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Negative Group Delay Circuit with Independently Tunable Center Frequency and Group Delay

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***Abstract* — In this paper, a design of negative group delay circuit (NGDC) with independently tunable center frequency and group delay (GD) is presented. Since the proposed structure consists of a parallel RLC resonance circuit, it is possible to obtain a variable negative GD by using a variable resistor and an adjustment of center frequency of GD is possible due to a variable inductor. To get the pure variable resistor, the transmission line (TL) terminated with the PIN diode is used. Similarly, the variable inductor is realized by TL terminated with the varactor diode. To show the effectiveness of the proposed NGDC, it is designed at 2.14 GHz of WCDMA downlink band. The measured negative GD time is -2 ~ -20ns, and are able to change the center frequencies of negative GD in the range of 2.04 ~ 2.24 GHz.**

***Index Terms* — negative group delay circuit, PIN diode, tunable center frequency, varactor diode.**

I. Introduction

Since after the negative GD characteristics are discovered, it was applied to the various applications of microwave communication system [1]-[6]. For example, by inserting a NGDC on a common path in the feed-forward amplifier, it is possible to remove delay element located in the output stage of main amplifier which results in efficiency and output power enhancement [6]. However, the previous works related to NGDC can provide only a fixed negative GD and only works with a fixed frequency. In comparison to the fixed NGDC, there has been little effort made in design of tunable microwave NGDC [7], [8]. However, these works cannot provide independent tunability of GD and center frequency simultaneously. If the negative GD time and operating frequency can be adjusted as needed, the applications of NGDC in communication systems will be more increased.

This paper presents the analysis and design of NGDC with independently tunable center frequency and GD. For this purpose, the variable resistor and inductor should be implemented to operate in the microwave band. Generally in the microwave band, the variable resistor can be implemented use a PIN diode but it contains the parasitic component in addition to the resistance. In this paper, the parasitic component of PIN diode is compensated by TL and is implemented as purely resistive. The variable inductor is realized by TL terminated with the varactor diode.

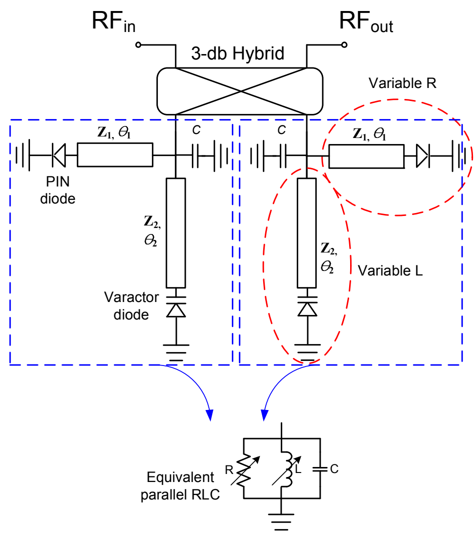

Fig. 1. Structure of proposed NGDC with independently tunable center frequency and group delay.

II. Mathematical Analysis

Fig. 1 shows the structure of proposed NGDC with independently tunable center frequency and GD. It consists of 3-dB hybrid coupler and parallel RLC circuits. The variable resistor is realized the TL terminated with the PIN diode and variable inductor is realized TL terminated with the varactor diode. At the resonant frequency, the negative GD characteristics and insertion loss of reflective-parallel RLC can be obtained as follows [6].

$$GD\Big|_{\omega=\omega_0} = -\frac{d\phi}{d\omega}\Big|_{\omega=\omega_0} = -\frac{4R^2Z_0C}{Z_0^2-R^2} = -\frac{4R^2Z_0}{\omega_0^2L\left(Z_0^2-R^2\right)} \quad (1)$$

$$\left|S_{21}\right|_{\omega=\omega_0} = \frac{R-Z_0}{R+Z_0} \quad (2)$$

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Where the GD is a function of C, L, and R, and negative GD can be obtained for $0<R<Z_0$. From (1), it is also clear that the GD can be tuned with variable R fixing the C and L at the required operating frequency. Moreover, the center frequency of GD can be adjusted with varying the C or L. Since C and L variation can change GD variation, it is necessary to tune R for the constant NGD. Equation (2) is described about an insertion loss along to the R at resonant frequency. The insertion loss is increased when R is closer to Z_0.

