2013 Asia-Pacific Microwave Conference

APMC 2013

November 5 ~ 8, 2013 / Coex, Seoul, Korea

Compact Negative Group Delay Circuit Using Defected Ground Structure

Girdhari Chaudhary[#], Junhyung Jeong[#], Phirun Kim[#], Yongchae Jeong[#], and Jongsik Lim[*]

[#]Division of Electronics and Information Engineering,
Chonbuk National Univeristy, Jeonju-si, Jellabuk-do, 561-756, Republic of Korea
[*]Department of Electrical Communication Engineering,
Soonchunhyang University, Asan-si, Choongnam, 336-745, Republic of Korea

girdharic@jbnu.ac.kr

***Abstract* — A novel design of compact negative group delay circuit (NGDC) using U-shaped defected ground structure (DGS) is presented in this paper. The required group delay (GD) time can be controlled by an external resistor connected across the DGS slot. For experimental verification, a single stage NGDC is designed, fabricated, and compared with a circuit simulation. To enhance NGD bandwidth, two stages NGDC with the different center frequencies in cascade are demonstrated and GD of -3.8 ns with maximum signal attenuation of 37.10 dB was obtained on 3.45-3.55 GHz.**

***Index Terms* — Defected ground structure, transmission line, negative group delay.**

I. INTRODUCTION

Abnormal electromagnetic wave propagation characterized by negative group velocity and consequently negative group delay (NGD) has been observed within the finite frequency intervals of signal attenuation in certain media as well in an artificially built structures [1]. So, it is growing interest in design of NGDC due to its various applications in communication systems such as shortening or reducing delay lines and efficiency enhancement of feedforward linearization [2], beam-squit minimization in phased array antenna systems [3], and eliminating phase variation with frequency in phase shifters [4]. So, the various kinds of NGDC based on active/passive *RLC* resonators have been presented in the previous studies [2]-[7].

Recently, it is growing interest on the periodic structures such as microstrip photonic bandgap (PBG), defected microstrip structure (DMS) and DGS, and which provide the attenuation at certain resonant frequency and applied successfully in various applications [8]. However, no previous works were focused to design NGDC using periodic structures such as DGS.

In this paper, the attenuation characteristics of DGS are utilized to design and investigate the compact NGDC. Firstly, the U-shaped DGS is investigated and its equivalent lumped elements are extracted using an equivalent circuit model. Then, the required amount of negative GD at the operating frequency is obtained by connecting external resistor.

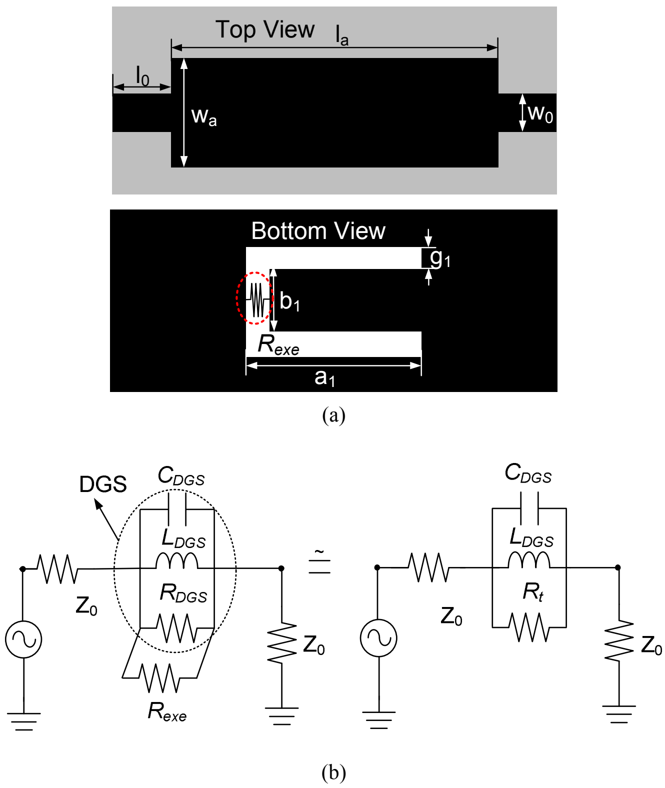

Fig. 1. (a) Proposed structure of NGDC using DGS with external resistor and (b) its equivalent circuit.

