Synthesis of Negative Group Delay Time Circuit

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I. Introduction

Negative group delay (NGD) can be introduced either by Left-Handed (LH) material or active/passive Negative Group Delay Circuits (NGDC) [1]-[3]. Among those techniques, passive NGDC (PNGDC) is preferred because of its simple structure and easy implementation. However, no general equation that provides intuition on the operation principle of the circuit has been presented in the previous researches. In this paper, we mathematically analyzed negative group delay circuit and derived general equations, and presented simulation and experimental results.

II. Mathematical Analysis of Passive NGDC Structure

A. Shunt-Series Resonance Circuit (SSRC)

Fig.1 (a) shows the equivalent circuit of SSRC. The input impedance of SSRC is expressed by (1). After calculating the transmission coefficient (S_{21}) using (1) based on the rule of energy conservation, we substituted the phase component of S_{21} into the group delay equation (2). When the resonance conditions were applied at the desired frequency, we could obtain the final expression as in (3).

$$Z_{\text{in},SS} = R + j\omega L + \frac{1}{j\omega C} \tag{1}$$

$$GD = -\frac{d\phi}{d\omega} \tag{2}$$

$$GD_{SSRC} = -\frac{2Z_0 L}{R(2R+Z_0)} \tag{3}$$

When we increase the inductance, the amount of negative group delay is also increased. Values of the resistors also affect the negative group delay. Based on the derived equations, we presented 3-dimensional graph showing the general tendency as shown in Fig. 1 (b). The amount of negative group delay is inverse proportional to the resistance and proportional to the inductance.

B. Series-Parallel Resonance Circuit (SPRC)

Fig. 2(a) shows the equivalent circuit of SPRC. The input impedance of SPRC can be expressed as in (4), and through the similar procedure we could obtain the group delay expression as in (5).

$$Z_{\text{in},SP} = \frac{1}{\frac{1}{R} + \frac{1}{j\omega L} + j\omega C} \tag{4}$$

$$G.D_{SP} = -\frac{2R^2C}{2Z_0 + R} \tag{5}$$

Fig. 2 (b) presents the 3-dimensional graph of (5). We found that the negative group delay is inverse proportional to the resistance and proportional to the capacitance of SPRC.

C. Broadband PNGDC

Since the above explained structures have negative group delay only for narrow bandwidth, possible application may be limited. For broader bandwidth NGDC, we combined SSRC and SPRC constituting π-structure as in Fig. 3 (a). Each branch of SSRC, SPRC, and SSRC has different center frequency, 2.11GHz, 2.14 GHz, and 2.17 GHz, respectively, and the whole circuit occupies 2.11~2.17 GHz. Bias circuits in Fig. 3 (b) are used to obtain the desired inductance value using varactor diode.

III. Experimental Results

As explained earlier, each branch of π-structured broadband NGDC has different center frequency. Measured group delay values at each band are -0.81 ns, -0.86 ns, and -0.86 ns, respectively, as shown in Fig. 4. Experimental results of broadband NGDC are shown in Fig. 5. The proposed NGDC has bandwidth of 60 MHz, insertion loss of -16 dB, and group delay of -1.7 ns with ±0.06 ns ripple. Insertion loss can be compensated with small gain amplifier.

IV. Conclusion

In this work, mathematical analysis and synthesis procedure on the negative group delay circuit has been presented with experimental results. Although broadband can be achieved with the proposed circuit, the work of increasing the amount of negative group delay time is still remained as a future work.

References

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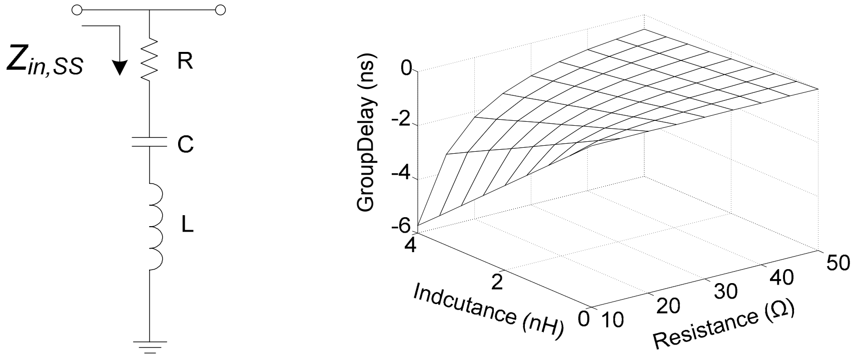
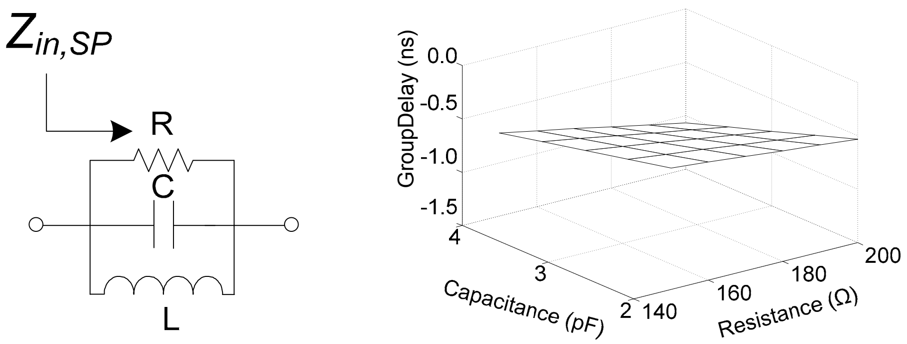
Figures



