Application Report

SLWA053B–November 2007–Revised April 2010

Design of Differential Filters for High-Speed Signal Chains

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High Speed - Wireless Infrastructure

ABSTRACT

Differential filters have many desirable attributes. The task of designing differential filters can seem daunting at first. Single-ended filters designed in any filter design package can be converted to a differential implementation. This application report explores simple conversion techniques for low-pass, high-pass, and band-pass LC filters.

1 Introduction

Differential signals have many desirable attributes in high-speed signal chains: namely, common-mode rejection from a balanced signal path and matched filter response, immunity from single-ended component parasitic effects, decoupling the signal from requiring a ground reference, and rejection of even-order harmonics. However, most LC filter design information, techniques, and software are for single-ended systems. This application report highlights some simple translations that can be made to convert the single-ended designs to fully differential designs. Some examples are used to demonstrate these translations.

The design of single-ended passive analog LC filters has been simplified greatly by various pieces of software that can be obtained freely on the Internet. An Internet search for *LC filter design* yields many results, any of which can be used for this tutorial.

This application report uses ELSIE (i.e., *LC*) which is freely available for download from the following link as a trial version with some limitations on filter order and usage. For commercial applications, the full version should be purchased. For purposes of this application report, the free version is sufficient.

http://www.tonnesoftware.com/elsiedownload.html

The SPICE simulator used in this tutorial is the TINA-TI SPICE simulator which can be downloaded from the Texas Instruments Web site at the following link.

http://focus.ti.com/docs/toolsw/folders/print/tina-ti.html

The full TINA version can be purchased from its vendor for access to its full feature set.

2 Single-Ended to Differential-Ended Filter Translation:

2.1 Low-Pass, High-Pass, and Band-Pass Filter Implementations

The process of designing a differential filter requires the design of a single-ended filter that meets the filter requirements. Freely available tools may be used to generate a single-ended filter with the desirable frequency response. The low-pass, high-pass and band-pass differential filter implementations are discussed in the following sections.

The single-ended LC low-pass filter can be converted to a differential filter by repeating and folding the design around GND to create the Vin+ and Vin-. The GND is removed and the center capacitor values are recalculated: the C is half-value (sum of two series C). The L in the horizontal parallel series paths are kept the same and the load resistor is doubled (sum of two series R). The process is illustrated in Figure 1.

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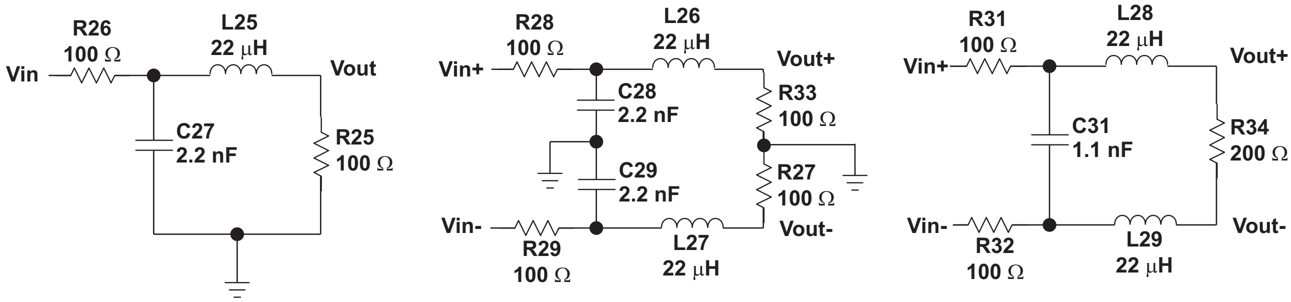

