Synthesis and Applied of High-Efficiency Balanced 2nd Active Filters Using a Generalized Cross-Over Architecture

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ABSTRACT

This paper proposes a novel methodology for the synthesis and practical realization of high-efficiency active filters. The approach is based on a generalized architectural framework that incorporates integrated cross-over feedback paths, enabling the development of active filter circuits with a substantially reduced number of passive and active components compared with conventional topologies. Unlike classical filter transformation techniques that are often associated with component redundancy and increased structural complexity, the proposed cross-over architecture provides a more efficient mathematical mapping of transfer functions onto physical circuit implementations. The resulting designs preserve key performance characteristics, including straightforward tuning procedures and low sensitivity to component tolerances and environmental variations. Consequently, the proposed methodology offers a streamlined and robust design strategy for achieving high-precision active filters without the overhead typically associated with component-intensive filter realizations.

I. Introduction

A balanced second-order active filter employing nonlinear electronic components such as operational amplifiers can be realized using a general balanced architecture with crossover connections. This class of filters is extensively utilized in a wide range of engineering applications owing to its inherent capability to suppress common-mode interference and to reduce common-mode radiation. Furthermore, balanced differential-mode circuits are capable of achieving up to twice the maximum signal amplitude of their single-ended counterparts when operated under identical power supply conditions. For integrated circuit implementation, strict circuit symmetry is highly desirable, as it enables the use of folded structures and ensures fully differential operation at all internal nodes of the circuit [1, 2, 3].

Traditionally, balanced active filters have been derived by starting from conventional single-ended active filter topologies based on integrator building blocks and subsequently replacing these integrators with their differential equivalents. More recently, a systematic transformation approach has been proposed, allowing arbitrary single-ended circuits to be converted into balanced configurations. However, a direct consequence of this method is that the resulting balanced circuits exhibit only vertical interconnections between the upper and lower halves of the structure, while lacking the cross-lattice connections that are possible in more general balanced architectures. Allowing such cross-lattice connections, as illustrated in Fig.1, can potentially lead to improved circuit performance and more optimal filter realizations [4].

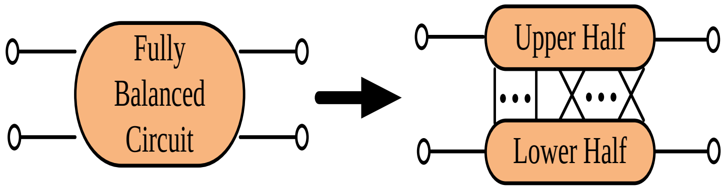


Fig.1 Balanced Circuit Equivalent Showing Cross-Overs.

As far as consideration of the well known Kerwin-Huelsman-Newcomb 2nd order state variable filter, the circuit provides low pass, high pass and band pass active filters frequency responses. The circuit after transforming to the balanced form is shown in Fig.2, which comprises two conventional Op-amp's, two balanced Op-amp's, four capacitors and twelve resistors. [5-8].

A balanced 2nd order low pass, high pass and band pass fitters obtained from a general balanced form which allows cross over between the upper and lower halves thereby resulting in fewer components. Only two balanced op-amp, four capacitors and eight resistors are required in low pass, high pass and band pass filters, but high pass filter will need only two balanced op amps, six capacitors and six resistors [6 7, 9].

