An Overview of Audio Volume Control

1. Introduction

One of the most important features on any audio system is signal level control. This function may be needed both for incoming audio signals, e.g. in a mixing desk or recording device, and for signals going out to a loudspeaker or headphone. Although at first sight, changing a signal's amplitude may seem simple, the requirements of today's increasingly sophisticated audio markets make volume control far from trivial.

The important parameters for a modern volume control circuit are:

- Sound quality: Low noise and distortion
- Logarithmic scale: As the sound volume perceived by the human ear depends logarithmically on the audio signal's amplitude, volume controls should also be logarithmic. With a linear scale, the perceived volume would change very rapidly at the low end of the scale, but not vary much at the high end.
- Digitally controllable: This is particularly important in remote-controlled audio equipment.
- High reliability
- Minimal physical size and power consumption: These are critical in portable or battery powered equipment.
- Accuracy: Setting the volume level accurately can be important in studio or professional audio; in the consumer market, accuracy is relatively unimportant.
- Cost effectiveness

This paper will examine some of the techniques that have been used for volume control, and present the advanced solutions offered by Wolfson Microelectronics.

2. Potentiometers

The simplest type of volume control is based on the potential divider principle, using a potentiometer that is mechanically adjusted with a slide or rotary knob.

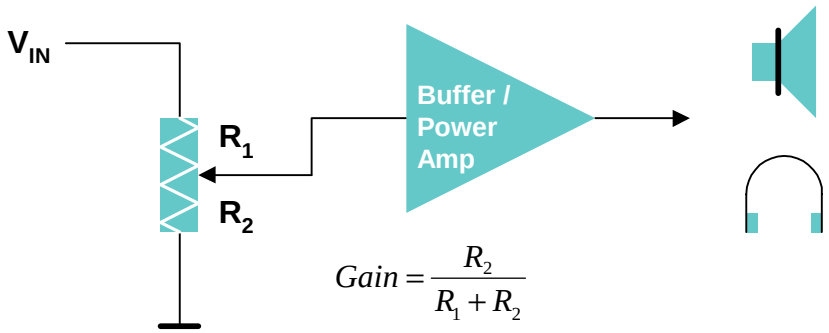

Figure 1 Volume Control using a Potentiometer

Logarithmic potentiometers are readily available as mono or stereo ('tandem') parts, sometimes with an integrated on/off switch. This solution is simple and cost effective and introduces very little noise and distortion to the audio signal. However, it carries some significant disadvantages:

- Like other electromechanical components, potentiometers are inherently prone to mechanical failure. Moreover, if dust particles find their way into the casing, they can cause crackling noises when the volume is adjusted.
- Remote or digital control is only possible with a stepping motor, which adds significant cost to the system.
- Gain accuracy and matching between channels is generally poor; more accurate potentiometers are expensive.

3. Voltage Controlled Amplifiers (VCAs)

Some of the problems associated with potentiometers can be avoided using voltage-controlled amplifiers. These are amplifiers whose gain depends on an externally applied DC voltage. The control voltage can be generated by a potentiometer or a digital-to-analogue converter (DAC), as shown in Figure 2.

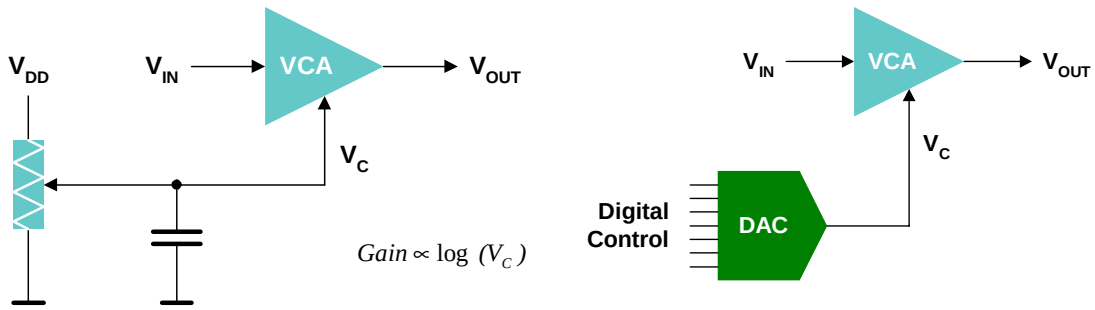

Figure 2 Volume Control using a VCA

If a potentiometer is used, crackling noises can be eliminated using a capacitor, as shown. Furthermore, the potentiometer can be situated at some distance from the VCA without lengthening the audio signal path and exposing the signal to interference. With a DAC, the control input is digital, enabling wireless remote control.