Figure 1. Conversion Process From Single-Ended to a Differential Filter

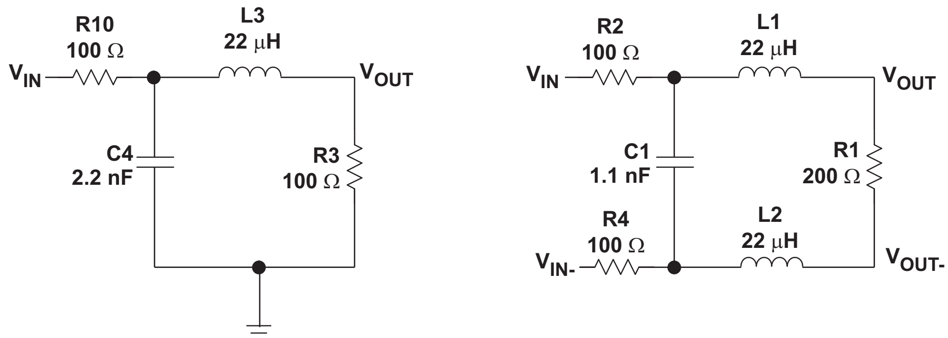

Figure 2. Shunt Capacitor Input Low-Pass Filter

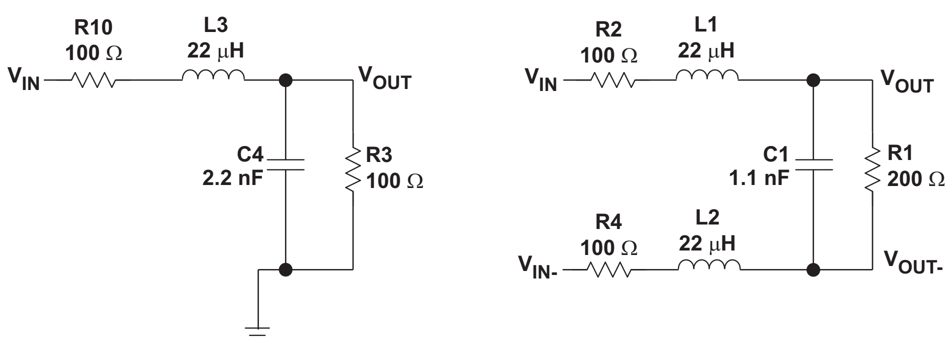

Figure 3. Series Inductor Low-Pass Filter

All four of these produce the same response as shown in Figure 4.

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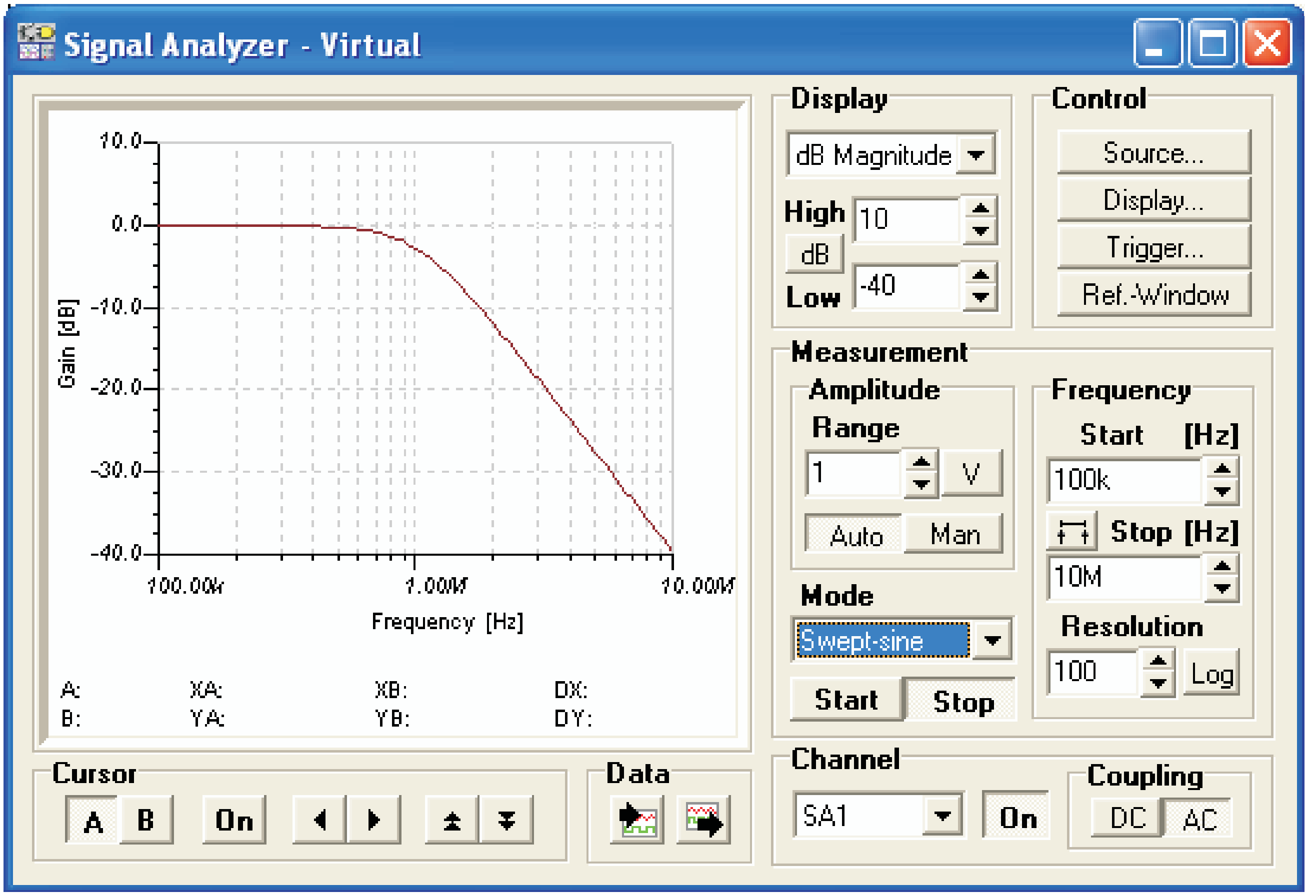

