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2018 INTERNATIONAL SYMPOSIUM ON INFORMATION TECHNOLOGY CONVERGENCE

Session TH4C : Semiconductor

16:10-18:10, Thursday, October 25
Session Chair : **Donggu Lim (Chonbuk National University, Korea)**
Session Co-Chair : **Ji-Hoon Lee (Chonbuk National University, Korea)**

Session TH4D : Microwave

16:10-18:10, Thursday, October 25
Session Chair : **Girdhari Chaudhary (Chonbuk National University, Korea)**
Session Co-Chair : **Heungjae Choi (Cardiff University, United Kingdom)**

Wideband Negative Group Delay Circuit Using 180° Hybrid and In-Phase Power Combiner

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***Abstract*—This paper demonstrates a design of negative group delay circuit (NGD) based on signal interference concept. The proposed circuit consists of arbitrary power division ratio 180° hybrid and Wilkinson power combiner. The prescribed NGD can be generated by controlling power division ratio of hybrid and power combiner. For proof of concept, the circuit is designed and simulated at center frequency of 1 GHz. From results, it can be concluded that the proposed circuit provides wideband flat magnitude and NGD bandwidth as compared to state of arts.**

Keywords*— *Arbitrary power division ratio hybrid, signal interference concept, wideband negative group delay circuit.

I. Introduction

Propagation of electromagnetic waves in dispersive media can be defined by phenomena incorporating abnormal phase, group delays, and velocities [1]. Abnormal group velocities incorporate superluminal and even negative group velocities (NGVs). The NGD and NGV intimate each other and they convey that peak of a pulse envelope appears from the medium at an instant before the peak of the pulse penetrate the medium. Such an ostensibly anti-causal phenomenon does not breach the principle of causality because turn-on and -off points of the wave packet propagate with a positive delay in agreement with the causality requirements [2]-[3].

To recognize the reality of the NGD, the group velocity can be revealed as (1) for homogeneous media or effective homogeneous periodic structures described by a propagation constant (β) and refractive index n where c and ω are the speed of light in vacuum and angular frequency, respectively [1].

$$v_g = \frac{\partial \omega}{\partial \beta} = \frac{c}{n + \omega \dfrac{\partial n}{\partial \omega}}. \tag{1}$$

From (1), it is evident that if n decreases rapidly with respect to ω, the group velocity and the GD can become negative. In short, NGV or NGD exists near an absorption line or signal attenuation condition, where "anomalous" wave propagation effects can occur [1]-[3]. Typically, n of the RF circuits is difficult to handle, therefore, it is only possible to achieve the NGD through the signal attenuation condition. The signal attenuation of NGD circuits can be easily recompensed with the small signal gain amplifier without reducing a significant amount of NGD.

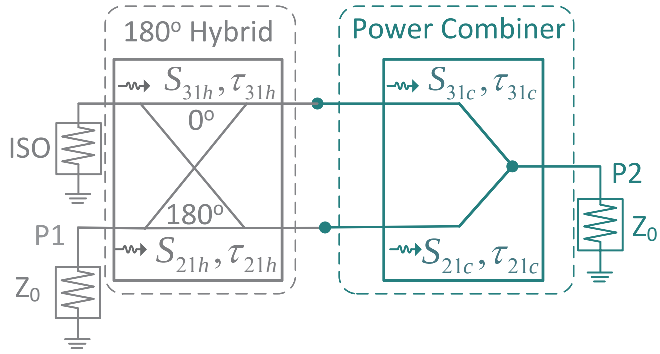

Fig. 1. Proposed structure of wideband negative group delay circuit.

The NGD circuits have been applied to various practical applications in communication systems, such as shortening or reducing delay lines, enhancing efficiency of a feedforward linear amplifier, enhancing the bandwidth of a feedback linear amplifier, minimizing beam-squint in phased array antenna systems and realization of non-Foster reactive elements [4]-[7].

