Design of Tunable Negative Group Delay Circuit for Communication Systems

Junhyung Jeong, Sungdoo Park, Girdhari Chaudhary and Yongchae Jeong

Division of Electronics and Information Engineering, IT Convergence Research Center,
Chonbuk National University, Jeonju, Republic of Korea
Email: girdharic@jbnu.ac.kr

***Abstract* — In this paper, a design of tunable microstrip transmission line negative group delay circuit (NGDC) using p-i-n diodes is proposed. The design was based on reflective parallel R-L-C circuit and group delay (GD) can be varied with help of variable resistance. To get the variable resistance, the transmission line (TL) terminated with p-i-n diode is used. The GD is varied with help of bias voltages of p-i-n diodes. Both design equations and design procedures are presented. The measured GD time variation range is 0 ~ -20 ns and well agreed with simulation results.**

***Index Terms* — negative group delay, transmission line, p-i-n diodes.**

I. INTRODUCTION

In a specific frequency band with signal absorption or attenuation condition, the group velocity is observed to be greater than a speed of light in vacuum or even to be negative. Faster phenomenon than speed of light in vacuum is defined as superluminal group velocity and negative group velocity is called a negative group delay (NGD) [1] [2]. Recently, the interesting experimental validations on NGD concept and their electronic circuit applications have been reported by various researchers [2].

The various kinds of NGDCs have been reported and have been applied these circuits to various useful practical applications in communication systems [3]-[11]. However, the previously presented NGDC had only focused on the design of fixed GD circuit.

In comparison to the fixed NGDC, there has been little effort made in design of tunable microwave NGDC. In [11], Lucyszyn *et. al.* had presented NGD synthesizer implemented on a monolithic microwave integrated circuit (MMIC) using cold FETs as variable resistor and varactor diodes as variable capacitor which increases number of biasing circuits.

In this paper, a reflection type microstrip transmission line tunable NGDC is presented. The design is based on simple reflective parallel R-L-C lumped element circuit. The GD of proposed circuit can be varied by changing the value of resistor. The variable resistors are implemented with transmission line terminated with p-i-n diode.

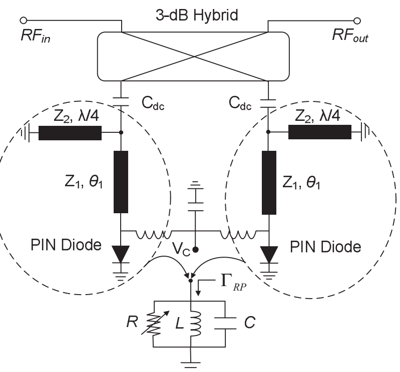

Fig. 1. Structure of proposed tunable negative group delay circuit.

II. ANALYSIS OF TUNABLE NEGATIVE GROUP DELAY CIRCUIT

Fig. 1 shows the structure of proposed tunable NGDC circuit. It consists of 3-dB hybrid, TL and p-i-n diodes terminated TL, which circuit is equivalently a reflective parallel R-L-C circuit with variable resistor. The GD of reflective parallel R-L-C circuit by assuming a resonance condition at the desired operating frequency is given as [9].

$$GD\big|_{\omega=\omega_0} = -\frac{d\phi}{d\omega}\bigg|_{\omega=\omega_0} = \frac{4R^2Y_0C}{(RY_0)^2-1} \quad (1)$$

The GD is a function of capacitance (C) and resistance (R). From (1), it is clear that GD can be tuned with help of variable resistor fixing the capacitance and inductance at the required operating frequency. One major difficulty of lumped element circuit is the feasibility of the designed component values at a microwave frequency. In order to overcome this problem, the short-circuited quarter-wavelength TL resonators with characteristic impedance Z_2 are used to implement the parallel LC resonator. The value of Z_2 is given as [9].

$$Z_2 = \frac{\pi}{4\omega_0 C} \quad (2)$$

The variable resistors are implemented with the TL terminated with p-i-n diode whose equivalent circuit is shown in Fig. 2. The input impedance Z_{R_in} looking into TL terminated to p-i-n diode is given as [12].

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$$Z_{R\_in} = Z_c A \frac{(Z_c + B\tan\theta) - (B - Z_c\tan\theta)\tan\theta}{(Z_c + B\tan\theta)^2 + (A\tan\theta)^2} - j\frac{(Z_c + B\tan\theta)(B - Z_c\tan\theta) + A^2\tan\theta}{(Z_c + B\tan\theta)^2 + (A\tan\theta)^2} \quad (3)$$

Where the values of A and B are given as below.

$$A = R_s + \frac{R_j}{1+(\omega R_j C_j)^2},\ B = \frac{\omega R_j^2}{1+(\omega R_j C_j)^2} - \omega L_s \quad (4)$$