Figure 4. Low-Pass Filter Response for All Four Low-Pass Filters.

Similar circuits can be translated for a simple LC high-pass filter. The circuit is folded along the GND point, the vertical series elements are added and the horizontal elements remain the same. This results in doubling the vertical inductors and load, similar to the approach used for the low-pass filters.

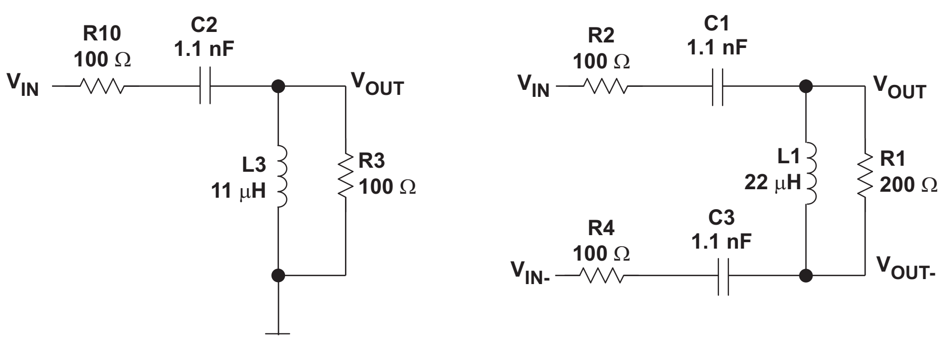

Figure 5. Series Capacitor Input High-Pass Filter

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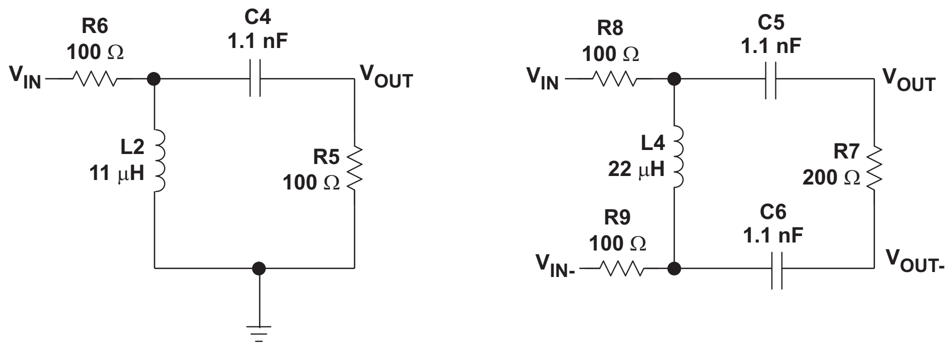

Figure 6. Shunt Inductor High-Pass Filter

All four high-pass filters have the same frequency response as shown in Figure 7.

