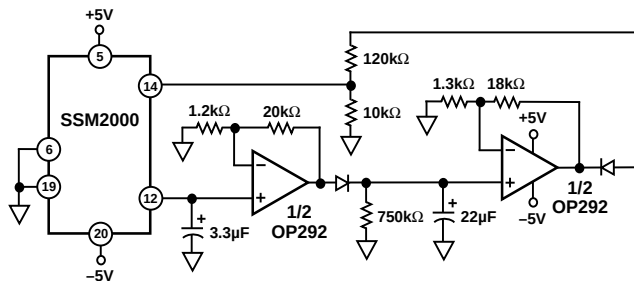


Figure 32. A Schematic to Use the SSM2000 in a Post-Volume Control Application

PRECAUTIONS, LIMITATIONS, AND OBSERVATIONS

Operating Temperature

Under light loading conditions HUSH runs relatively cool, typically only 4°C over ambient room temperature. If HUSH is hot, then check to make sure that the capacitive and resistive loading requirements are not being exceeded.

Operating Signal Amplitude and Frequency Range

The output signal range of the SSM2000 is set internally (3.67 V p-p @ 0.1 THD) and will not increase even if the power supply rails are raised. The frequency range is set by the input ac coupling capacitors (< 10 Hz) and by the VCF which is internally limited to 35 kHz.

Excess External Noise

Even though the SSM2000 is a noise reduction IC, excessively high noise floor amplitudes may result in no noise reduction. Common causes of this condition are high audio volume or very poor reception. In this case the VCF and the VCA will remain at their maximum settings and the audio signal will simply pass through HUSH.

Prefiltering Out-of-Audio Band Tones

The most common cause of SSM2000 operational error is due to large amplitude fixed-frequency tones. When SSM2000 detector's are exposed to large fixed-frequency tones, they recognize these types of tones as signal and automatically adjust the VCA and VCF to allow this frequency to pass through to the output along with the underlying noise. The following is a list of typical fixed-frequency tones which might cause this type of HUSH behavior: switching power supply noise (20 kHz–200 kHz), sampling frequency in digitized music (44 kHz), PC monitor scan frequency (30 kHz), microprocessor operating frequency or submultiple, and FM stereo subcarrier frequency (19 kHz). Figure 33 is a scope photo of a spectrum analyzer output showing the 19 kHz FM stereo subcarrier frequency. So, if your application will encounter any of these types of noise sources, then a preconditioning filter for the internal detector is necessary.

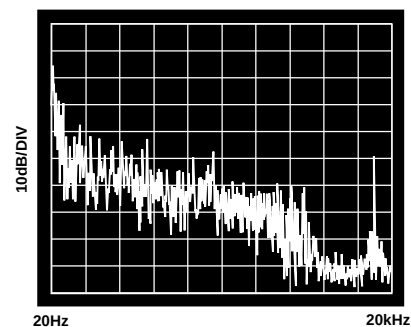


Figure 33. Scope Photo of the 19 kHz FM Subcarrier Frequency

Figures 34 and 35 illustrate two different approaches to filtering these undesired tones. If the interfering tone frequency is less than 20 kHz (e.g., TV-15.625 kHz), a Twin-T Hi-Q notch filter as shown in Figure 34 should be used. The notch filter will attenuate the tone while having a minimal effect on the audio band signal. For interfering tones above 20 kHz, a general 3-pole low-pass filter is recommended, such as the Butterworth filter shown in Figure 35. The input of the filter should always be connected to the output, SUM OUT. Filtering the SUM OUT signal will not affect audio quality because the SUM OUT signal is not part of the main audio path. However, overaggressive filtering may remove noise and signal that is necessary to set the VCA control, VCF control, and noise threshold levels. The OP292 or OP275 shown in the example filter circuit are high performance, low cost amplifiers suitable for this application.