Mono and stereo VCAs are readily available as integrated circuits (ICs), sometimes with integrated tone controls. Despite their advantages, VCAs suffer from some important drawbacks:

- The linearity of VCAs is relatively poor, resulting in harmonic distortion.
- Like all amplifiers, VCAs generate thermal noise, degrading the audio quality.
- Gain accuracy is relatively poor.

4. Volume Control in the Digital Domain

Where the audio source is in digital format, e.g. in a CD, DVD or MP3 player, volume control can be performed in the digital domain, before the signal is converted into analogue form. This is achieved by simply multiplying each signal sample with the volume setting.

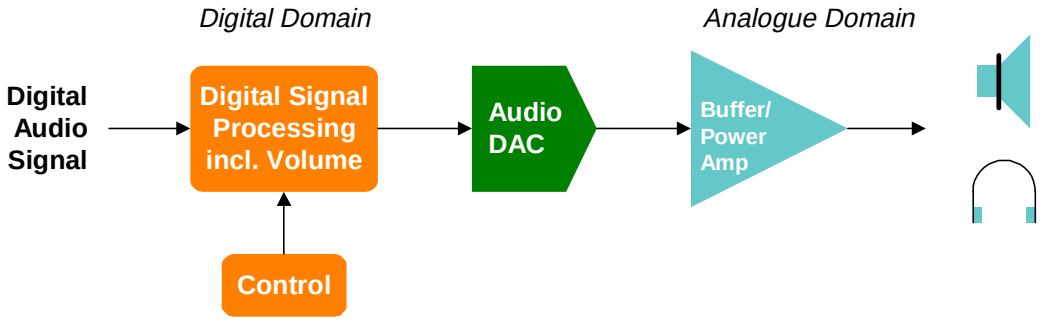

Figure 3 Volume Control in the Digital Domain

Digital volume control algorithms are often used in digital recording and mixing. Implemented as logic circuitry on a Digital Signal Processor (DSP) or other IC, they offer highly accurate, high fidelity signal level control. In microprocessor or DSP-based consumer systems, they enable high-reliability volume control at no extra hardware cost.

Wolfson Microelectronics has incorporated digital volume control as a feature on most of its audio DACs, such as the WM8720, WM8716, WM8728 and WM8740. These devices have digital control registers that allow the user to signal attenuations between 0 and −127 dB, in 0.5dB (logarithmic) steps.

The obvious disadvantage of digital volume control is that the audio source needs to be digital. Although it is possible to digitise analogue signals, perform digital volume control and convert them back to analogue, the added cost, complexity and performance degradation make it more practical to keep volume control in the analogue domain where the signal source is analogue.

Another drawback of digital volume control is that the signal-to-noise ratio (SNR) worsens at low volumes. This is due to the quantisation error, which is inherent in any digital system and may result in audible noise. Its magnitude depends on the resolution of the digital audio data and/or the DAC. High-end audio systems are designed such that any noise is negligible compared to the magnitude of the audio signal, and therefore inaudible. However, when volume control is performed in the digital domain, the digital audio signal's amplitude may be decreased by several orders of magnitude while quantisation noise remains constant, resulting in a lower SNR (see Figure 4). This is not the case with analogue volume control, where any gain or attenuation applied to the signal affects DAC quantisation noise equally, so that the signal to noise ratio stays constant.

