Audio Engineering Society

Convention e-Brief

Presented at the 131st Convention
2011 October 20–23 New York, NY, USA

Digital Control of an Analog Parametric Equalizer

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ABSTRACT

This project focuses on creating a digitally controllable analog band-pass filter with an adjustable resonant frequency for a middle frequency adjuster in an audio equalization stage. The design of the band-pass filter is a standard series resistor, inductor, and capacitor filter network. An adjustable gyrator circuit simulates an inductor to change the resonant frequency of the filter. Inside the gyrator circuit, a voltage-controlled amplifier is configured to simulate a resistor to change the gyrators simulated inductance. A digital to analog converter controls the gain of the voltage-controlled amplifier to make the analog filter digitally controlled. This circuit successfully acts as a band-pass filter with a digitally controllable resonant frequency.

1. INTRODUCTION

Filters are an important tool used in electronics, especially in audio applications. Engineers create many different types of filters for a variety of purposes. Audio filters are used in a variety of electronics ranging from cell phones to music recording mixers. In these various electronics, a filter can remove unwanted noise or amplify a band of frequencies. [2]

Two common filter configurations used in analog circuitry are graphic and parametric equalizers. A graphic equalizer is composed of a number of filters that generally logarithmically spaced from each other. Each of these filters generally have the same bandwidth relative to their selected frequencies [4]. Graphic equalizers may have as few as three filters, also known as bands, or they could have as many as thirty. In contrast, parametric equalizers have a fewer number of bands, usually between three and six. Parametric equalizers also differ from graphic equalizers in that the user can set a band's frequency.

Although graphic equalizers are easy to use and design, their functionality is limited if they do not have enough bands. Parametric equalizers can be advantageous because one can adjust the frequency each filter controls. Engineers also create audio filters using digital signal processors (DSP), which are only limited by their cost, speed and programming complexity [5].

Analog filters are usually controlled with potentiometers which are inexpensive and easy to find, but they also take up physical space, increasing the size of the electronic device. In addition, having a physical control also restricts how the device can be used; it can only be controlled from one location. While digital potentiometers can replace regular potentiomers, there are limitations. Digital Potentiometers are only available with select resistances and voltage ratings. Digital control allows several ways to operate devices and can save space [1]. While a DSP could be used to save on space, the price and complexity of designing the device increases drastically. Often times if a device needs to be smaller or operated digitally, a DSP is the only viable solution. If a DSP is outside of the design capabilities or cost constraints how could a similar device be made and still be digitally controlled?

This paper provides a method for creating a digitally controllable analog filter. By using novel analog circuitry techniques to create a simulated resistor and inductor, such a filter can be designed. First, the paper will describe the design of a simulated inductor using a gyrator circuit. Then the paper will describe the design and implementation of the simulated resistor for the gyrator circuit. Finally the paper will discuss the findings of this approach to creating a digitally controllable filter.

2. DESIGN

2.1. Simulated Inductor

Inductors are large electrical devices with high tolerances that easily pick up noise; three undesireable traits in electronics. Simulating an inductor allows similar performance to a real inductor, but it is smaller, does not pick up noise as easily and can achieve more precise values of inductance. Gyrator circuits do have a limited quality factor (Q) and are required to operate as an inductor tied to ground. [3]

The gyrator circuit can simulate an inductance using one operational amplifier (opamp), two resistors and one capacitor. The schematic of the gyrator circuit is shown in figure 1. [3]

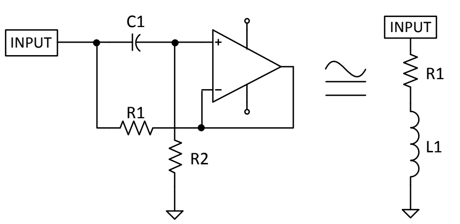

Figure 1 Gyrator schematic and equivalent Circuit

The equivalent inductance of the gyrator circuit, measured in the unit of Henry, can be found using equation 1. [3]

$$L_1 = C_1 R_1 (R_2 - R_1) \quad (1.)$$

An important aspect of the inductor is its resistance to a change in current. The gyrator circuit takes advantage of how capacitors resist a change in voltage to adjust the current flowing through a resistor so the circuit can achieve the same characteristics of an inductor.