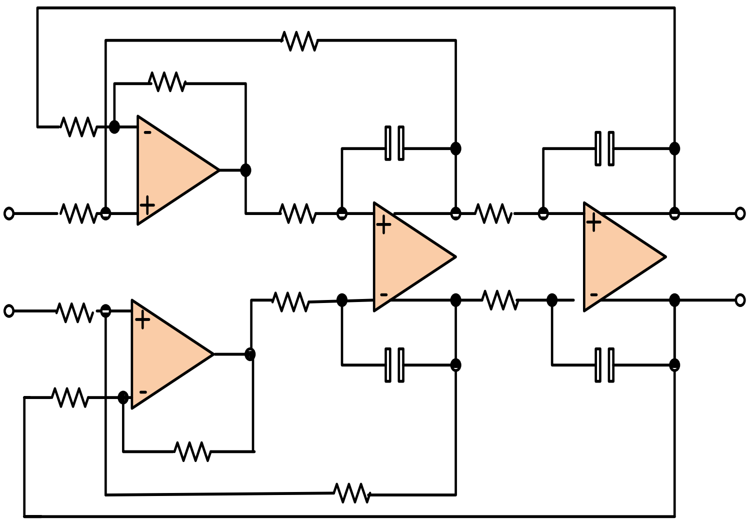


Fig.2 Balanced KHN State Variable Circuit.

II. Transfer Function of the Balanced Active Filter

The transfer function is the ratio of the Laplace transformation of the output to the Laplace transformation of the input. The generalized second-order transfer function of a balanced active filter can be expressed as:[11].

$$H(s) = \frac{K.s^m}{s^2 + \frac{\omega_o}{Q}s + \omega^2{}_o} \qquad (1)$$

Where

K is a DC gain of the filter

$\omega_o = 2\pi f_o$ is the natural angular frequency in rad/sec

f_o is the cut-off frequency in HZ

Q is quality factor

s is the laplace complex frequency variable

For the specific cases:

Low pass filter:

$$H_{LP}(s) = \frac{K.\omega^2{}_o}{s^2 + \frac{\omega_o}{Q}s + \omega^2{}_o} \qquad (2)$$

High pass filter:

$$H_{HP}(s) = \frac{K.s^2}{s^2 + \frac{\omega_o}{Q}s + \omega^2{}_o} \qquad (3)$$

Band pass filter:

$$H_{BP}(s) = \frac{K\frac{\omega_o}{Q}s}{s^2 + \frac{\omega_o}{Q}s + \omega^2{}_o} \qquad (4)$$

The overall transform functions of the low pass, high pass and band pass balanced 2nd order active filters are given by the following expressions respectively.[11-13].

$$H_{LP}(s) = \frac{V_o(s)}{V_i(s)} = \frac{\frac{1}{R_b R_f C_e C_g}}{s^2 + \frac{1}{R_g C_g}s + \frac{1}{R_d R_f C_e C_g}} \qquad (5)$$

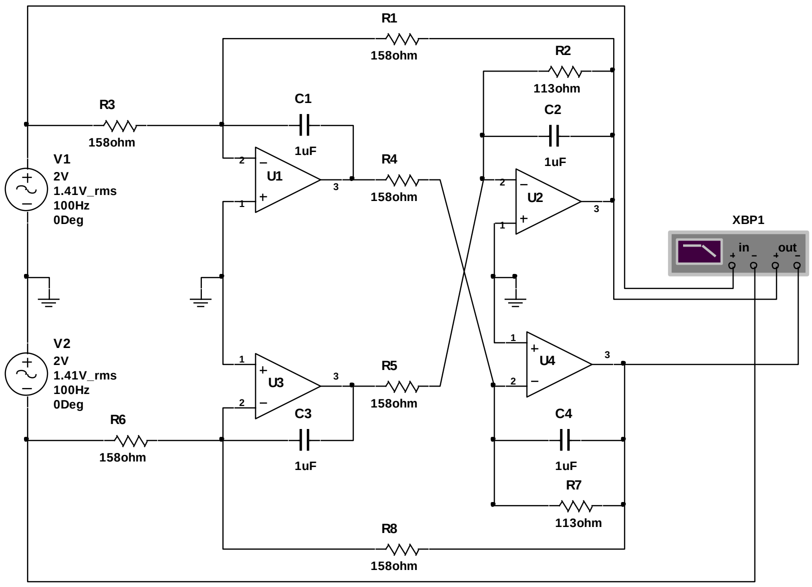
$$H_{HP}(s) = \frac{V_o(s)}{V_i(s)} = \frac{\frac{C_e}{C_g}s^2}{s^2 + \frac{1}{R_g C_g}s + \frac{1}{R_d R_f C_e C_g}} \qquad (6)$$

$$H_{BP}(s) = \frac{V_o(s)}{V_i(s)} = \frac{\frac{1}{R_a C_g}s}{s^2 + \frac{1}{R_g C_g}s + \frac{1}{R_d R_f C_e C_g}} \qquad (7)$$