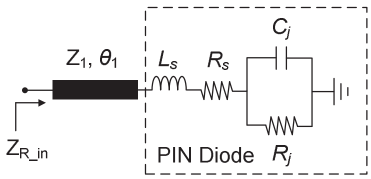
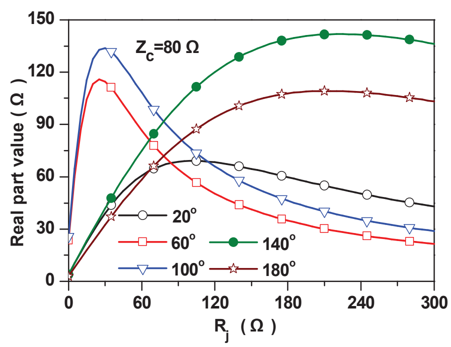
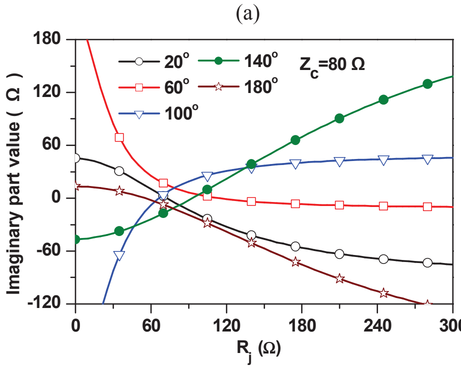


Fig. 2. Equivalent circuit transmission line terminated with p-i-n diode.



(a)



(b)

Fig. 3. Input impedance of transmission line terminated with p-i-n according to value of R_j: (a) real part and (b) imaginary part.

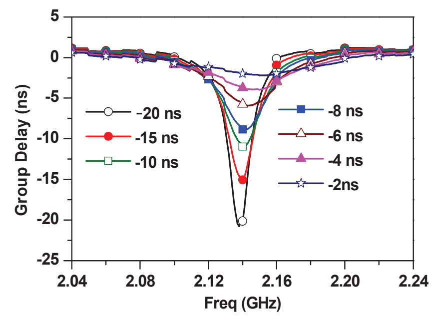
In order to get the purely real Z_{R_in}, the imaginary part of Z_{R_in} should be equal to zero. For this purpose, the real and imaginary parts of Z_{R_in} are plotted in Fig. 3 according to the different characteristic impedances and electrical lengths of TL at the operating frequency 2.14 GHz. In this case, the equivalent circuit parameters of Avago HSMP-4810 p-i-n diode were used whose values are given as L_s=1 nH, R_s=3 Ω, and C_j=0.35 pF, respectively. Fig. 3 shows that the imaginary part of Z_{R_in} is almost zero when the electrical length is around 60°, where the characteristic impedance of TL is 80 Ω.

III. Simulation and Experimental Results

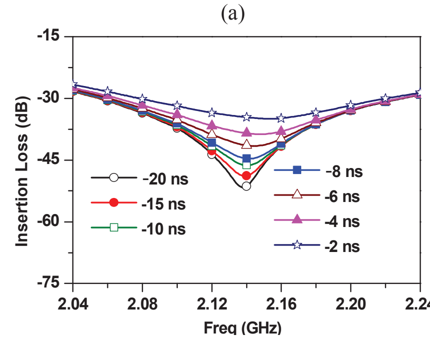
To verify the proposed structure, the reflection type tunable NGDC is designed, simulated and measured at around 2.14 GHz. The used substrate is an RT/Duriod 5880 made by Rogers with a dielectric constant ($_r$) of 2.2 and thickness (h) of 31 mils.

From the previous section analysis, the electrical length and characteristic impedance of TL terminated with p-i-n diode are found as 60° and 80 at 2.14 GHz. The parallel LC resonators are also implemented with short circuited quarter-wavelength TL line at 2.14 GHz.

Fig. 4 shows the simulation results of proposed tunable NGDC. From the simulation as shown in Fig. 4(a), it was found that the GD is varied from -2 ns to -20 ns by varying the R_j of p-i-n diode. The insertion loss varies from 34.9 dB to 52.4 dB. The return loss characteristics are better than 38 dB in over all tuning range of GD as shown in Fig. 4(c).



(a)



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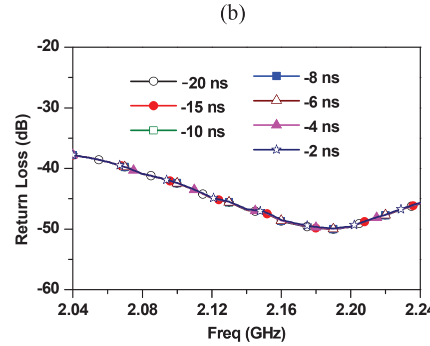
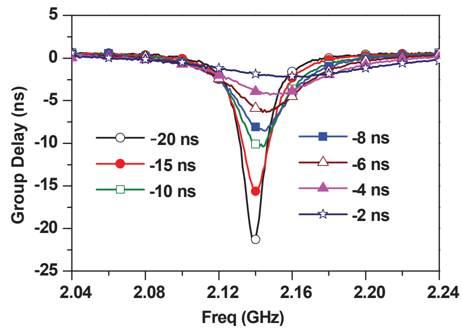


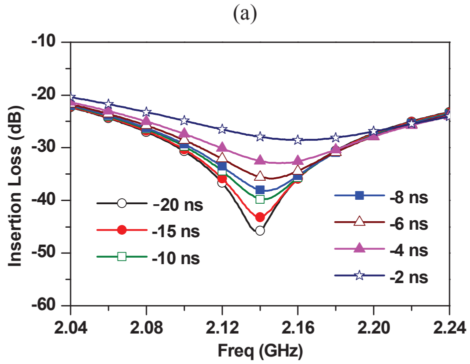
(c)

Fig. 4. Simulated results of tunable negative group delay circuit: (a) group delay variation, (b) insertion loss, and (c) return loss characteristics.