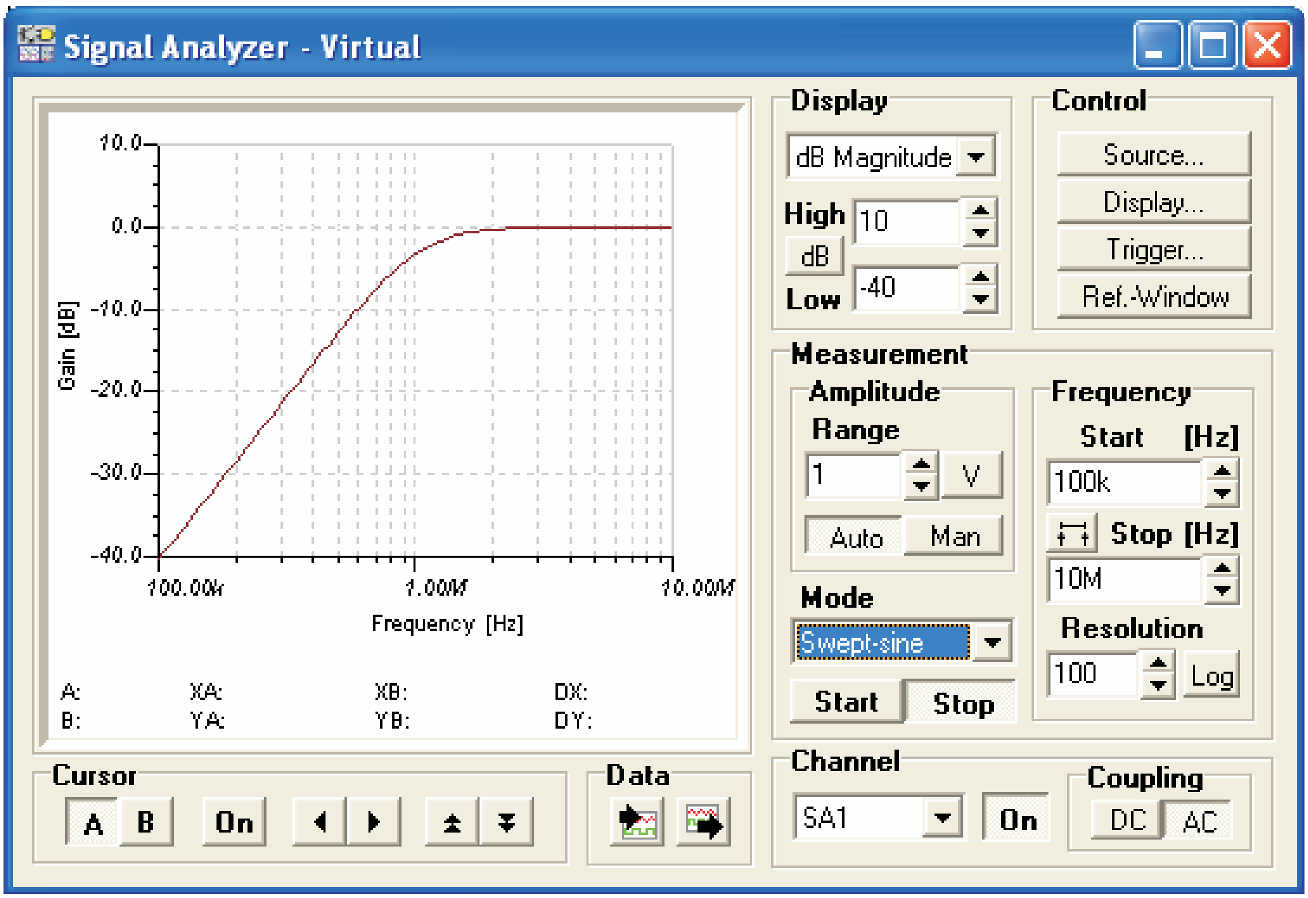

Figure 7. Frequency Response for All Four High-Pass Filters

This same principle holds for more complex BPF architectures. The single-ended filter is reflected around the GND point, the GND is removed, and the middle elements are added together. Figure 8 provides an example of a third-order Butterworth BPF.