III. Computer Simulation

Several simulation packages available in the market can be used in many engineering applications such as Electronic Workbench, Multisim, Matlab,…etc. In this paper, Multisim 2001 is used to get the response s of the balanced active 2nd order low pass, high pass and band pass filters. Simulation of the balanced active 2nd order filter is done to check the performance of the 2nd order balanced active low pass, high pass and band pass filters. The schematic diagrams of these filters are built in Multisim environment and Bode plotter is used to draw the magnitude and phase responses.

Testing was primarily started by simulating a low pass, high pass and band pass filters as illustrated in Fig.3a, 5a and 7a respectively. Both responses of the low pass and high pass filter are achieved as shown in Fig.3b, c and 5b, c respectively and its clearly observed from the graphs that the cut-off frequency is a 1kHz at 3dB and the responses obtained for Q factor equal 0.707 which mains is maximally flat responses. When Q=10 for the same cut-off frequency the achieved responses of the low pass and high pas filters are shown in Fig.4b, c and 6b, c respectively.



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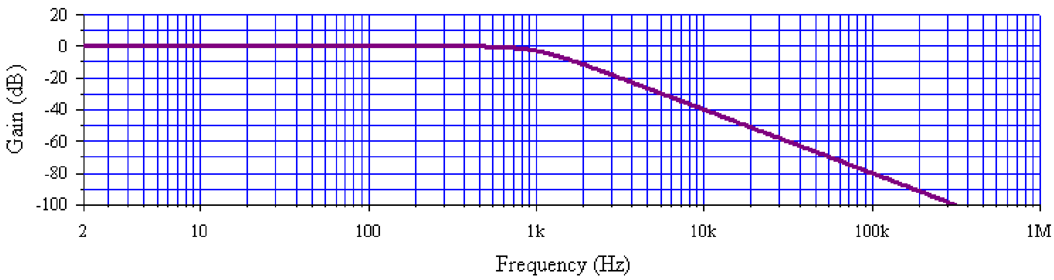

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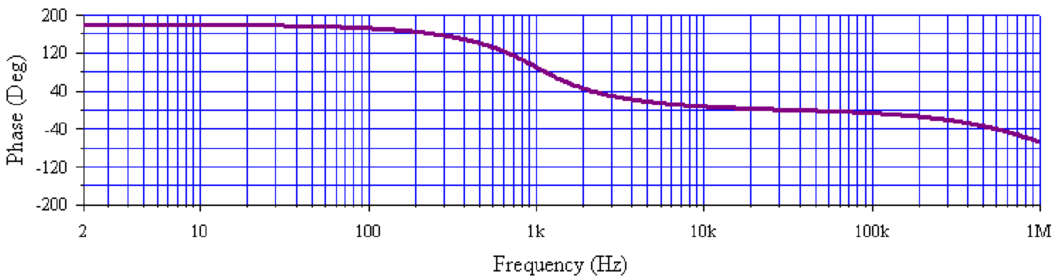
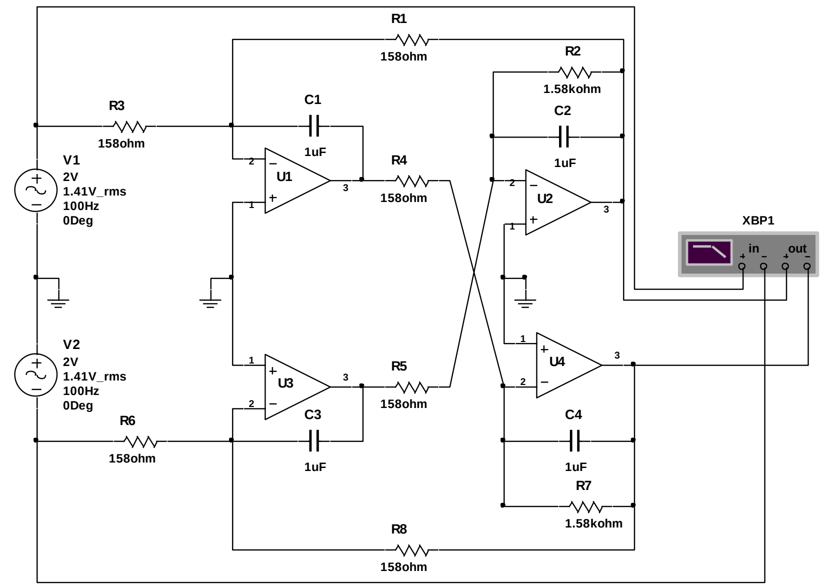