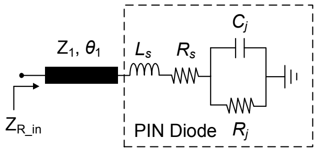


Fig. 2. Equivalent circuit transmission line terminated with PIN diode.

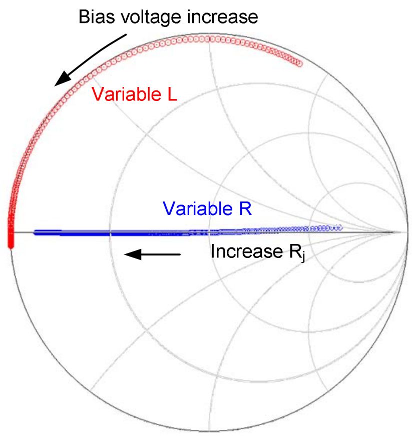


Fig. 3. Simulation results of variable resistor and inductor at 2.14 GHz.

Fig. 2 shows an equivalent circuit of TL terminated with the PIN diode. The input impedance Z_{R_in} looking into TL terminated with PIN diode is given as [8].

$$Z_{R\_in} = Z_1 A \frac{(Z_1 + B\tan\theta_1) - (B - Z_1\ \tan\theta_1)\tan\theta_1}{(Z_c + B\tan\theta)^2 + (A\tan\theta)^2} - j\frac{(Z_c + B\tan\theta_1)(B - Z_1\tan\theta_1) + A^2\tan\theta_1}{(Z_c + B\tan\theta_1)^2 + (A\tan\theta_1)^2} \quad (3)$$

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

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

From (3), it is clear that for purely real Z_{R_in}, the imaginary part of Z_{R_in} should be equal to zero. Therefore, the TL with specific characteristic impedance and electrical length can remove the reactance of variable resistor so that it can be realized as pure variable resistor.

Fig. 3 is show the simulation result of proposed variable resistor at 2.14 GHz. In this simulation, the PIN diode from Avago HSMP-4810 and the TL with characteristic impedance of Z_1=88.3 and electrical length of $_1$=61.5° were used. From the simulation results, it is seen that the reactance amplitude is smaller than 0.01 when the resistance variation is 40~50 range. So it presents almost similar characteristic as like the pure resistor. Fig. 3 also shows the simulation result of variable inductor. In this case, Skyworks SMV-1233 varactor diode and the TL with characteristic impedance Z_2=82 , electrical length $_2$=50° were used. The variation range of inductance is 0~7 nH.

III. Fabrication and Measurement

The goal was to design the NGDC with GD variation from -2~-20 ns and center frequency variation from 2~2.3 GHz. For this purpose, the proposed NGDC was designed at 2.14 GHz of WCDMA downlink band which is middle of required center frequency variation. 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.