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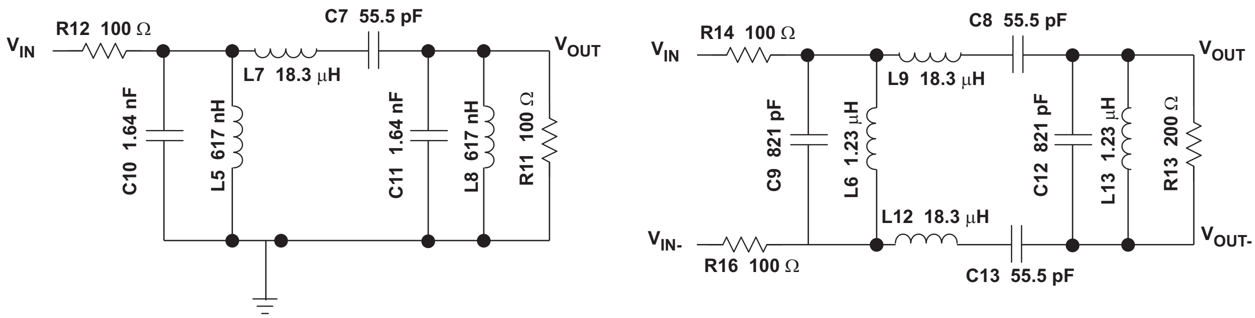