(c)

Fig.3 Low Pass Filter, where Q=0.707.
a-Simulation Circuit Diagram.
b-Frequency Response.
c-Phase Response.



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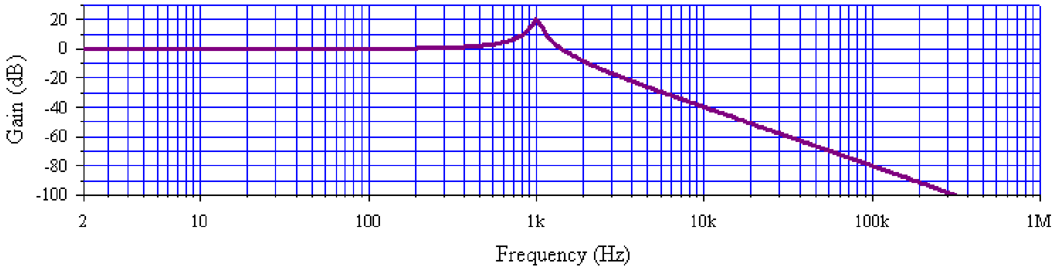

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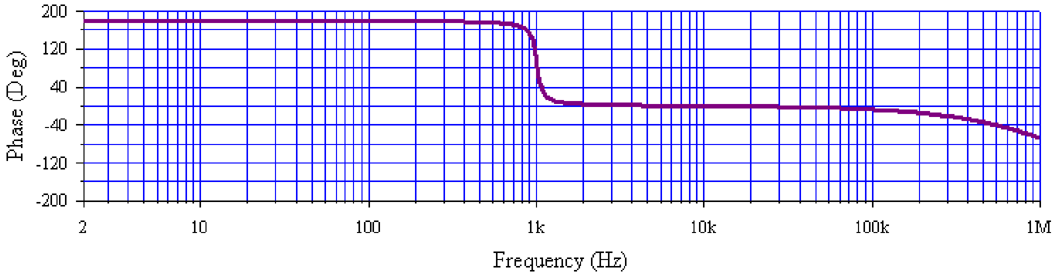

