Miniaturized Negative Group Delay Circuit Using Defected Microstrip Structure and Lumped Elements

Girdhari Chaudhary[1], Yongchae Jeong[1], and Jongsik Lim[2]

[1]Division of Electronic and Information Engineering,
Chonbuk National University, Jeonju-si, Jollabuk-do, 561-756, Republic of Korea

[2]Department of Electrical Communication Engineering,
Soonchunhyang University, Asan-si, Choongnam, 336-745, Republic of Korea

Abstract—In this paper, a design of miniaturized negative group delay circuit (NGDC) using U-shaped defected microstrip structure (DMS) and lumped elements is presented. The resonant center frequency and group delay (GD) time are controlled by an external capacitor and resistor connected across the DMS slot. To verify the design concept, a single stage NGDC is designed, fabricated and compared with the circuit simulation. To get wideband bandwidth of GD, two stages NGDC is also demonstrated and the GD of -7 ns with the maximum insertion loss of 34 dB was obtained over 60 MHz bandwidth.

Index Terms — Defected microstrip structure, distributed transmission line, negative group delay, WCDMA.

I. Introduction

Within the finite frequency intervals of signal attenuation in the certain media, the negative group delay phenomenon is observed where higher frequency components of applied waveform are propagated with phase advancement, not delay, relative to the lower frequency components [1]. The various kinds of NGDC based on active/passive RLC resonators have been theoretically and experimentally validated in the previous studies [2]-[6]. Researches have applied these circuits to various useful practical applications in the communication systems such as shortening or reducing delay lines and efficiency enhancement of feedforward linearization [4], beam-squit minimization in the phased array antenna systems [5], eliminating phase variation with frequency in the phase shifters [6]. However, none of previous works were implemented NGDC using a transmitive parallel RLC resonator with a distributed transmission line because of implementation difficulty.

Recently, it is growing interest on the periodic structures such as microstrip photonic bandgap (PBG), defected ground structure (DGS), and defected microstrip structure (DMS) which provide the attenuation at certain resonant frequency and applied successfully in various applications [7], [8]. In the DMS, the patterned structure is etched on signal strip instead of the ground plane which provides the band-rejection characteristics at the certain frequency. However, none of previous works were focused to design NGDC using DMS.

In this paper, the attenuation characteristics of DMS are utilized to design and investigate the compact NGDC. Firstly, the U-shaped DMS is investigated and equivalent lumped elements are extracted using equivalent circuit model.

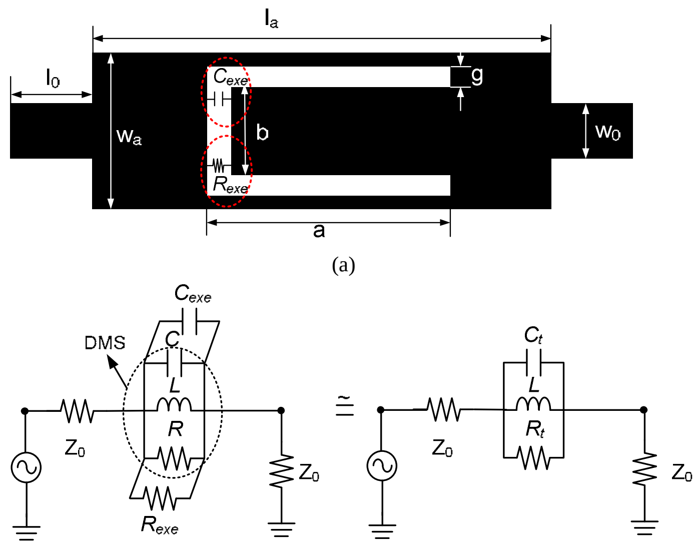

Fig. 1. (a) Proposed structure of NGDC using DMS with external capacitor and resistor and (b) its equivalent circuit.

Secondly, external capacitor is connected across the DMS to get the required operating resonant frequency. Then, the required amount of negative group delay at the operating frequency is obtained by connecting external resistor.