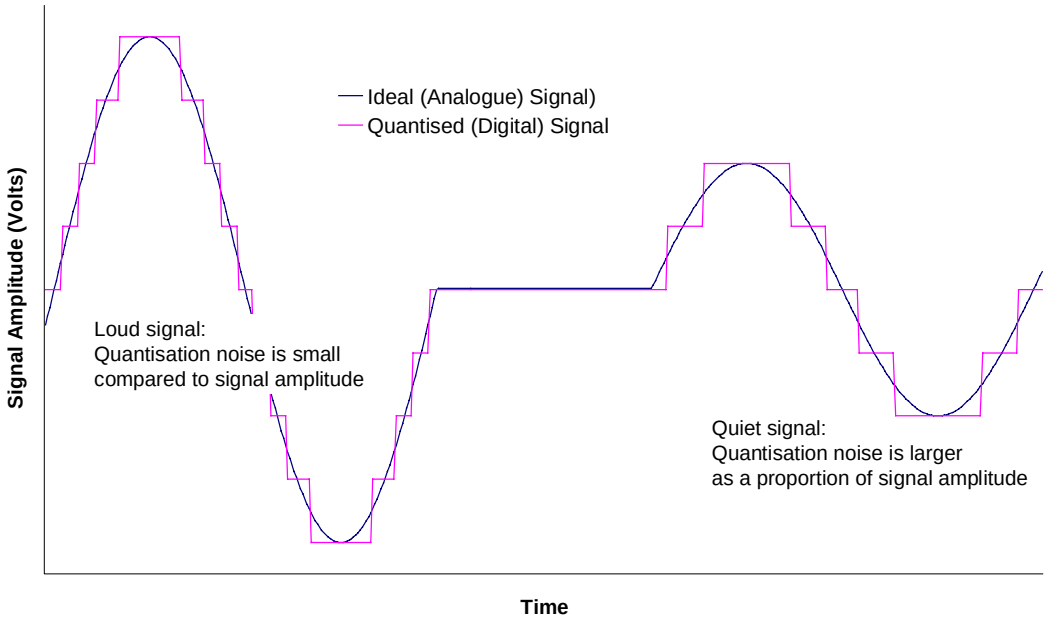

Figure 4 Effect of Quantisation Error

In the consumer market, a lower SNR is often acceptable at low volumes, where it is harder to hear in any case. For high-fidelity sound reproduction, on the other hand, it is preferable to convert digital sources to analogue first and control the volume in the analogue domain.

5. Resistor Networks

Striving for the best possible sound quality, many manufacturers of high-end audio equipment are using resistor networks to digitally control the volume control of analogue audio signals. Such networks consist of a number of well-matched resistors and digitally controlled switches. Two common circuit architectures are 'digitally controlled potentiometers' and Programmable Gain Amplifiers (PGAs), illustrated in Figures 5 and 6, respectively. Another option is to use a two-quadrant multiplying DAC, with the audio signal connected to the DAC's reference input and the volume controlled by the digital input code.