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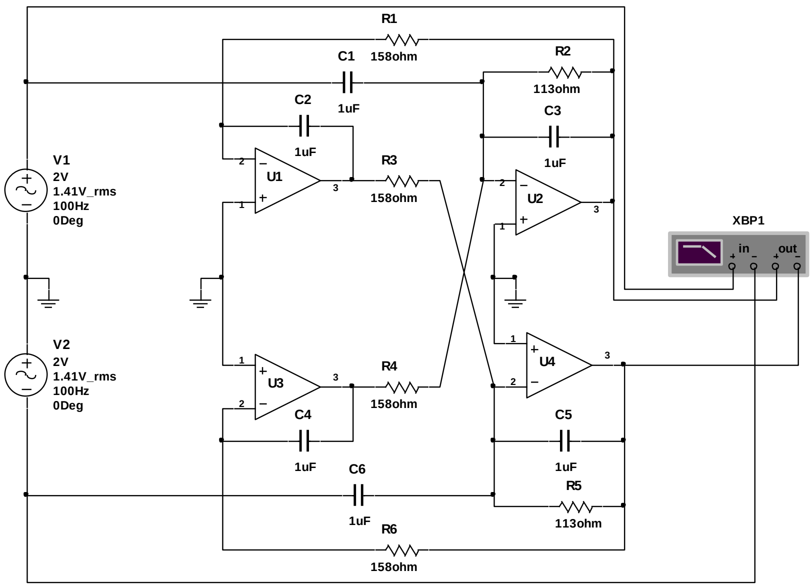
Fig.4 Low Pass Filter, where Q=10.
a-Simulation Circuit Diagram.
b-Frequency Response.
c-Phase Response.



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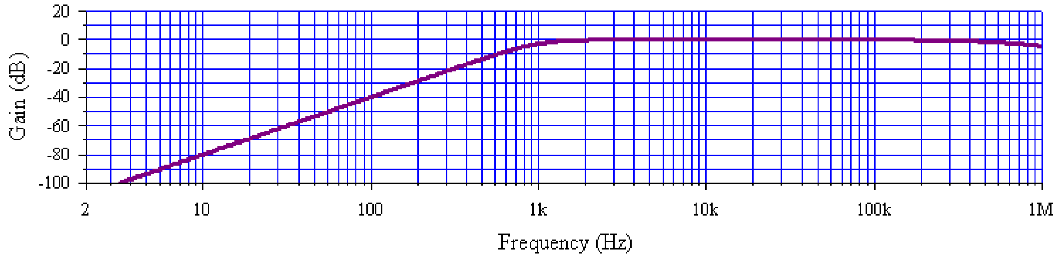

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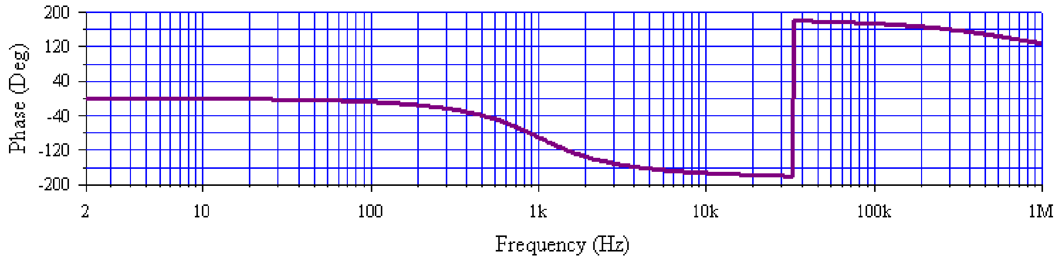
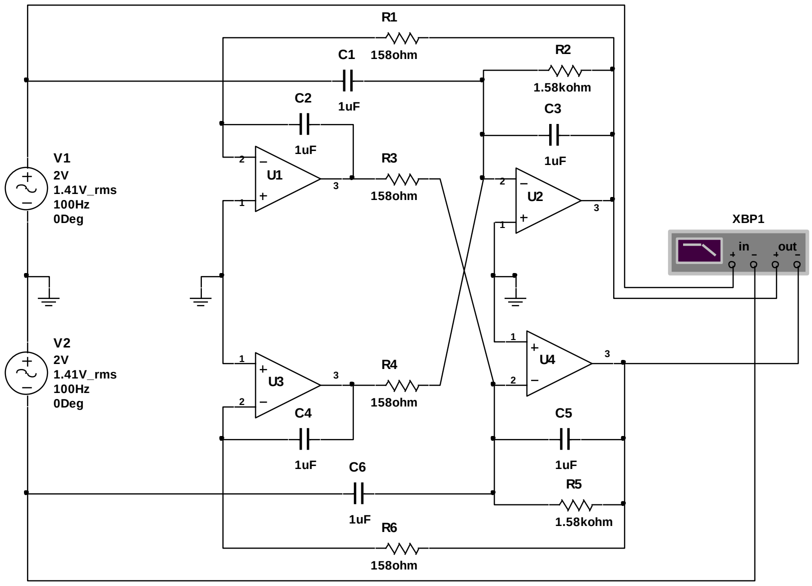


