5.1 Channel
Volume Control

The circuits within this application note feature THAT218x to provide the essential function of voltage-controlled amplifier (VCA). Since writing this note, THAT has introduced a new dual VCA, as well as several Analog Engines®. Analog Engines combine a VCA and an RMS detector (RMS) with optional opamps in one part. With minor modifications, these newer ICs are generally applicable to the designs shown herein, and may offer advantages in performance, cost, power consumption, etc., depending on the design requirements. We encourage readers to consider the following alternatives in addition to the 218x:

- Analog Engine (VCA, RMS, opamps): 4301

- Analog Engine with low supply voltage and power consumption (VCA, RMS, opamps): 4320

- Analog Engine with low cost, supply voltage, and power consumption (VCA, RMS): 4315

- Analog Engine with low cost and power consumption (VCA, RMS): 4305

- Dual (VCA only): 2162

For more information about making these substitutions, please contact THAT Corporation's technical support group at apps_support@thatcorp.com

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Newer 5.1 channel home theater systems will benefit from a rethinking of existing approaches for controlling volume. In the past, ganged, audio taper potentiometers controlled the stereo (2 channel) signal, and the mis-tracking between channels was tolerated, since it could be easily compensated for with a balance control. This situation no longer applies, since the digital stream in which the audio is encoded is directly decoded into the left, center, right, left rear, right rear, and sub-woofer channels, and there must be independent control of each of these signals.

Voltage controlled amplifiers (VCAs) provide a superior alternative to a six section ganged potentiometer. The exponential control input of log/anti-log VCAs is considered by many to be a superior control function in comparison with a ganged, audio taper potentiometer. The audio taper potentiometer uses concatenated linear sections to approximate logarithmic volume control. A linear control voltage applied to the VCA's control port results in volume control that is linear in decibels. Additionally, tracking between VCAs is superior to that of ganged potentiometers, being essentially limited by the thermal mismatches between devices.
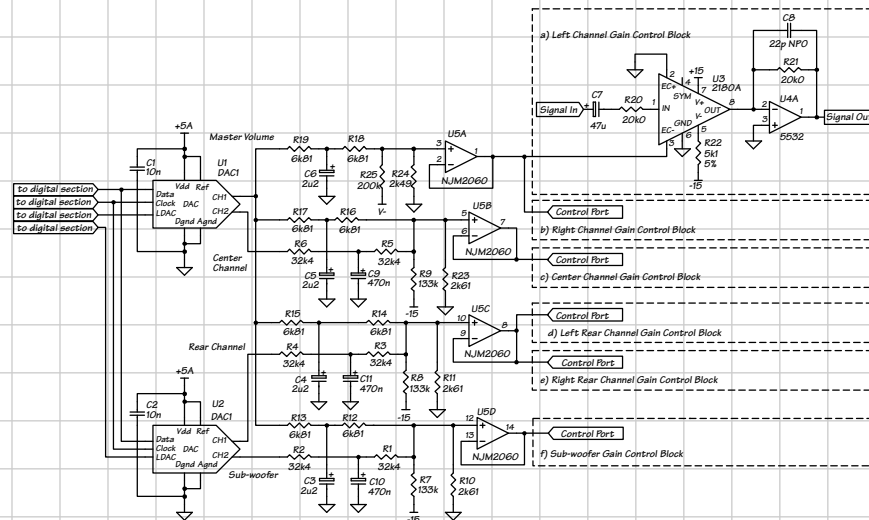
5.1 Channel Volume Control Circuit (see page 6 for a larger version of this diagram)

The attached schematic show how VCAs facilitate remote gain control without the use of a motorized potentiometer (though a single, linear, motorized pot could be used as a master volume control), and simplify the implementation of independent balancing of center, rear, and sub-woofer level. This circuit uses four, linear 8-bit DACs to control the Master (overall) volume and to provide greater than ±12 dB of fine adjustment to the Center, Rear, and Sub-woofer channels.

Only one channel is shown in the VCA section. The remaining 5 channels are identical to the left channel gain control block, and consist of a THAT 2180A VCA and one half of a 5532 op-amp. The THAT 2180A provides the best distortion performance of any pre-trimmed VCA available on the market today. The 5532 is a good audio op-amp, though any number of

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amplifiers including the OP-275 and the LM833 could be used in its place. Layout for this VCA is relatively straightforward, and there are only two basic issues to be concerned with:

1. The node connected to the output of the VCA (and the inverting input of the 5532) should be as small as it can reasonably be made. This will help minimize channel to channel cross talk and maximize "off isolation", which are both due to signal being capacitively coupled from a channel input to the output node of the VCA. Also, with the 5532s and their associated de-coupling capacitors placed close to the VCA, there should be no need for additional de-coupling around the VCA.

2. The packages of the VCAs should ideally be arranged in a line with the bodies actually touching. This arrangement helps keep the VCAs at the same temperature, and minimizes temperature dependent gain variations between devices. These VCAs are superior to ganged potentiometers with respect gain linearity and tracking, and when we do see problems, thermal mis-tracking is usually the problem. A benefit of this arrangement is that the layout is made very simple. With the VCAs in-line and all in the same orientation, GND, V+, and EC+ of all of the VCAs can be connected to each other with straight traces on one side of the board. The traces connecting EC- and V- can be on the other side of the board and run between the VCAs. The input and output are at the ends of the package and should not be difficult to route.