Figure 8. Example of Third-Order Butterworth Band-Pass Filter

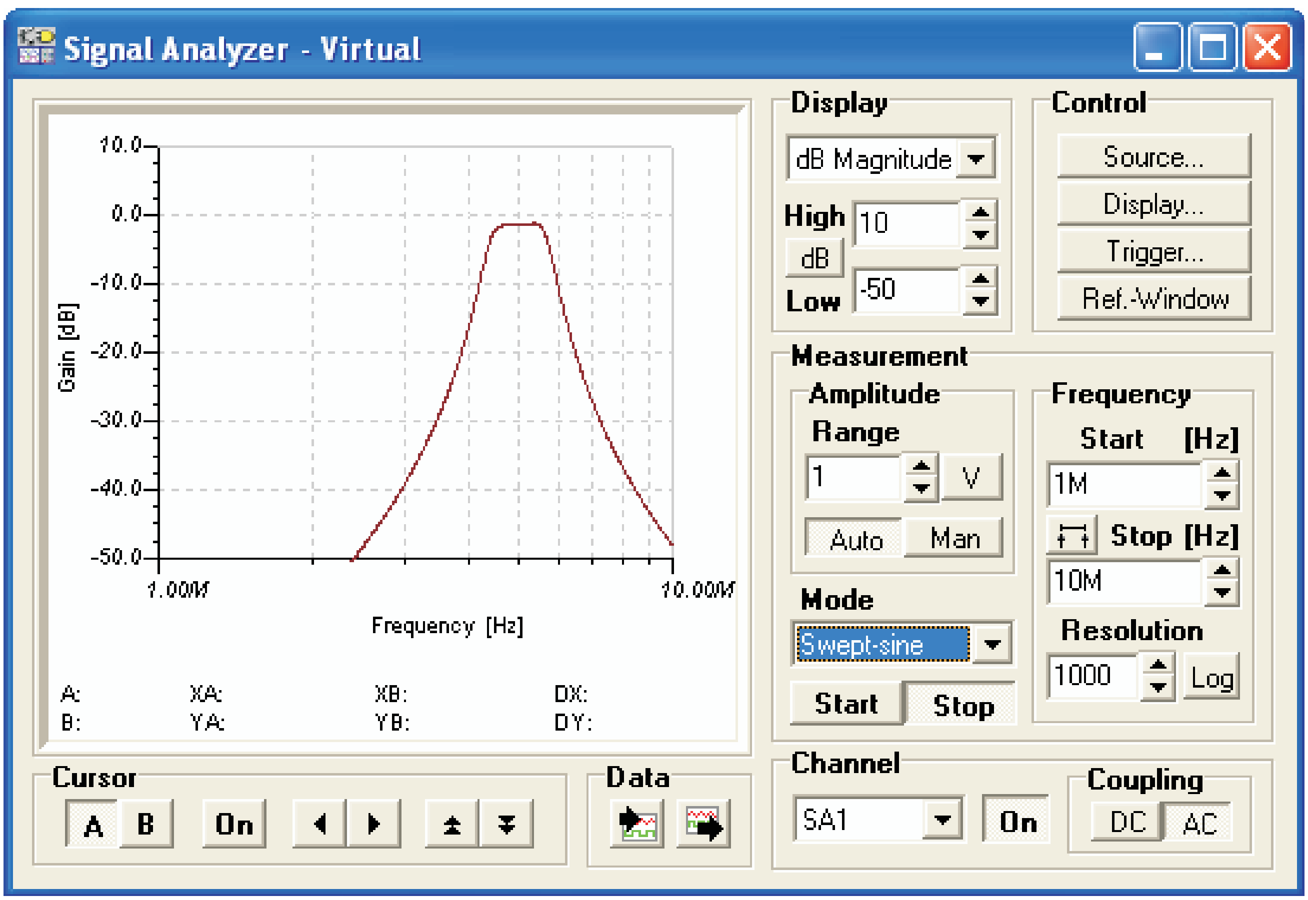

Figure 9. Frequency Response of the Third-Order Butterworth Band-Pass Filter

Figure 10 provides an example of a third-order Cauer BPF with some parallel horizontal elements. Performing the translation results in the network on the right. Both these filters have the same frequency response.

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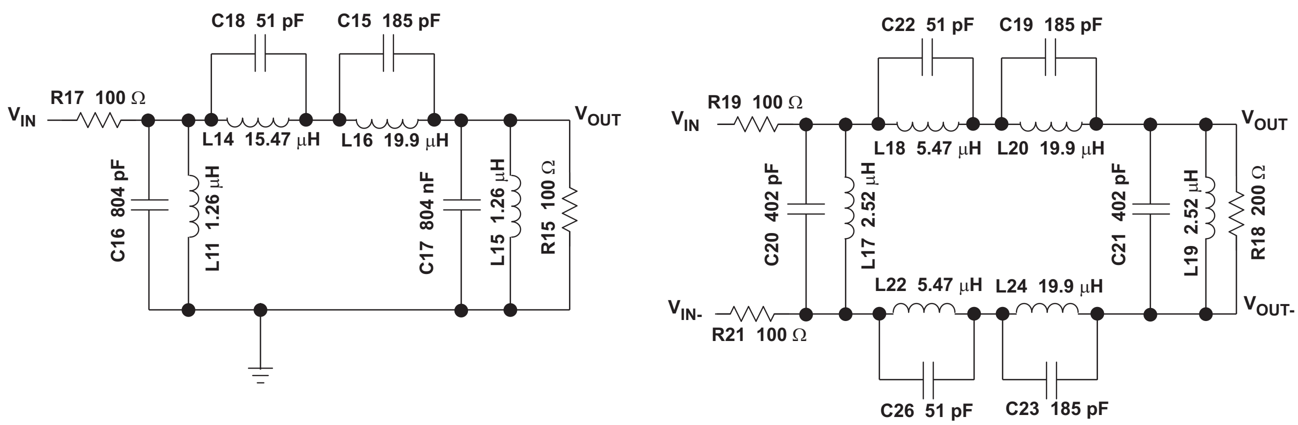