II. DESIGN AND IMPLEMENTATION

Fig. 1(a) shows the layout of proposed NGDC which consists of the U-shaped DGS and external resistor connected across the DGS slot. The equivalent circuit of proposed NGDC is shown in Fig. 1(b). The equivalent model of DGS can be expressed as the parallel *RLC* circuit [8]. The element values of equivalent DGS can be obtained by performing EM simulation whose values are given as below [8].

978-1-4799-1472-2/13/$31.00 ©2013 IEEE

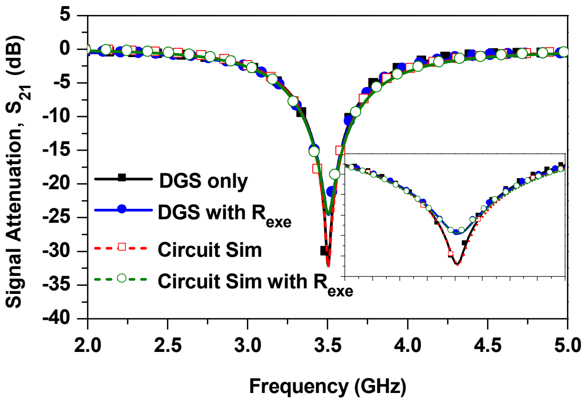

Fig. 2. Simulation results of U-shaped DGS microstrip line.

$$C_{DGS} = \frac{f_c}{4\pi Z_0\left(f_0^2 - f_c^2\right)} \quad (1)$$

$$L_{DGS} = \frac{1}{4\pi^2 f_0^2 C_{DGS}} \quad (2)$$

$$R_{DGS} = 2Z_0 \frac{1 - S_{21}(f_0)}{S_{21}(f_0)}. \quad (3)$$

Where f_c, f_0, and S_{21} are the 3-dB cut-off frequency, resonant frequency and transmission coefficient obtained from an electromagnetic (EM) simulation, respectively. The externally connected R_{exe} is equivalently in parallel with the *RLC* circuit of DGS as shown in Fig. 1(b). The added R_{exe} is used to get the required value of transmission characteristics at the resonant frequency. From the equivalent circuit of proposed structure, the GD and signal attenuation can be calculated as below.

$$\tau\big|_{f=f_0} = -\frac{1}{2\pi}\frac{d\angle S_{21}}{df} = -\frac{2R_t^2 C_{DGS}}{2Z_0 + R_t}. \quad (4)$$

$$\left|S_{21}\right|_{f=f_0} = \frac{2Z_0}{2Z_0 + R_t}. \quad (5)$$

Where Z_0 is termination port impedance. The total value of R_t is given as.

$$R_t = \frac{R_{DGS}R_{exe}}{R_{DGS} + R_{exe}}. \quad (6)$$

From (4) and (6), it is clear that the GD time is controlled by R_{exe}. To verity the design concept of proposed NGDC, firstly, the U-shaped DGS are simulated with a full-wave solver Ansoft HFSS v13 with following dimensions: w_0=2.4, l_0=2, w_a=4, a_1=16, b_1=2.4, g_1=0.4 (all units are in mm). The simulation is performed using a substrate RT/Duroid 5880 with dielectric constant (ε_r) of 2.2 and thickness (*h*) of 31 mils.