Since NGD occurs when signal attenuation is maximum, therefore, bandstop *RLC* resonators have been widely used to design NGD circuits [4]-[7]. To overcome the limited availability problem of lumped elements in RF and microwave, the NGD networks using distributed elements were also presented [8]. The major drawbacks of previously presented NGD circuits are high insertion loss, very narrow magnitude and NGD flatness bandwidth.

In this paper, novel wideband NGD circuit based on signal interference concept is demonstrated. The proposed circuit does not use any additional lossy bandstop resonators to generate the NGD. In addition, the proposed circuit can provide the wideband magnitude and NGD flatness bandwidth.

II. Design Method

Fig. 1 shows the proposed structure of NGD circuit. The circuit consists of arbitrary power division ratio 180° hybrid and Wilkinson power divider. The hybrid divides the input signal into paths with out of phase characteristics and these signals are combined in-phase. Assuming power division ratio of hybrid and power combiner as k and k_1, respectively, transmission coefficients of hybrid and power combiner are defined as (2).

$$S_{21h} = \frac{k}{\sqrt{1+k^2}} e^{-j\varphi_{21h}}, S_{31h} = \frac{1}{\sqrt{1+k^2}} e^{-j\varphi_{31h}} \quad (2a)$$

$$S_{21c} = \frac{1}{\sqrt{1+k_1^2}} e^{-j\varphi_{21c}}, S_{31c} = \frac{k_1}{\sqrt{1+k_1^2}} e^{-j\varphi_{31c}}, \quad (2b)$$

where subscript h and c represent hybrid and power combiner, respectively. From Fig.1, the transmission coefficient magnitude and group delay can be derived as (3) by using circuit theory.

$$|S_{21}| = |S_{21h}||S_{21c}| \sqrt{\left(1+\alpha\cos\frac{\pi f}{f_0}\right)^2 + \alpha^2 \sin^2\frac{\pi f}{f_0}} \quad (3a)$$

$$\tau_{21} = \left\{ \begin{aligned} &\tau_{21h} + \tau_{21c} \\ &-\frac{\alpha}{1-\alpha}\left(\tau_{31h} + \tau_{21c} - \tau_{21h} - \tau_{31c}\right) \end{aligned} \right\}, \quad (3b)$$

where

$$\alpha = \frac{|S_{31h}||S_{31c}|}{|S_{21h}||S_{21c}|}. \quad (4)$$

From (3b), the proposed circuit can provide the NGD only if condition (5) satisfies.

$$\tau_{21h}\big|_{f=f_0} > \tau_{31h}\big|_{f=f_0} \quad (5a)$$

$$k < k_1 \quad (5b)$$

Fig. 2 shows the calculated group delay, insertion loss, and NGD fractional bandwidth (bandwidth of group delay < 0) for different k and k_1. As seen from these figures, the proposed circuit provides higher NGD when k approaches to k_1. However, the NGD fractional bandwidth (FBW) decrease. It is also noted from Fig. 2 that the proposed circuit provides the wideband NGD FBW which is very essential for practical application of NGD circuits.