(c)

Fig.5 High Pass Filter, where Q=0.707.
a-Simulation Circuit Diagram.
b-Frequency Response.
c-Phase Response.



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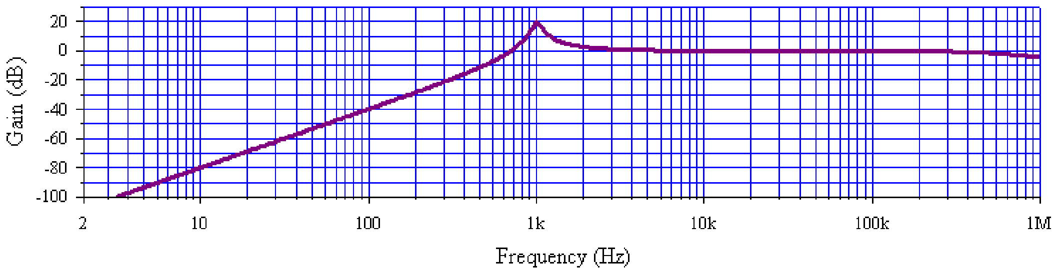

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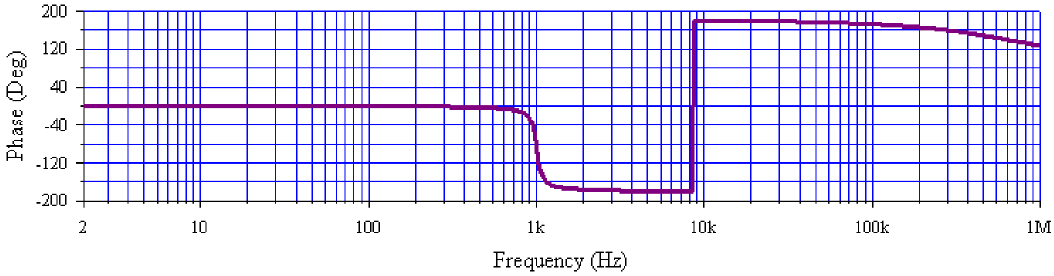

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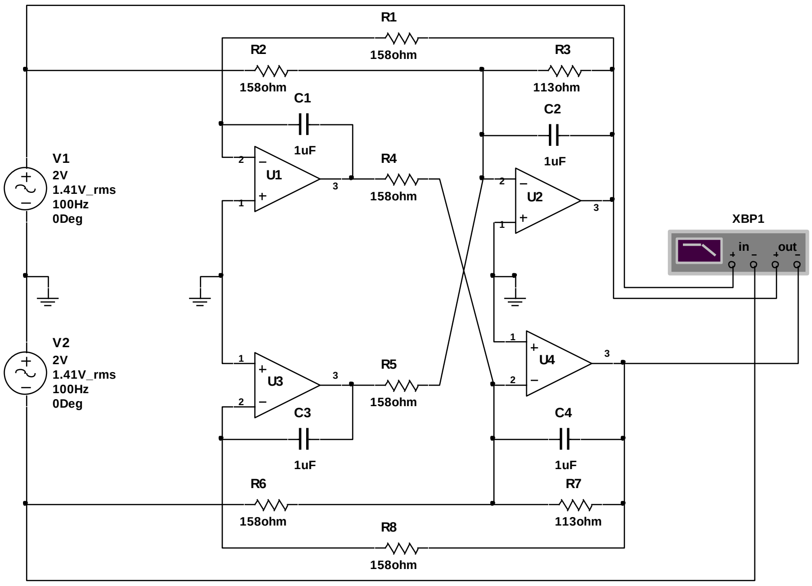
Fig.6 High Pass Filter, where Q=10.
a-Simulation Circuit Diagram.
b-Frequency Response.
c-Phase Response.