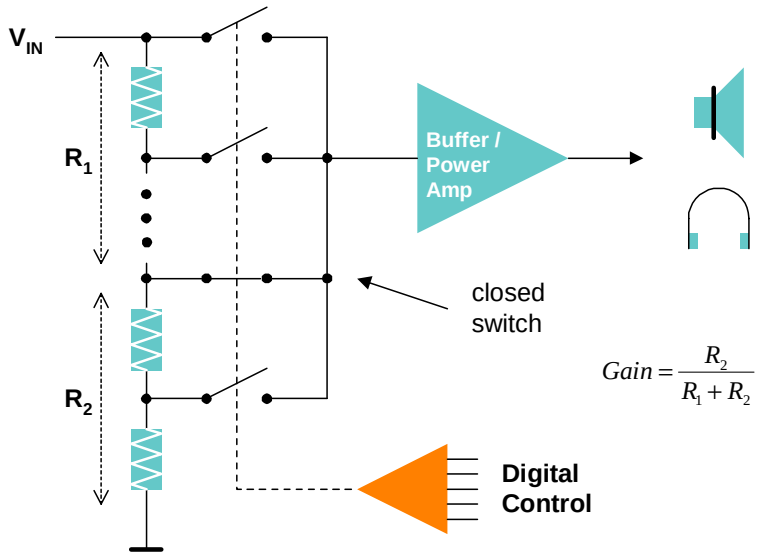

Figure 5 Digitally Controlled Potentiometer Circuit

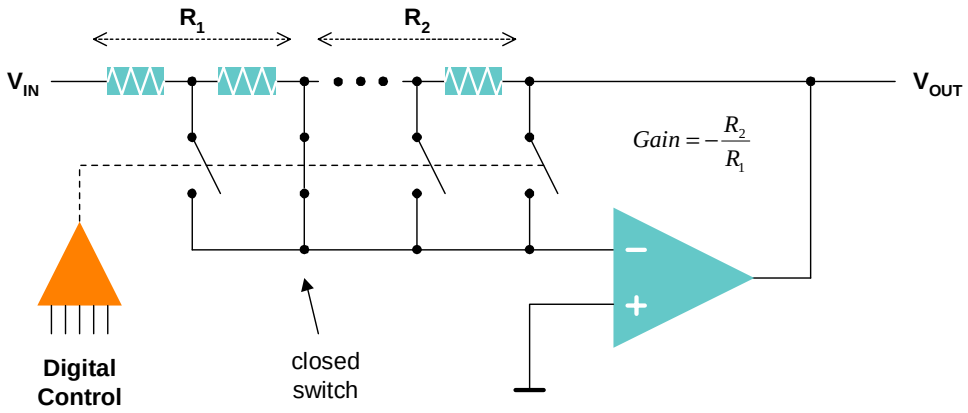

Figure 6 Programmable Gain Amplifier (PGA)

Both the resistors and the switches used in a resistor network may be implemented in different ways, as summarised in Table 1. Historically, integrated solutions were often avoided in high-end designs because of the non-linearity of semiconductor resistors and switches, which causes harmonic distortion of the audio signal. However, resistor networks with excellent audio performance can now be integrated on a silicon chip if the resistors are produced from polycrystalline silicon or thin film materials, and special care is taken in the design of the semiconductor switches. The benefits include shorter interconnections (reducing parasitic inductances, crosstalk and interference), improved reliability, smaller physical size and lower cost.

Table 1 Technology Options for Resistor Networks

Resistor Type	Advantages	Disadvantages
Metal film (discrete)	• Excellent linearity & accuracy • Low noise	• Bulky • Cost
Diffused or implanted in silicon chip	• Low cost • Easy to integrate on IC	• Non-linearity distorts signal • Poor accuracy
Polycrystalline silicon ('poly') on silicon chip	• Good linearity & accuracy	
Thin film on silicon chip	• Excellent linearity & accuracy (as good as discretes) • Low noise	• Unusual fabrication process
Switch Type	**Advantages**	**Disadvantages**
Mechanical	• Low Noise • Low 'ON' resistance • Excellent linearity	• Poor reliability • Digital control is difficult • Cost, Board Space
Semiconductor	• Excellent reliability • Digitally Controllable • Low cost	• Non-linearity may cause distortion • May generate noise

Wolfson Microelectronics has designed a number of audio ICs that integrate PGA-style resistor network volume control with other audio functions, e.g.

- WM8731, an audio codec for portable applications such as MP3 players
- WM8722, an audio subsystem for digital TV applications
- the WM97XX series of AC'97 codecs

The sound quality of these devices is sufficient for the majority of applications. Nevertheless, true high-end performance is best achieved by avoiding the design trade-offs which inevitably occur when integrating a resistor network on a chip with other components: that is, with a dedicated volume control chip.

6. WM8816 Ultra Low Distortion Volume Controller

For those audio applications where no performance compromise can be accepted in the volume control, Wolfson Microelectronics has released the WM8816, an ultra low distortion stereo volume control IC with Total Harmonic Distortion plus Noise (THD+N) at 0.001% (100dB). This unsurpassed audio performance is achieved using on-chip resistor networks and external op-amps (see Figure 7).

An on-chip digital interface controls the switches in the networks. In order to eliminate any clicks when changing the volume, switching takes place only when a zero crossing is detected in the signal. The network's input impedance is kept constant by means of an extra resistor chain across the signal input. This eliminates the common problem of RC filter cut-off frequencies changing with the volume setting.