This design uses four linear 8-bit DACs to accomplish both overall gain adjust of all six channels and fine trim of the center, rear, and sub-woofer channels. The master volume signal is injected into all of the channels, and center, rear, and sub-woofer controls are superimposed onto the master volume signal.

The exact derivation of the component values used in these summing networks is rather tedious, and not particularly instructive. It is useful, however, to understand the actual functions of these components. In the left and right channel control path (which is buffered by U5A), the master volume signal is injected through R18 and R19, and the actual control signal develops across the parallel combination of R24 and R25:

$$R_{eq\ R24,R25} = \frac{1}{\frac{1}{2.49k\Omega} + \frac{1}{200k\Omega}} = 2.45k\Omega$$

And

$$R_{eq\ R18,R19} = 2 \times 6.81\ k\Omega = 13.62\ k\Omega$$

With a DAC reference of 5V, the control port voltage can swing

$$CV_{swing} = \frac{5\ V \times 2.54\ k\Omega}{2.45\ k\Omega + 13.62\ k\Omega} = 0.762\ V$$

which, in dB, is

$$CV_{dB} = \frac{0.762}{6.1\frac{mV}{dB}} = 125\ dB$$

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Since this voltage connects to EC-, this swing is from zero dB to -125 dB. R25 serves to offset this swing into the usable range of the VCA. The current through this resistor develops across the parallel combination of R24 and R18 plus R19.

$$R_{eq\,R18,R19,R24} = \frac{1}{\frac{1}{2.49\,k\Omega} + \frac{1}{13.62\,k\Omega}} = 2.11\,k\Omega$$

Since R25 is connected to -15V,

$$CV_{offset} = \frac{15\,V \times 2.11\,k\Omega}{2.11\,k\Omega + 200\,k\Omega} = 0.157\,V$$

which, in dB, is

$$CV_{dB\,off} = \frac{0.157}{6.1\frac{mV}{dB}} = 25\,dB$$

resulting in a gain range of -100 dB to +25 dB.

The fine trim of the center, rear, and sub-woofer channels is accomplished in a similar manner. The center channel trim is injected through R5 and R6, and developed across the parallel combination of R9, R23, and R16 plus R17. R9 serves the same purpose as R25 in the previous discussion, but it must now offset both the master volume signal and the center channel trim, and its value has been reduced accordingly. R23 serves the same purpose as R24 in the discussion above, but since the master volume signal now develops across the parallel combination of R23, a reduced R9, and the series combination of R5 and R6, the value of R23 has been increased to keep the scale factor of the master volume constant.

The equivalent resistances used when calculating the center channel trim sensitivity are:

$$R_{eq\,R9,R23,R16,R17} = \frac{1}{\frac{1}{2.61\,k\Omega} + \frac{1}{133\,k\Omega} + \frac{1}{2 \times 6.81\,k\Omega}} = 2.15\,k\Omega$$

And

$$R_{eq\,R5,R6} = 2 \times 32.4\,k\Omega = 64.8\,k\Omega$$

With a DAC reference of 5V, the control port voltage can swing

$$CV_{swing} = \frac{5\,V \times 2.15\,k\Omega}{2.15\,k\Omega + 64.8\,k\Omega} = 0.161\,V$$

which, in dB, is

$$CV_{dB} = \frac{0.161}{6.1\frac{mV}{dB}} = 26\,dB$$

Since this voltage connects to EC-, this swing is from zero dB to -26 dB. R9 serves to offset this swing and make the adjustment range symmetrical. The current through this resistor develops across the parallel combination of R23, R5 plus R6, and R16 plus R17.

$$R_{eq\,R6,R7,R16,R17,R23} = \frac{1}{\frac{1}{2.61\,k\Omega} + \frac{1}{2 \times 32.4\,k\Omega} + \frac{1}{2 \times 6.81\,k\Omega}} = 2.11\,k\Omega$$

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Since R23 is connected to -15V,

$$CV_{offset} = \frac{15\,V \times 2.11\,k\Omega}{2.11\,k\Omega + 133\,k\Omega} = 0.234\,V$$

which, in dB, is

$$CV_{dB\,off} = \frac{0.234}{6.1\frac{mV}{dB}} = 38.4\,dB$$

25 dB are used to offset the master volume as was the case in the left and right channel control path, while the remaining 13.4 dB (approximately one half of 26 dB) offset the center channel signal.

The same control path is used for the rear and sub-woofer channels. C3 through C6 and C9 through C11 are used to limit the slew rate of the control port voltage as well as serving to absorb any glitch energy from the DACs.

This approach satisfies the basic requirements for a 6 channel volume control. Using linear 8-bit DACs to generate a control voltage for the exponential control port of a VCA is a low cost way to control volume over a 125 dB range, and the use of DACs makes remote control easier to implement.

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