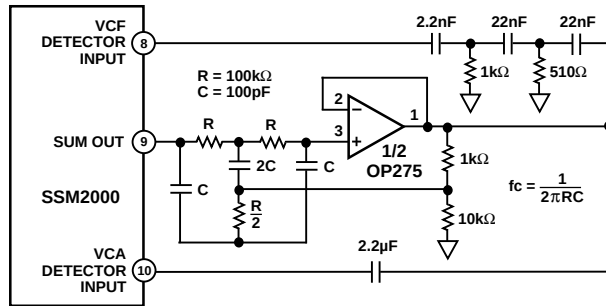


Figure 34. A Hi-Q Twin-T Notch Filter with the Center Frequency at 15.625 kHz

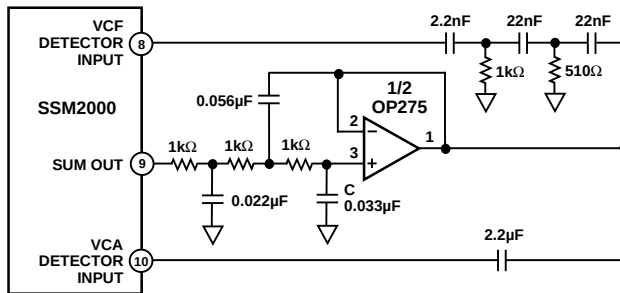


Figure 35. A Three-Pole Butterworth Filter

Channel-to-Channel Separation

The SSM2000 has a 60 dB of channel separation specification at 1 kHz. As shown in Figure 36, the Left input to the R VCF node and the Right input to the L VCF node are tied together with 50 kΩ of resistance, and tied to ground with 2.5 kΩ. If the Left and Right ac coupling capacitors were not present this would result in a dc separation of around -27 dB. However, the inputs of the SSM2000 are usually ac coupled; therefore the low frequency channel separation is a function of the value of the ac coupling capacitors and the theoretical dc separation. The higher the value of the ac coupling capacitor, the better the channel separation will be. For example, using 10 μF ac coupling capacitors will result in 32 dB of channel separation at around 6 Hz–8 Hz, improving at a rate of 20 dB/decade, till it reaches a maximum -60 dB. Therefore, to achieve 60 dB of channel separation at 75 Hz and above, 47 μF capacitors are recommended.

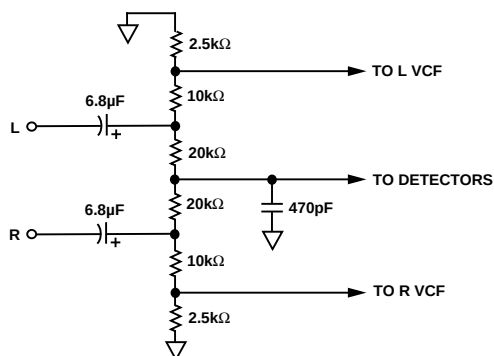


Figure 36. The SSM2000's Input Impedance Network

EVALUATING THE SSM2000

Because the SSM2000 is a dynamic system, it will respond to test signals that are applied during the evaluation procedures. Without thorough understanding of how the HUSH noise reduction system works, attempts to apply standard test procedures can produce misleading results. The following paragraphs will present evaluation techniques to avoid many of these common evaluation pitfalls.

The SSM2000 has been designed as a stereo system. As a result the input to the detector circuits is the sum of both the left and right inputs. Monaural signals that used during evaluation should be applied to both inputs, because the detectors' input requires both the left and right signal. Otherwise, the control levels from the VCA detector, VCF detector, and the Adaptive Noise Threshold will be about one-half the necessary amplitude for proper evaluation results.

The SSM2000 has exceptional tolerance for varying line levels with noise reducing capability between line levels of 100 mV rms to 1 V rms. However, the IC has been optimized for an industry standard input line level of 300 mV rms. Audio line levels not equal to 300 mV rms will exhibit slightly degraded specifications (e.g., distortion). If the line levels are outside of the 100 mV rms to 1 V rms range, then audio output may appear to have no noise reduction or to be muted. The circuit shown in Figure 32 will enable noise reduction for very low line level audio.

THD measurement instruments typically sweep a sine wave across the audio spectrum. The normal SSM2000 response to this type of signal results in the automatic noise threshold detector slowly rising to its maximum value; the VCA detector at maximum value, the VCF detector will initially be closed at low frequencies and will gradually open as the frequency is increased. When the testing signal reaches about 500 Hz, it will begin to be attenuated by the "closed" VCF. This attenuation will reach at maximum of about 1 dB at 660 Hz for recommended line levels, at which point the VCF detector begins to open up. However, all these conditions and characteristics are not representative of a normal music signal. To properly measure THD, it is necessary to activate HUSH Defeat. THD measurements in DEFEAT mode give accurate results because it does not remove the VCA and VCF from the signal chain, rather it sets their values to unity (VCA) and maximum frequency (VCF).