II. Design and Implementation

Fig. 1(a) shows the layout of NGDC which consists of U-shaped DMS, external lumped capacitor (C_{exe}) and resistor (R_{exe}) connected across the DMS slot. The equivalent circuit of proposed NGDC is shown in Fig. 1(b). The equivalent circuit model of DMS can be expressed as the parallel RLC circuit [7]. The lumped element values of the equivalent DMS can be obtained by performing EM simulation whose values are given by [7].

$$C = \frac{f_c}{4\pi Z_0\left(f_0^2 - f_c^2\right)} \tag{1}$$

$$L = \frac{1}{4\pi^2 f_0^2 C} \tag{2}$$

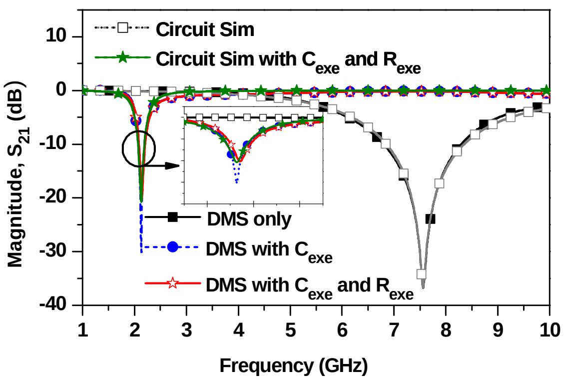

Fig. 2. Full-wave and circuit simulated transmission response of U-shaped DMS with external lumped elements.

$$R = 2Z_0 \frac{1 - S_{21}(f_0)}{S_{21}(f_0)} \tag{3}$$

Where f_c, f_0 and S_{21} are the 3-dB cut-off frequency, resonant frequency and transmission coefficient at the resonant frequency obtained from EM simulation, respectively. The externally connected C_{exe} and R_{exe} are equivalently in parallel with the *RLC* circuit of DMS as shown in Fig. 1(b). The added C_{exe} is used to obtain the required resonant frequency whereas 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 insertion loss can be calculated as.

$$\tau\Big|_{f=f_0} = -\frac{1}{2\pi}\frac{d\angle S_{21}}{df} = -\frac{2R_t^2 C_t}{2Z_0 + R_t} \tag{4}$$

$$\left|S_{21}\right|_{f=f_0} = \frac{2Z_0}{2Z_0 + R_t} \tag{5}$$

Where Z_0 is termination port impedance. The values of C_t and R_t are given as.

$$C_t = C + C_{exe} \tag{6}$$

$$R_t = \frac{RR_{exe}}{R + R_{exe}} \tag{7}$$

From (4) and (7), it is clear that the GD time is controlled by R_{exe}. To verity the design concept of proposed NGDC, firstly, the U-shaped DMS are simulated with a full-wave solver Ansoft HFSSv13 with following dimensions: w_0=2.4, l_0=2, w_a=4, a=6.8, b=2.8, g=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.

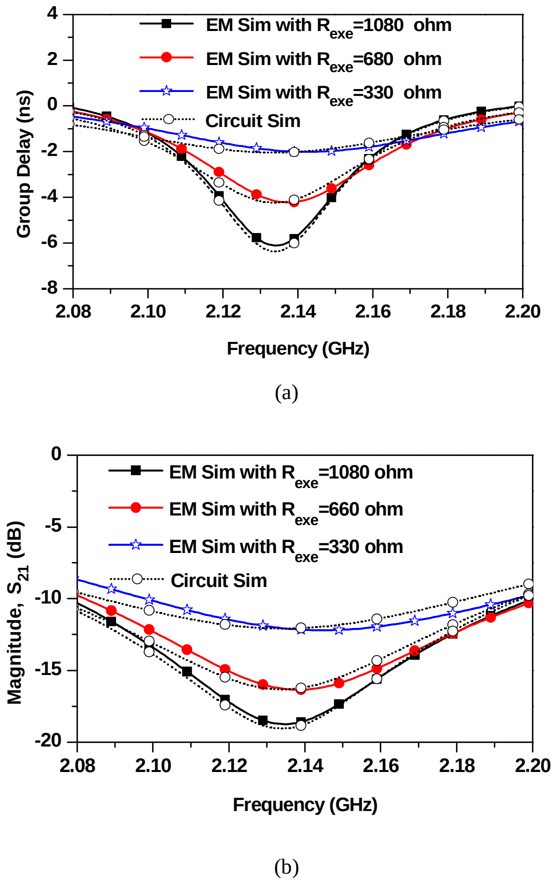

Fig. 3. Simulation results of NGDC: (a) group delay and (b) insertion loss.

Fig. 2 shows the simulated resonance characteristics of U-shaped DMS where 3-dB cut-off and resonant frequencies are at 5.66 GHz and 7.56 GHz Therefore, the extracted value of equivalent circuit of DMS are given as *C*=0.3586 pF, *L*=1.2389 nH and *R*=3.5119 kΩ. By connecting C_{exe} =4.15 pF, the resonant frequency is moved toward lower frequency around 2.14 GHz as shown in Fig 2. Similarly, the transmission coefficient (S_{21}) is controlled by connecting R_{exe}= 1.1 kΩ.

