Op amp linearizes attenuator control response

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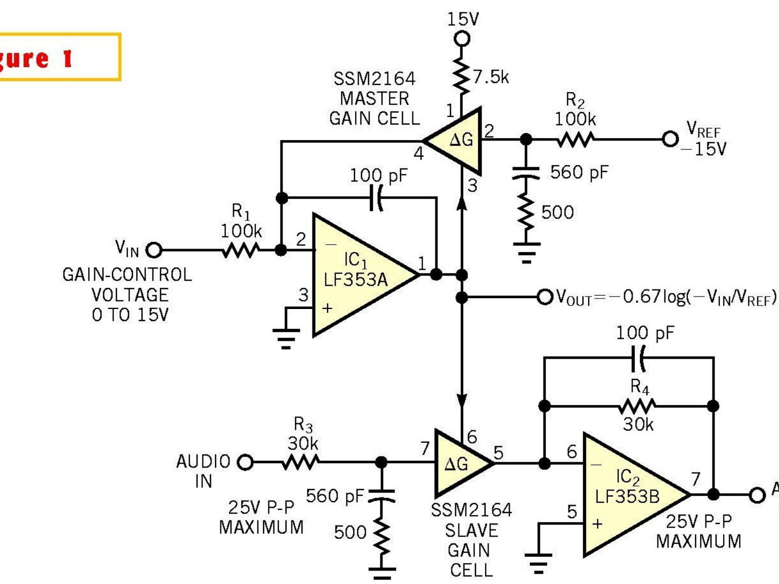
Professional-audio equipment commonly uses Analog Devices' (www.analog.com) high-performance, quad-voltage-controlled SSM2164 attenuator. The control response is −30 dB/V, with 0V producing unity gain. Attenuation increases as the applied control voltage increases in the positive direction. The circuit in **Figure 1** extends the range of applications for this versatile chip by providing a simple means of linearizing the control response. The result is an amplifier with gain directly proportional to the control voltage. In addition, the circuit also functions as a simple logarithm generator. You can use a single SSM2164 to make two high-quality, linear voltage-controlled amplifiers using this method. The four gain cells in the SSM2164 are tightly matched, current-in, current-out transconductance multipliers. The control response of each gain cell is: $\text{gain}=10^{(-V/0.67)}$. The cells are noninverting structures.

Figure 1

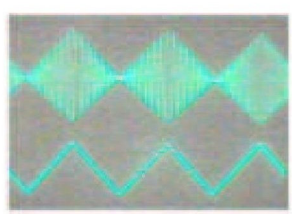


You can obtain both a gain-controlled output and a logarithmic output using this configuration.

Each voltage-controlled amplifier uses two gain cells. A "master" cell in the feedback loop of an op amp generates a logarithmic voltage output in response to a linear voltage input. This log voltage then goes to the control pin of the second (matching) "slave" cell, which processes the audio signal. Op amp IC_1 maintains its inverting input at virtual ground by servo-controlling the gain of the master SSM2164 cell, which connects to the negative reference voltage. The output of IC_1 is a logarithmic function of the input: $V_{OUT}=-0.67\log[(-V_{IN}R_2)/(V_{REF}R_1)]$. V_{IN} is the gain-control voltage, and V_{REF} is the negative reference voltage. V_{OUT} then drives the control pin of the slave cell. Substituting the expression for V_{OUT} for V in the expression for gain yields the following: $\text{gain}=(V_{IN}R_2)/(V_{REF}R_1)$, which is the desired linear response.

Op amp IC_2 converts the slave cell's output current to an audio voltage with a gain of R_4/R_3. The overall expression for the gain is: $\text{gain}=(V_{IN}R_2R_4)/(V_{REF}R_1R_3)$. If $R_1=R_2$ and $R_3=R_4$, the expression reduces to: $\text{gain}=V_{IN}/V_{REF}$, and gain (in decibels) $=20\log(V_{IN}/V_{REF})$. Setting V_{IN} to 15V and V_{REF} to −15V produces unity gain with the indicated component values. The gain decreases smoothly to −70 to −80 dB as the control voltage decreases (**Figure 2**). The voltage-controlled amplifier then shuts off completely (attenuation=100 dB) when the control voltage drops to within a few millivolts of 0V. Negative voltages make the output of IC_1 swing close to the positive rail, but IC_1 promptly comes off the rail when the control voltage returns to the 0 to 15V range. The circuit produces no audible clicks and works well at lower supply voltages, such as ±5V.

Figure 2



The lower trace is a 0 to 3V triangle wave, which you use to modulate the 10-kHz sine wave in the upper trace. Note the linear modulation envelope.

For best performance, IC_1 should be a low-offset, low-input-current unit, and IC_2 should be a high-quality, low-noise audio op amp. However, you can obtain reasonably good performance with inexpensive op amps, such as the TL072 and LF353. The prototype unit achieved a control range of 75 to 80 dB, using an OP-290 for IC_1. The control-voltage feedthrough on the audio output is minimal, varying 10 to 20 mV when you sweep the gain through a 70-dB range. The noise and distortion performance is excellent, because the design uses the gain cells in the standard configuration in the SSM2164 data sheet.