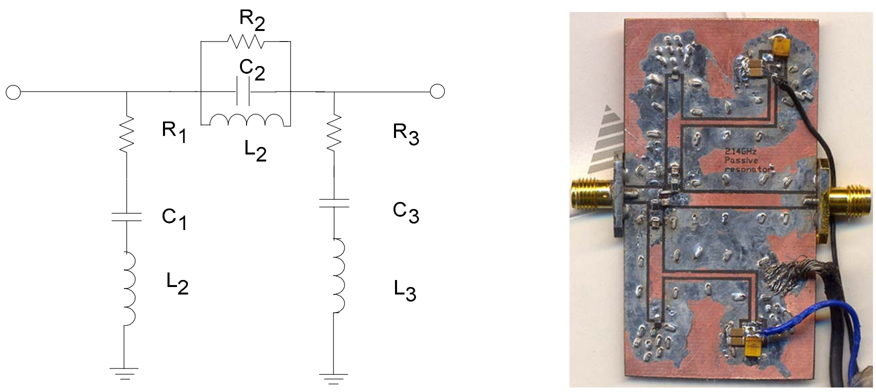
(a) (b)

Fig. 1. (a) Equivalent circuit of SSRC and (b) 3-D plot of SSRC according to the resistance and inductance.



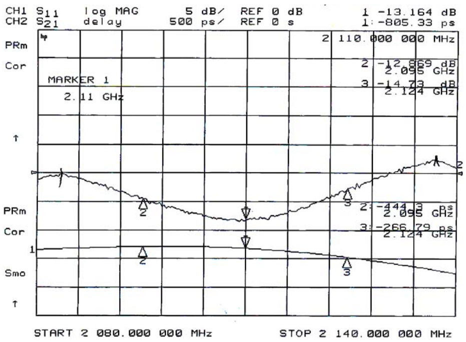
(a) (b)

Fig. 2. (a) Equivalent circuit of SPRC and (b) 3-D plot of SPRC according to the resistance and capacitance.

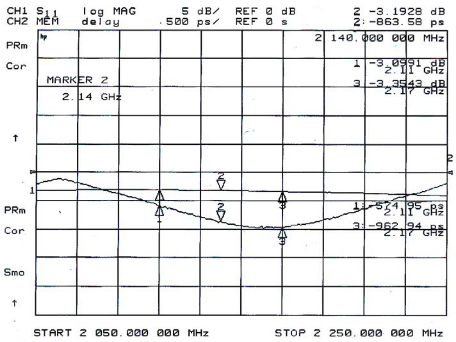


(a) (b)

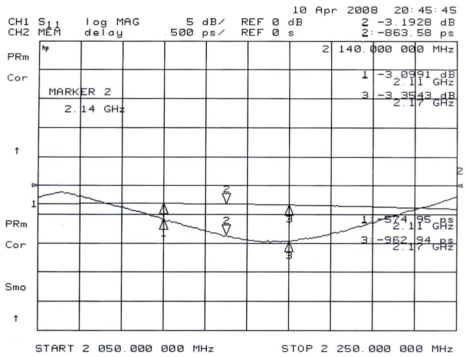
Fig. 3. (a) Equivalent circuit of broadband PNGTC and (b) fabricated circuit.



(a)

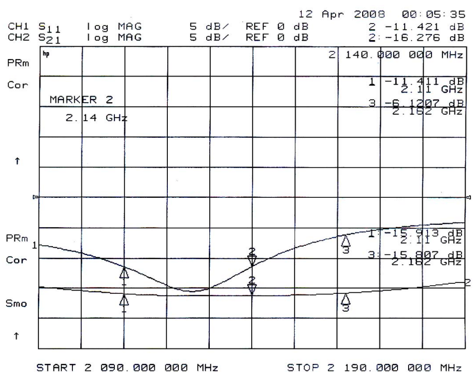


(b)

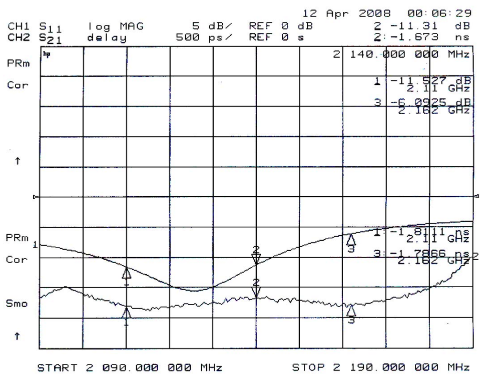


(c)

Fig. 4. Measured results of (a) SSRC @ 2.11 GHz, (b) SPRC @ 2.14 GHz, and (c) SSRC @ 2.17 GHz.



(a)



(b)

Fig. 5. Measured results of broadband NGDC: (a) S_{11} & S_{21} and (b) S_{11} & group delay.