Figure 10. Example of Third-Order Cauer Band-Pass Filter

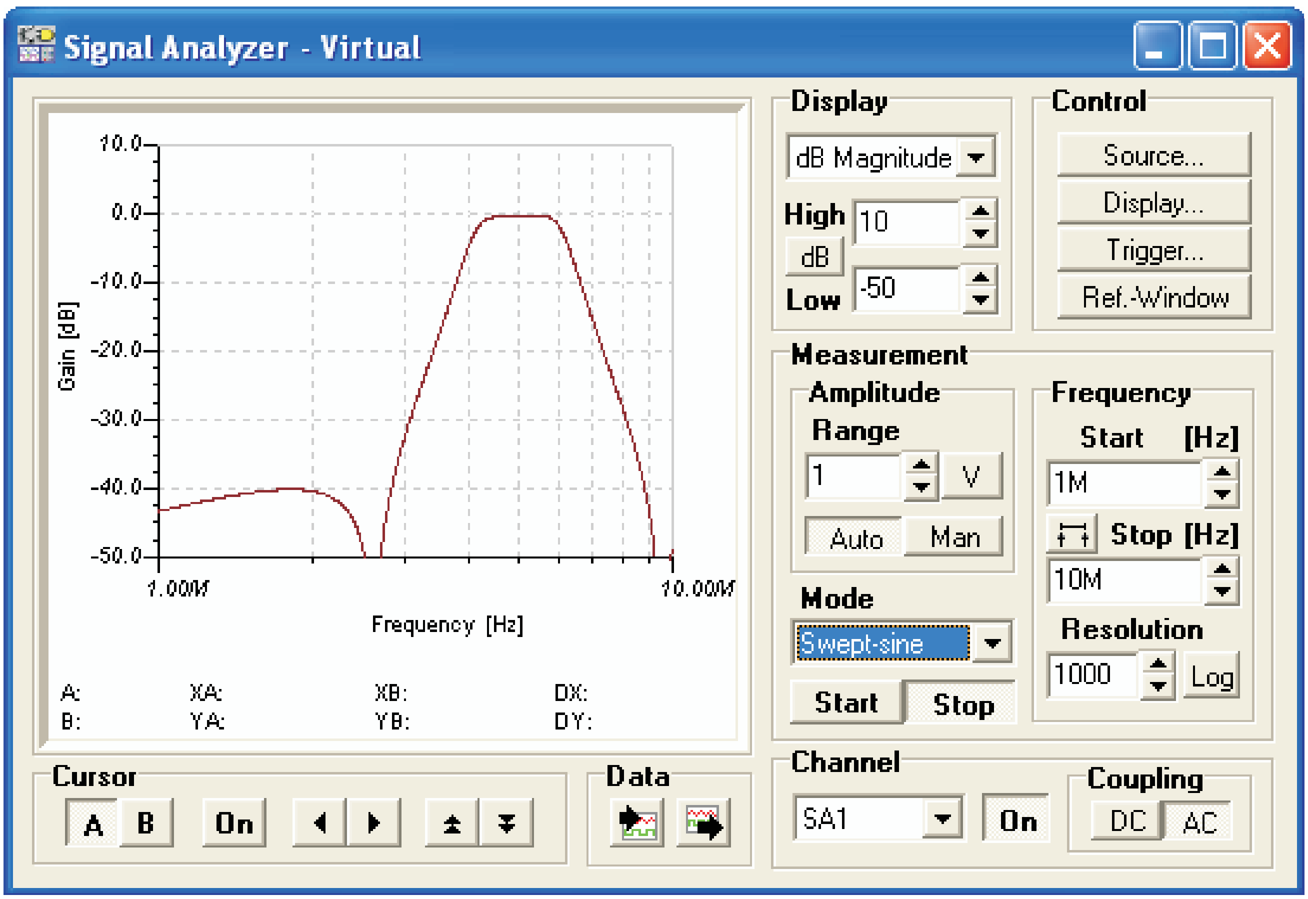

Figure 11. Frequency Response of Third-Order Cauer Band-Pass Filter

3 Implementation and Simulation Notes

Note that all of the networks should show a 6-dB loss due to the voltage divider created by the 100-Ω source impedance and the 100-Ω termination impedance. In the voltage source simulation, the transfer function response is determined with the voltage signal source at the input to the source impedance, in effect grouping the response of the source-to-termination resistor divider into the response of the filter. A 2x VCVS was used at the output of the voltage source to account for this fixed 6-dB loss in the resistor divider and to highlight the actual response of the LC network.

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4 Summary

The task of designing differential LC filters can seem daunting at first. But by using some basic single-ended filter design tools and applying some simple translations, it is possible to design differential LC filters to have the same response as the single-ended filter. The examples in this document have shown that this method can be applied to any singled-ended LC filter network to produce a passive equivalent differential filter.

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