Fig. 3 shows the simulation results of NGDC under different R_{exe}. The circuit simulation results have a good agreement with EM-simulation results. From this figure, it is shown that the group delay amount is controlled by R_{exe}. From the simulation, the negative group amount of -6.5 ns with insertion loss 19.4 dB was obtained at center frequency 2.14 GHz.

III. Simulation and Measurement

The goal was to design the GD of -7 ns for the wideband code division multiple access (WCDMA) downlink band operating at the center frequency 2.14 GHz. For this purpose, the NGDC using DMS is simulated and fabricated. The physical dimensions of U-shaped DMS are same as previous.

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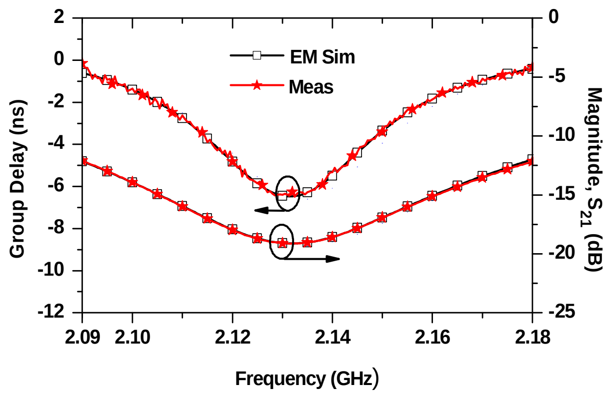


Fig. 4. Simulation and measurement results of single stage NGDC.

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, C_{exe}=4.14 pF and R_{exe}=1.1Ω are used. From the measurement, it is found that the GD of -6.4 ns with the maximum insertion loss of 19.2 dB at the center frequency 2.134 GHz.

To increase the negative GD bandwidth, the two stages NGDC is simulated and fabricated. For this purpose, two unit NGDC cells operated at the center frequencies 2.11 GHz and 2.15 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 5.4 mm. The value of C_{exe1}=4.16 pF, R_{exe1}=1.1 kΩ and C_{exe2}=4.10 pF, R_{exe2}=1.1 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 -7 ns over the operating bandwidth 60 MHz. The measured maximum insertion loss at center frequency 2.13 GHz is around 34 dB.

Fig. 6 shows the photograph of fabricated NGDC. The overall size of single and two stage NGDCs are 18×16 mm^2 and 34×16 mm^2, respectively which are very compact as compared to the previous works.

IV. Conclusion

In this paper, the compact negative group delay circuit using the defected microstrip structure and lumped elements are investigated. Taking advantage of attenuation characteristic of defected microstrip structure and connecting external resistor and capacitor, the desired amount of negative group delay and operating center frequency were 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.

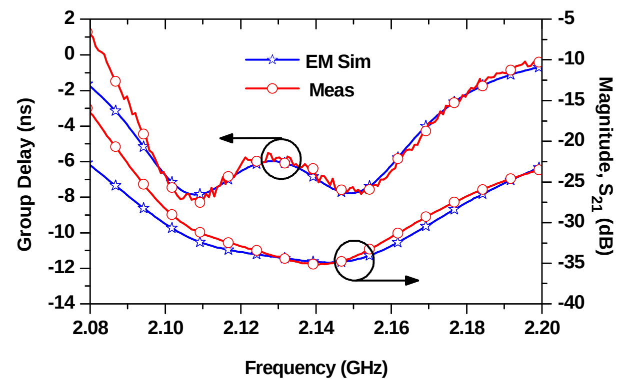
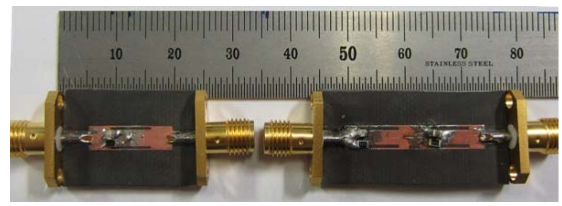


Fig. 5. Simulation and measurement results of 2-stages NGDC.



(a) (b)

Fig. 6. Photograph of fabricated NGDC: (a) single stage and (b) two-stage

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] 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.

[3] 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.

[4] 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.

[5] 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.

[6] 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.

[7] 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.

[8] J. J. A. T. Mendez, H. J. Aguilar, F. I. I Sanchez, I. G. Ruiz, V. M. Lopez, and R. A. Herrera, “A proposed defected microstrip structure (DMS) behavior for reducing rectangular patch antenna size,” *Microwave Optical Tech. Letters,* vol. 43, no. 6, pp. 481-484, Dec. 2004.

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