Imagine the input for the gyrartor circuit is at zero volts and has been for some time. The voltage across the capacitor and resistors is zero volts and the circuit is not drawing any current. Now some positive voltage, V_{in}, is applied to the input. The capacitor resists a change in voltage, meaning the voltage across R_2 eqauls V_{in}. With the opamp setup as a voltage follower, its output is also V_{in} meaning the voltage across R_1 equals zero. Therefore the gyrator circuit does not draw any current from the input just as it was before V_{in} was applied. The gyrator circuit has resisted a change in current even though the voltage has changed. As time passes, the capacitor will charge to V_{in} and the voltage across R_2 will be zero. Now the voltage across R_1 equals V_{in} and current flows through the resistor.

Now imagine that the input voltage returns to zero. The capacitor holds the original V_{in} value and now the voltage on the non-inverting pin of the opamp is $-V_{in}$. The output also goes to $-V_{in}$ meaning the voltage across R_1 is still V_{in} and the gyrator circuit continues to draw current from the input as it had been before V_{in} was removed. The gyrator circuit has again resisted a change in current just as an inductor would.

2.2. Simulated Resistor

The resistor for the gyrator circuit is simulated so that a wider range of values can be used. Many potentiometers are only available to a maximum size of 100 kΩ and a limited number of voltage operation abilities. The simulated resistor allows for a wider range of resistances and operating voltages. The simulated resistor is limited because it needs to operate as a resistor tied to ground.

To simulate the resistor only an amplifier with a gain less than one and a resistor are needed. To change the simulated resistance the gain of the amplifier needs to be changed. The concept of the simulated resistor is shown in figure 2.

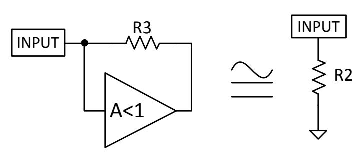

Figure 2 Simulated resistor diagram

The gain A must be a number greater or equal to zero and less than one. The simulated resistance, R_2, can be found using equation 2.

$$R_2 = \frac{R_3}{1 - A} \tag{2.}$$

Since the simulated resistor must be tied to ground, the resistor should be viewed as a current sink rather than just a resistor. The voltage across R_3 depends on the gain A. If the gain equals zero, the voltage across R_3 equals the input voltage and R_2 equals R_3. If the gain is anything else then the voltage across R_3 will be smaller meaning less current. Since the circuit draws less current, the outside system acts as if a larger resistance is tied to ground.

To construct the simulated resistor, a *THAT 2162* voltage controlled amplifier (VCA) acts as the gain component. The device is a current sink and current source device. Some additional circuitry is needed to ensure the circuit's operation. Refer to the $THAT$ 2162 datasheet for more information. The circuit can be seen in figure 3.

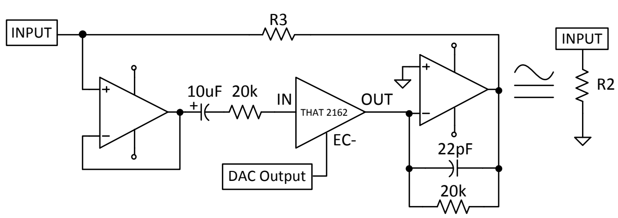

Figure 3 Simulated resistor using THAT 2162 VCA

The EC- gain control pin voltage determines the gain of the amplifier. This pin can be controlled using a digital to analog converter meaning the simulated resistor value can be digitally controlled. Most DAC outputs will require some additional circuitry so that the voltage levels are correct on the EC- gain control pin; refer to the $THAT$ 2162 datasheet for more information.

2.3. Equalization Stage

The equalization stage uses a standard RLC bandpass filter to adjust boost or cut out some audio frequencies. By using an opamp and changing the electrical connection of the bandpass filter those frequencies will either be amplified or attenuated. Since a standard RLC filter is used, equation 3 is used to calculate the values needed for a specific center frequency.

$$f = \frac{1}{2\pi\sqrt{L_1 C_2}} \tag{3.}$$

Using a digital potentiometer, the bandpass filter will be electrically located closer to either the non-inverting or inverting pin of the opamp to cut or boost the selected frequency. The schematic can be seen in figure 4.