For band pass filter the response is achieved as shown in Fig.7b and c and its clearly that the center frequency is 1kHz and the response obtained for Q=0.707 is maximally flat response. When Q=10 and with the same center frequency when Q=0.707 the responses of the band pass filter is represented in Fig.8b and c.



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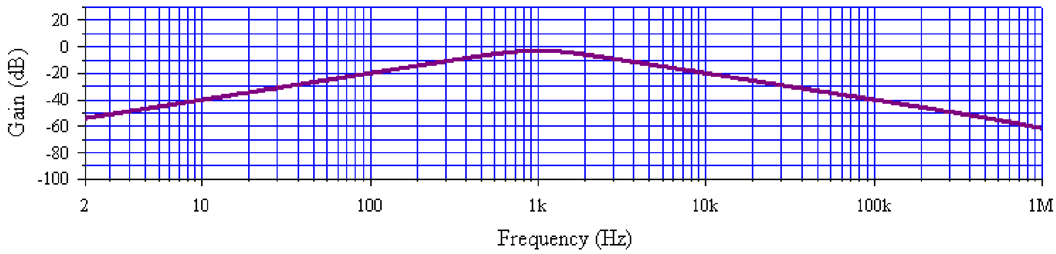

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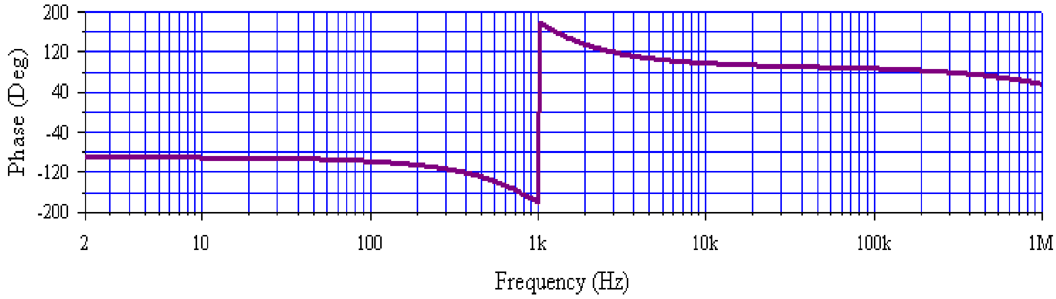

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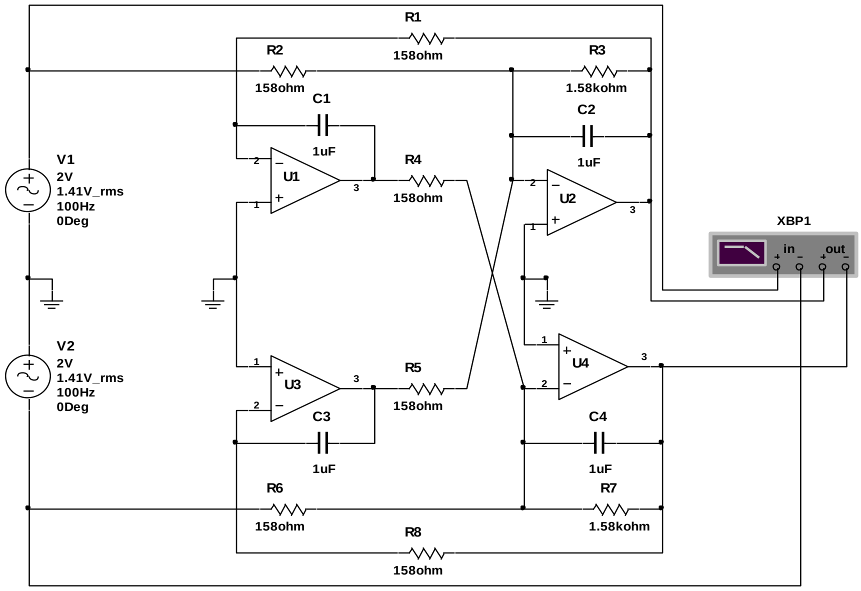
Fig.7 Band Pass Filter, where Q=0.707.
a-Simulation Circuit Diagram.
b-Frequency Response.
c-Phase Response.