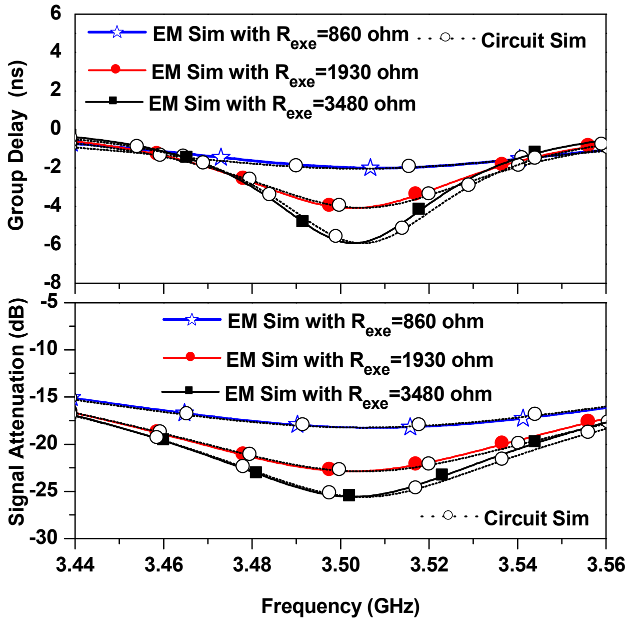

Fig. 3. Simulation results of NGDC with different values of external resistor R_{exe}.

Fig. 2 shows the simulated resonance characteristics of U-shaped DGS where 3-dB cut-off and resonant frequencies are at 3.065 GHz and 3.505 GHz Therefore, the extracted value of equivalent circuit of DGS are given as *C*=1.6874 pF, *L*=1.2219 nH, and *R*=3.9414 kΩ. The transmission coefficient (S_{21}) is controlled by connecting R_{exe}= 3.48 kΩ.

Fig. 3 shows the simulation results of NGDC under different R_{exe}. The circuit simulation results have a good agreement with the EM-simulation results. From this figure, it is shown that the GD time is controlled by R_{exe}. From the simulation, the GD time of -5 ns with signal attenuation of 24.49 dB was obtained at the center frequency of 3.50 GHz.

IV. Simulation And Measurement

The goal was to design the GD of -5 ns for the worldwide interoperability for microwave access (WiMax) band operating at the center frequency 3.50 GHz. For this purpose, the NGDC using DGS is simulated and fabricated. The physical dimensions of U-shaped DGS are same as the previous.

Fig. 4 shows the simulation and measurement results of proposed NGDC. The measurement results have a good agreement with the EM simulation results. In this measurement, R_{exe}=2.4 kΩ are used. From the measurement, it is found that the GD of -4.6 ns with the signal attenuation of 22.68 dB at the center frequency 3.506 GHz.

To increase the negative GD bandwidth, the two stages NGDC is simulated and fabricated.

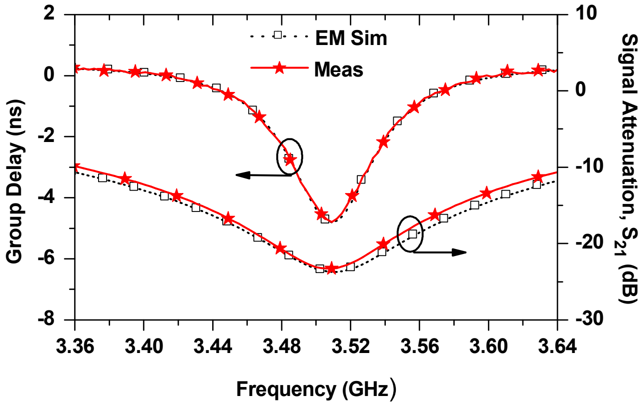

Fig. 4. Simulation and measurement results of single stage NGDC.

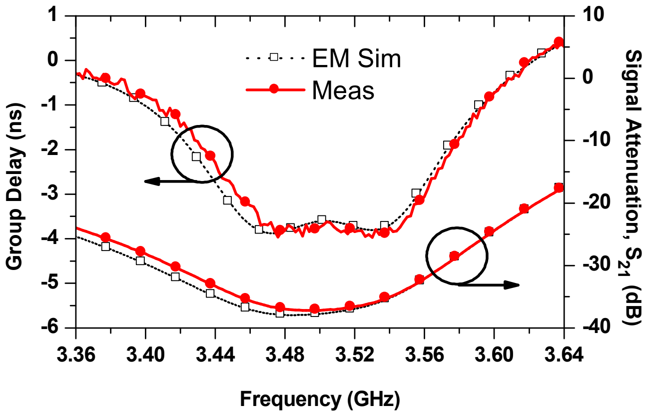

Fig. 5. Simulation and measurement results of 2-stages NGDC.