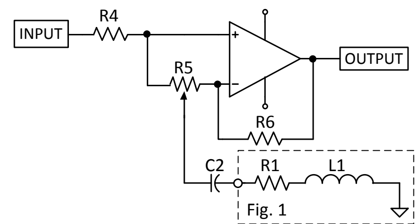

Figure 4 Bandpass filter for equalizer

When the bandpass filter, which is connected to the R_5 digital potentiometer's wiper, is closer to the non-inverting pin of the opamp the filter and R_4 act as a voltage divider to reduce, cut, those frequencies affected by the filter. Alternatively, when the bandpass filter is closer to the inverting pin of the opamp, the filter and R_6 create a non-inverting amplifier to boost the affected frequencies. When the filter is in the middle, both effects of the voltage divider and non-inverting amplifier are negligible; the circuit then acts as a voltage follower for all of frequencies without boosting or cutting them. [4]

To make the circuit an equalizer and not just a single filter, additional digital potentiometers are connected in parallel with R_5. The wipers are not connected to each other, instead they are connected to other filters as shown in figure 4.

3. RESULTS

The fully implemented audio equalization stage has three bands: bass, middle and treble. The middle band is parametric and features the simulated resistor to control the center frequency of the filter. The bass band has a center frequency of 80 Hz, the high band a center frequency of 12 kHz, and the middle frequency was designed to change its center frequency between 600 Hz and 1.7 kHz.

An *Audio Test System 2* measured the frequency response curves of the device in different settings. Each band's maximum boost and cut were measured while the other bands were turned off. The low and high bands both performed as expected and show that the gyrator circuit is a suitable replacement for an inductor in an audio application. The middle band results show that the simulated resistor was successful at adjusting the center frequency of the filter; the filter's bandwidth was also adjusted. The frequency response curves can be seen in figure 5.

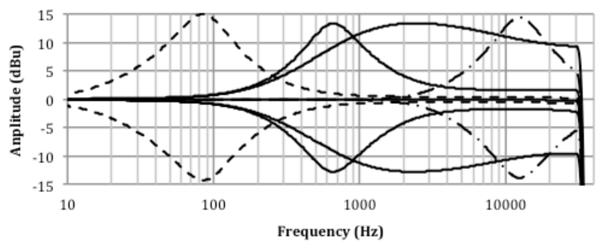

Figure 5 Equalization frequency response curves

The short dashed lines, solid lines, and long dash dot lines represent the low band, middle bands, and high band responses respectiviely. The results show that this type of circuit architecture is an effective methodolody to create an audio equalization device. This is not a design that needs to be used for all applications, but does show that this design could be applicable in industry.

4. DISCUSSION

This paper shows that gyrator circuits, simulated resistors and digital control of analog circuitry are applicable for audio products. In particular, the use of a simulated resistor allows for complete digital control of a completely analog circuit.

These devices do have some limitations that can lower their functionality. The simulated inductor does not have any physical magnetic storage of energy resulting in the opamp supplying a limited amount of energy. In the case of the RLC filter, the opamp limits how small the bandwidth can be for the filter. However, this is not a limiting factor for audio applications.

The simulated resistor also has some limitations. From a theoretical standpoint the resistor should have been able to change its value a full order of magnitude in value. Had this been possible, the range of the center frequencies available would have been much higher. The $THAT$ 2162 VCA gain control pin is very sensitive making the device more difficult to control. A possible substitute for the VCA is a digital potentiometer or a DAC. Either of those devices may be able to achieve a larger range of resistances for the simulated resistor.

Changing center frequency also posed a problem that was not initially investigated. When the center frequency changes without changing the resistor in series with the inductor and capacitor the bandwidth also changes; optimally the bandwidth would stay the same regardless of the center frequency. One possible way to fix this problem is replacing R_1 in the gyrator circuit with a digital potentiometer. The values that are used for R_1 are relatively small and a digital potentiometer should work very well for that application. Changing the minimum resistance of the simulated resistor is another possible solution for a higher range of center frequencies and starting with a much higher Q to make the change less noticeable.

Overall this concept was a success. The goal was to create an audio equalization stage that was controlled digitally, but was functionally analog. The use of a simulated resistor is a novel approach that could also be used for other applications beyond audio.

5. ACKNOWLEDGEMENTS

The Electrical and Computer Engineering Technology Department of Purdue University supported this work. In particular, professors James M. Jacob, Jeffrey W. Honchell and Robert J. Herrick helped with the development of this paper.

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