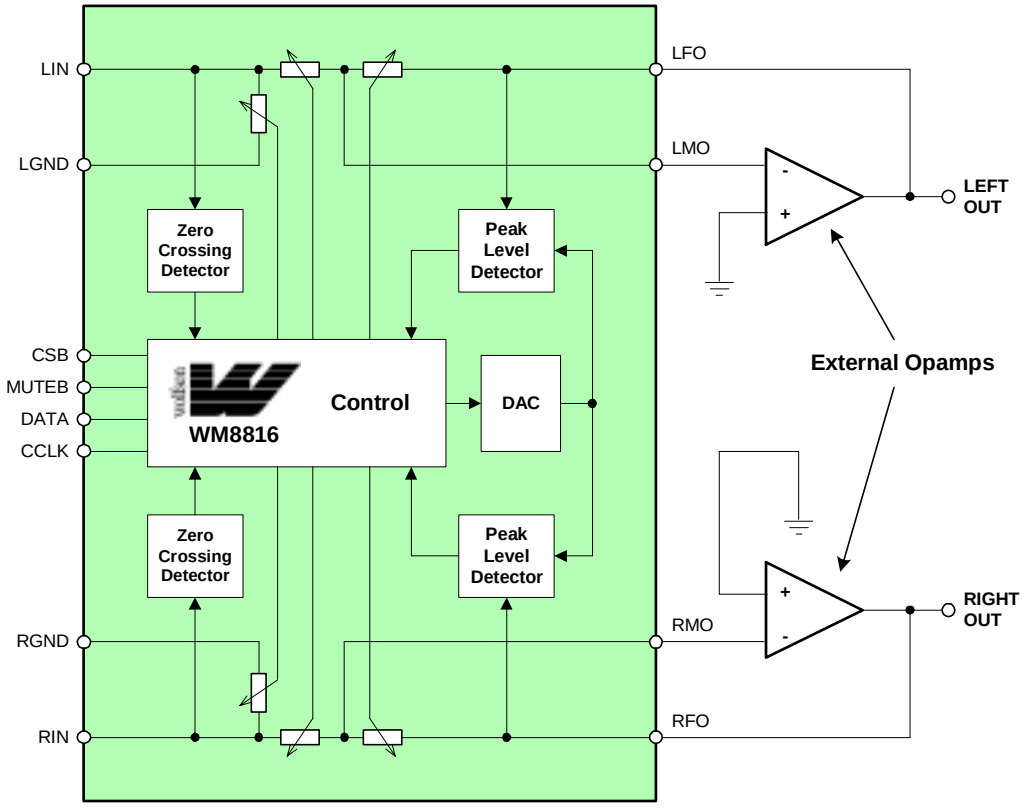

Figure 7 WM8816 Block Diagram

The WM8816 also incorporates peak level detection, to monitor the signal amplitude in each channel and then adjust the gain accordingly, if necessary. This feature is particularly useful in recording equipment and Automatic Gain Control (AGC) systems.

Features

- Resistor Network based design with external Op-amps
- Independent Volume Control for Two Channels
- Gain Range −111.5 dB to +15.5 dB, in 0.5dB (logarithmic) steps
- Zero Detection for gain changes eliminates audible clicks
- Signal Peak Level Comparator with DAC adjustable reference
- Digital Serial Control Interface
- Hardware and Software Mute

WM8816 Applications

- High-End Audio Amplifiers
- Audio Preamplifiers
- Consumer Audio
- Home Entertainment Systems
- Mixing Desks
- Audio Recording Equipment

Combining outstanding audio performance, accuracy and easy programmability with all the advantages of an integrated solution such as high reliability, small size, low power and cost effectiveness, the WM8816 is the ideal solution for volume control in high-end, professional and consumer applications.

7. Conclusion

For many decades, potentiometers were the natural choice for nearly all volume control applications. Today, they are becoming increasingly obsolete as superior solutions have emerged in the different market segments.

In the consumer market, the poor reliability of potentiometers is been especially problematic because expensive components cannot be employed. Indeed, mechanical failure of the potentiometer is still the most common fault in many consumer products. Furthermore, the appearance of digital user interfaces and/or remote control even on very low-cost products has created a need for digital controllability. Both of these problems are solved by the more recent techniques of digital-domain volume and PGAs integrated on consumer audio ICs such as Wolfson's audio DACs and codecs.

The professional and high-end markets are now using dedicated resistor networks such as Wolfson's WM8816, which achieve higher accuracy, matching, reliability and digital controllability.