The bandwidth of the SSM2000, as stated before, is limited to 35 kHz because of the VCF capacitors. This bandwidth limitation must be taken into account when the slew rate of the SSM2000 is measured. The simplest method to measure slew rate is to remove the VCF capacitors from the circuit, and take the slew rate measurement while in DEFEAT mode. If the VCF capacitors are not removed, then the audio signal is limited by the VCF's bandwidth and not by the overall slew rate.

One standard of the SSM2000's audio quality is the characteristics of the attack and release times of the VCA and VCF. The attack and release times of the VCA and VCF are controlled by 1.1 μA current sources which charge the VCA Time Constant capacitor and VCF Time Constant capacitor. The attack and released times are typically measured from the VCA's and VCF's fully closed position (e.g., VCA—maximum attenuation,

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VCF—minimum bandwidth) to their fully open positions. If the VCA and VCF are fully opened then at least 1.5 seconds of no signal is required for the VCA and VCF detectors to return to the closed position. A series of 10 kHz pulses interspersed with 1.5 seconds of no signal will accomplish this requirement. The system's attack and release times will be dominated by VCA since the attack and release times of the VCA are slower than the VCF's. In addition, monitoring Pins 11 (VCF) and 12 (VCA) will ensure that the VCA and VCF are either fully opened or fully closed.

As stated before, the most common cause of a failure to reduce noise is fixed-frequency tones that are being detected by the output. A solution for this condition is detailed in the "Precautions, Limitations, and Observations" section.

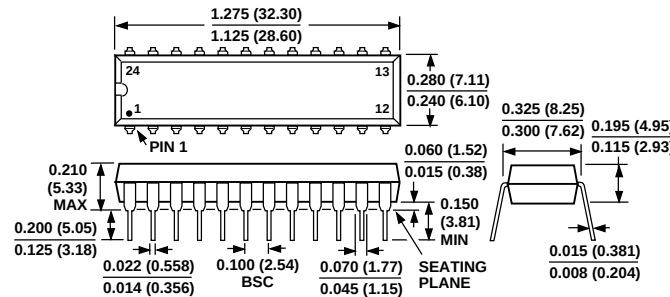
In single-supply applications, ACOM should be driven with a well regulated reference capable of both sinking and sourcing current. Zener-resistor references are unacceptable, because of their inability to sink significant amounts of current.

By following these simple suggestions, the common pitfalls to a successful implementation of the HUSH noise reduction system can be avoided.

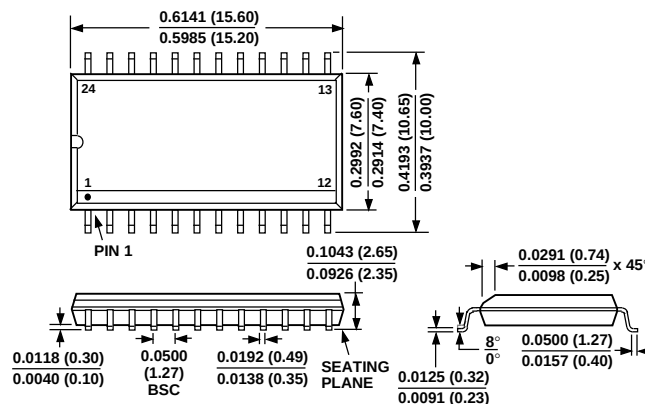
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

24-Pin Plastic DIP (N-24)



24 Pin SOIC (SOL-24)



IMPORTANT NOTICE—LICENSING

The SSM2000 is manufactured under a license granted to Analog Devices, Inc., by Rocktron Corp. and embodies technology covered by the following patents: 4696044, 4893099, 5124657, 5263091, 5402498, and 5493617. Foreign patents are pending. Rocktron Corp. grants a royalty-free license to purchasers of the SSM2000 for use in end equipment, and no further rights are implied. The use of the HUSH logo is encouraged on products, packaging,

promotional and descriptive literature. Rocktron Corp. reserves the right to approve use of the HUSH logo and may require submission of a schematic illustrating the use of the SSM2000; a physical sample of the end product may also be required. Applications for approval of the use of the HUSH name and logo may be obtained by contacting ADI.