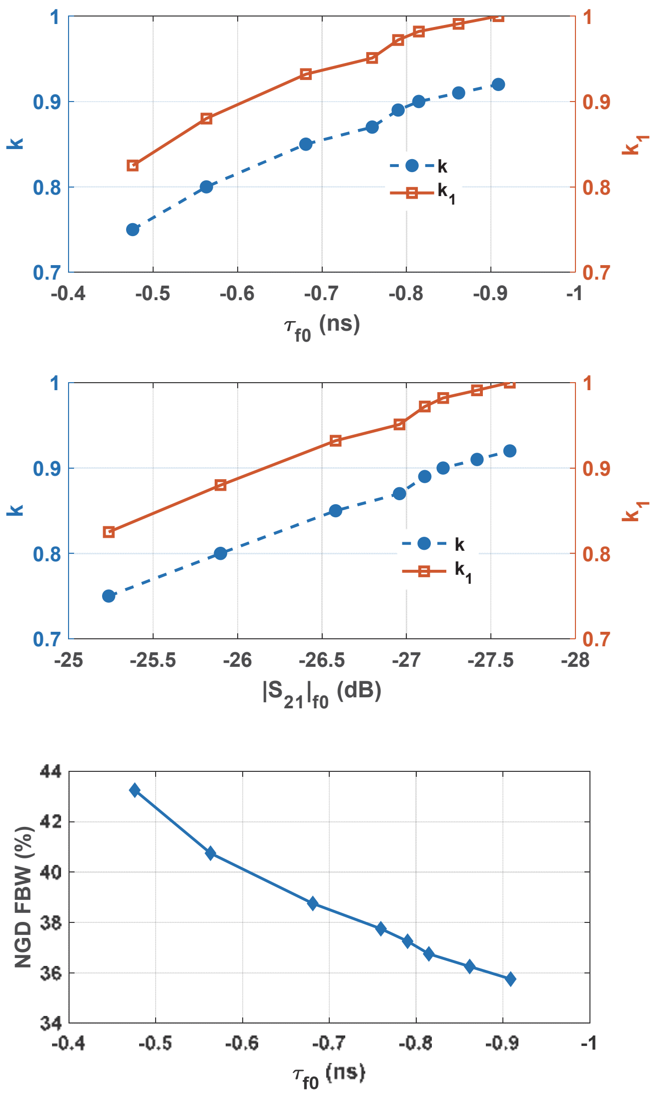

Fig. 2. Calculated group delay, insertion loss, and NGD fractional bandwidth for different k and k_1 with f_0 = 1 GHz.

III. Results

For validation of analytical analysis, the proposed circuit is designed and simulated at center frequency f_0 = 1 GHz. For this purpose, the microstrip line hybrid and Wilkinson power combiner are designed in substrate with dielectric constant of 2.2 and thickness of 31mils.

Fig. 3 shows the simulated responses of the proposed circuit. From simulation results, the group delay and magnitude are determined as τ_{21} = -1.02 ns and $|S_{21}|$ = -30.43 dB at f_0 = 1 GHz. Similarly, NGD FBW is determined to be 33.75%. As observed from result, the proposed circuit provide flat magnitude and group delay response without cascading two NGD circuits with slightly different center frequencies. In addition, the input and out reflection coefficients are matched with port impedance as shown in Fig. 3 without any additional matching circuit.

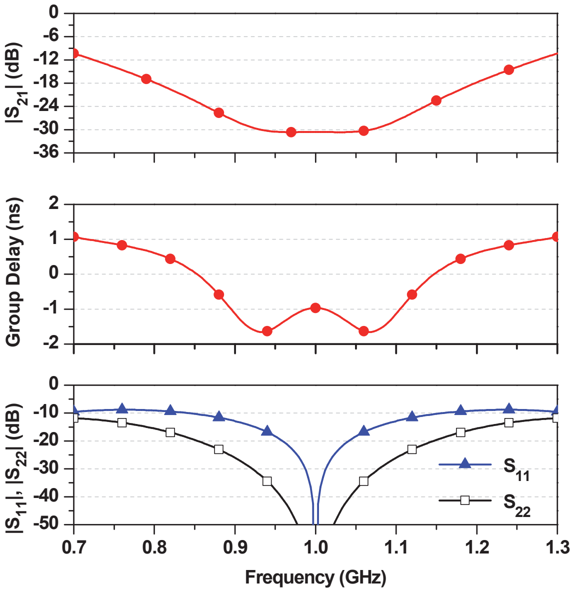

Fig. 3. Simulated results of the proposed wideband negative group delay circuit.

IV. CONCLUSION

This paper demonstrated the signal interference concept for designing wideband negative group delay circuit. The analytical analysis showed that the proposed circuit can provide wideband negative group delay and magnitude flatness bandwidth by controlling power division ratios of hybrid and power combiner. In addition, the proposed circuit does not use any additional lossy bandstop resonators for generating negative group delay.

ACKNOWLEDGMENT

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