For this purpose, two unit NGDC cells operated at the center frequencies 3.47 GHz and 3.53 GHz, respectively, are cascaded. The physical dimensions of the unit cell NGDC is same as the previous and the separation between two unit cells is 7.84 mm. The value of R_{exe1}=2.52 kΩ and R_{exe2}=2.54 kΩ are used to get desired operating center frequency and GD.

Fig. 5 shows the simulation and measurement result of two-stage NGDC. The measurement results are well agreed with the simulation results. From the measurements, it is found that the GD of -3.8 ns over the operating bandwidth 100 MHz. The measured maximum signal attenuation at the center frequency of 3.505 GHz is around 37.16 dB.

Fig. 6 shows the measured phase characteristics of transmission coefficient (S_{21}). As seen from this figure, the proposed circuit exhibits the positive slope over certain region. The photograph of fabricated circuit is shown in Fig. 6. The overall size of single and two stage NGDCs are 26×16 mm^2 and 52×16 mm^2, respectively which are very compact as compared to the previous works [2], [5].

VII. Conclusion

In this paper, the compact negative group delay circuit using the defected ground structure with external resistor is investigated. Taking advantage of attenuation characteristic of defected ground structure and connecting external resistor the desired amount of negative group delay at the operating

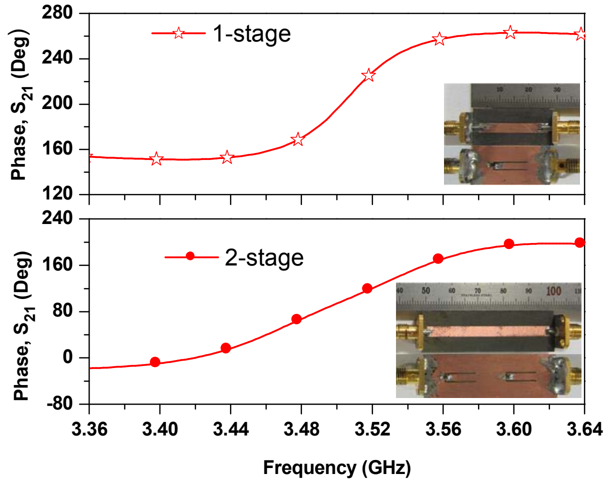

Fig. 6. Measured phase characteristics of S_{21}.

frequency was obtained. The group delay time of proposed circuit is independently controlled by external resistor. To enhance negative group delay bandwidth, the two stage NGDC was also designed and fabricated. The proposed NGDC has compact size, easy to implement and expected to be applicable in wireless communication systems.

References

[1] M. Kitano, T. Nakanishi, and K. Sugiyama, "Negative group delay and superluminal propagation: an electronic circuit approach," *IEEE J. Sel. Top. Quantum Electron.,* vol. 9, no. 1, pp. 43-51, Feb. 2003.

[2] 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.

[3] S. S. Oh and L. Shafai, "Compensated circuit with characteristics of lossless double negative materials and its application to array antennas," *IET Microw. Antennas & Propagation*, vol. 1, no. 1, pp. 29-38, Feb. 2007.

[4] B. Ravelo, M. L. Roy, and A. Perennec, "Application of negative group delay active circuits to the design of broadband and constant phase shifters," *Microw. Optical Tech. Letters*, vol. 50, no. 12, pp. 3078-3080, Dec. 2008.

[5] H. Choi, Y. Kim, Y. Jeong and C. D. Kim, "Synthesis of reflection type negative group delay circuit using transmission line resonator," *Proc. of 39th European Microw. Conference*, 902-905, Sept. 2009.

[6] 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.

[7] 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.

[8] D. Ahn, J. Park, C. Kim, J. Kim, Y. Qian, and T. Itoh, "A design of the low-pass filter using a novel microtrip defected ground structure," *IEEE Tans. Microw. Theory Tech*. vol. 49, no. 1, pp. 86-93, Jan. 2001.