Fig. 5 shows the measured results of fabricated tunable NGDC. The measured results are well agreement with the simulation results. From the measurement result as shown in Fig. 5(a), the GD variation is from -2 ns to -20 ns by varying the bias voltage 0.60 V to 0.597 V of p-i-n diodes. The measured insertion loss variations as shown in Fig. 5(b) are 28.55 dB to 46.12 dB. The measured return loss characteristics are better than 35 dB as shown in Fig. 5(c).



(a)



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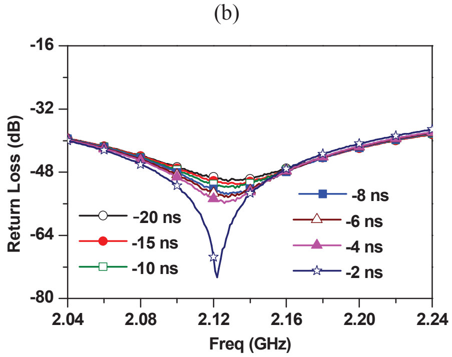

Fig. 5. Measured results of tunable negative group delay circuit: (a) group delay variation, (b) insertion loss, and (c) return loss.

IV. Conclusion

In this paper, a microstrip transmission line tunable negative group delay for communication systems is investigated. The design was based on a reflective parallel R-L-C resonator. The variable resistance was implemented by transmission line terminated with the p-i-n diodes. The group delay variation is obtained by varying the bias voltage of the p-i-n diode. The optimum design method is explained based on derived general design equations. Both theoretical and experimental results are provided in order to validate the proposed structure. The measured results have good agreement with simulation results. We are now working toward to enhance the bandwidth of operating frequency with the variable negative group delay circuit.

References

[1] L. Brillouin and A. Sommerfeld, *Wave Propagation and Group velocity*, Acamedic Press Network, 1960.

[2] K. Kitano, T. Nakanishi, and K. Sugiyama, "Negative group delay and superluminal propagation: an electronic circuit approach," *IEEE Journal of Selected Topics in Quantum Electronics,* vol. 9, no. 1, pp. 43-51, Jan. 2003.

[3] B. Ravelo, A. Perennec, M. L. Roy, and Y. G. Boucher, "Active Microwave circuit with negative group delay," *IEEE Microw. Wireless Compon. Letters*, vol. 17, no. 12, pp. 861-863, Dec. 2007.

[4] S. Lucyszyn and I. D. Robertson, "Analog reflection topology building blocks for adaptive microwave signal processing applications," *IEEE Microw. Theory Tech.,* vol. 43, no. 3, pp. 601-611, Mar. 1995.

[5] M. Kandic and G. E. Bridges, "Bilateral Gain-compensated negative group delay circuit," *IEEE Microw. Wireless Compon. Letters,* vol. 21, no. 6, pp. 308-310, Jun. 2011.

[6] M. Kandic and G. E. Bridges, "Asymptotic limits of negative group delay in active resonator-based distributed circuits," *IEEE Trans. Circuits and Systems*, vol. 58, no. 8, pp. 1727-1735, Aug. 2011.

[7] Y. Jeong, H. Choi, and C. D. Kim, "Experimental verification for time advancement of negative group delay in RF electronics circuits," *Electronics Letters,* vol. 46, no. 4, pp. 306-307, Feb. 2010.

[8] H. Choi, Y. Kim, Y. Jeong, and C. D. Kim, "Synthesis of reflection type negative group delay circuit using transmission line resonator," *Proceeding of 39th European Microw. Conf.*, pp. 902-605, Sep. 2009.

[9] H. Choi, Y. Jeong, C. D. Kim and J. S. Kenney, "Efficiency enhancement of feedforward amplifiers by employing a negative group delay circuit," *IEEE Trans. Microw. Theory Tech.*, vol. 58, no. 5, pp. 1116-1125, May 2010.

[10] H. Choi, Y. Jeong, C. D. Kim, and J. S. Kenney, "Bandwidth enhancement of an analog feedback amplifier by employing a negative group delay circuit," *Progress in Electromagn. Research*, vol. 105, pp. 253-272, 2010.

[11] S. Lucyszyn, I. D. Robertson, and A. H. Aghvami, "Negative group delay synthesizer," *Electronics Letters*, vol. 29, no. 9, pp. 798-800, Apr. 1998.

[12] G. Chaudhary and Y. Jeong, "Design of vector modulator using low phase deviation attenuators with large amplitude variations range," *Journal of Electromagnetic Waves and Applications*, vol. 26, no. 2-3, pp. 402-410, Apr. 2012.