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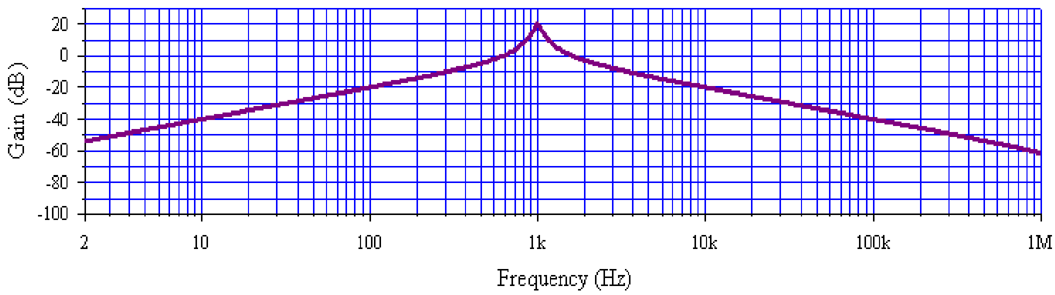

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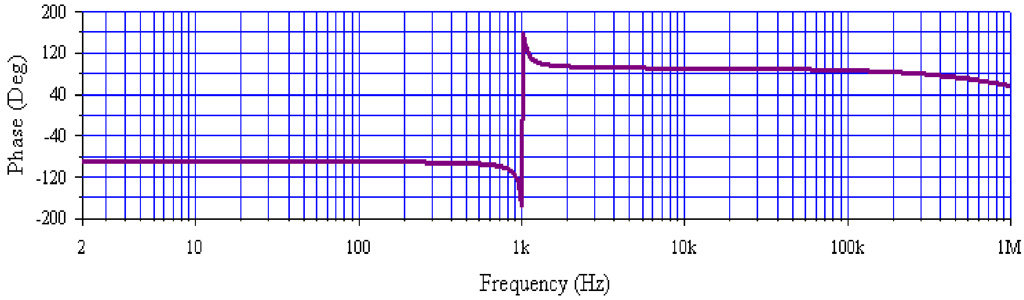

(c)

Fig.8 Band Pass Filter, where Q=10.
a-Simulation Circuit Diagram.
b-Frequency Response.
c-Phase Response.

IV. Conclusion

This work presented a systematic methodology for the synthesis of high-efficiency balanced second-order active filters based on a generalized cross-over architecture. Unlike conventional balanced filter realizations derived from single-ended transformations, the proposed topology enables cross-lattice interconnections between symmetrical halves of the circuit, resulting in a reduced component count and improved structural efficiency. The analytical derivation of the transfer functions confirmed that the proposed architecture maintains standard second-order behavior while allowing precise control of the natural frequency and quality factor.

Simulation results obtained using Multisim demonstrated excellent agreement with theoretical predictions for both maximally flat responses (Q = 0.707) and high selectivity cases (Q = 10), confirming correct filter operation across varying specifications. Compared to traditional KHN-based balanced implementations, the proposed design achieves equivalent functional performance with fewer passive and active components, thereby reducing system complexity and potential sensitivity to component tolerances. Consequently, the proposed cross-over methodology provides a robust and efficient alternative for the realization of balanced active filters suitable for high-performance analog applications and integrated circuit designs

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