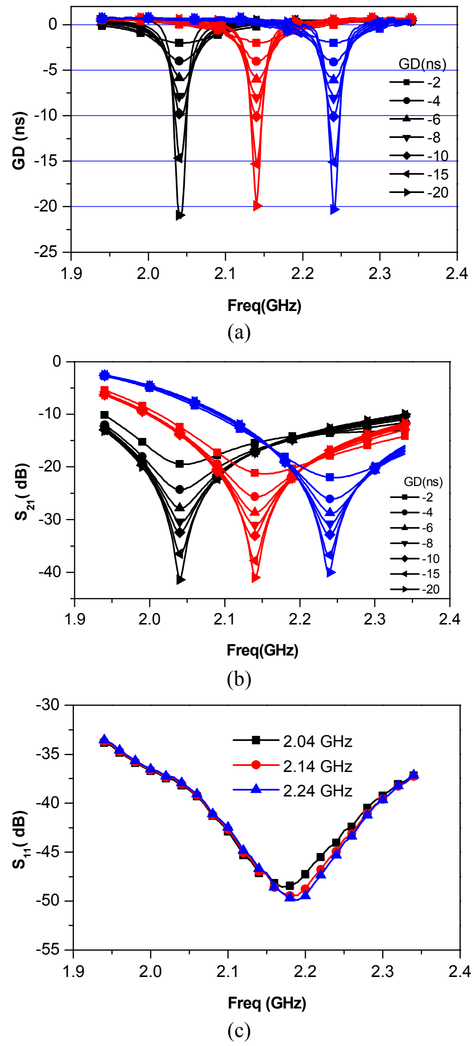
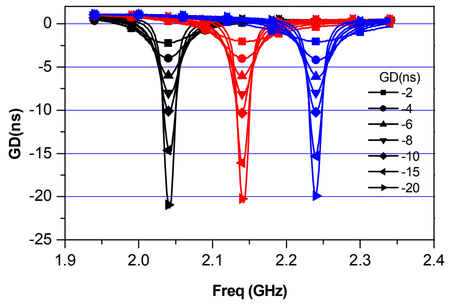
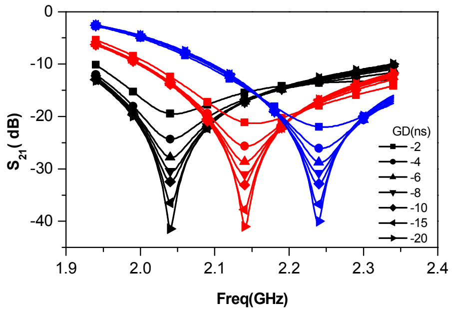


Fig. 4. Simulated results of tunable negative group delay circuit: (a) group delay variation, (b) insertion loss, and (c) return loss characteristics.

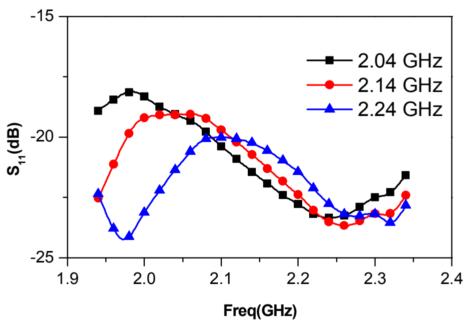
Fig. 4 shows the simulation results of proposed NGDC. From the simulation as shown in Fig. 4(a), it was found that the GD is varied from -2 ns to -20 ns by varying the R_j of PIN diode and the center frequency is tuned from 2.04 to 2.24 GHz. The insertion loss varies from 19.3 dB to 40.8 dB. The return loss characteristics are better than 32 dB in overall tuning range of GD and center frequency as shown in Fig. 4(c).



(a)



(b)



(c)

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

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 ~ 0.657 V of PIN diodes and center frequency variation is from 2.04 to 2.24 GHz by varying bias voltage of varactor diode. The measured insertion loss variations as shown in Fig. 5(b) are 19.45 dB to 41.5 dB. The measured return loss characteristics are better than 17 dB as shown in Fig. 5(c). Fig. 6. show the Photograph of fabricated circuit.

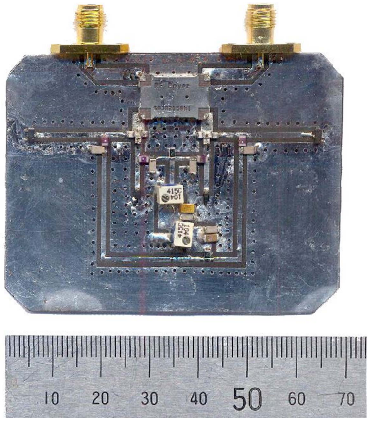


Fig. 6. Photograph of fabricated NGDC with independently tunable center frequency and group delay.

IV. CONCLUION

This paper is analyzed about NGDC with independently tunable center frequency and group delay at WCDMA downlink band. The proposed circuit showed the group delay variation characteristics of -2 to -20 ns at the center frequency of 2.04 to 2.24 GHz (200MHz). The insertion loss variation according to GD can be compensated using the small signal amplifier. The proposed circuit is expected to be applied in various microwave communication systems.

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