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Proceedings

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Poster Presentation

Kaide Hotel Lobby

Poster Session

Session Chairs: Dehua Ren (Tianjin University of Science and Technology, China)
Jianzheng Liu (Tianjin University of Science and Technology, China)
Qing Zhao (Tianjin University of Science and Technology, China)

ID7. Research and Application of E-Government Ontology Model based on CBR

Congcong Xiong, Lanting Wang, Xiankun Zhang and Lumeng Hao
Tianjin University of Science and Technology, China

ID9. Application of CBVR in Smart Home Based on NGB

Hui-Bin Liu, Fei Wu,Hao-Min Hu, Ze-Jie Wang
Shanghai University of Engineering Science, China

ID13. Inducing Homeotropic Orientation of Nematic Liquid Crystal by Surface Adsorption of Bent-Core Molecules

Sunggu Yeo, Jiyong Hwang, Seungbin Yang, Hyojin Lee and Ji-Hoon Lee
Chonbuk National University, South Korea

ID17. Tunable Negative Group Delay Power Divider for Communication Systems

Girdhari Chaudhary[1], Seungwook Lee[1], Jageon Koo[1], Yongchae Jeong[1], Jongsik Lim[2]
Chonbuk National University, South Korea [1],
Soonchunhyang University, South Korea [2]

ID24. Accuracy, Convenience and Flexibility about Opinion-Base Phone APPS Search Engine

Yin Lei, Jiahong Zhong
Gannan Medical University, China

ID27. Affects Way Analysis to Build Innovative Organizational Culture by IT Technology

Jiahong Zhong, Yin Lei
Gannan Medical University, China

ID32. Laser Induced Real-time Photoacoustic Tomography with GPU Accelerated System

Prasannakumar Palaniappan, Dong Ho Shin, Sang Hun Park, Moung Young Lee, Chul Gyu Song, Bong Han Go, Jonghyun Oh, Yoon Seok Yang
Chonbuk National University, South Korea

ID34. IR Beacon study for Mobile Robot Direction

Se Hyun Mo[1], Ja U Kim[1], Jong Ho Park[2], Gil Ung Kim[1], Kil To Chong[1]
Chonbuk National University, South Korea [1],
Seonam University, South Korea [2]

ID35. A Pile-up Pulse Processing Method for XRF systems

Zheyan Piao, Ji-Yeon Hwang, Jin-Gyun Chung
Chonbuk National University, South Korea

ID37. Plant Recognition from Leaf Image through Local Discriminative Tangent Space Alignment

Guoyuan Li[1], Shanwen Zhang[2], Chuanlei Zhang[3], Weidong Fang[4]
Stetson Engineers Inc. San Rafael, USA[1], Xi Jing University, China[2]
Tianjin University of Science and Technology, China[3], Shanghai University, China[4]

ID39. CBR-Based Psychology Case Ontology Model

Xian-kun Zhang, Qian Zhang
Tianjin University of Science and Technology, China

Tunable Negative Group Delay Power Divider for Commnucation Systems

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***Abstract*— In this paper, we propose a tunable power divider with negative and positive group delays. The proposed circuit consists of 1:1 Wilkinson power divider and branch-line tunable negative group delay (NGD) circuit. In the designed circuit, the tunable NGD is obtained through a transmission path 3 and 1, whereas the fixed positive group delay (PGD) is in between path 2 and 1. The NGD between path 3 and 1 and power division ratio can be tuned by varying bias voltage of PIN diodes. For experimental verification, the tunable NGD power was designed and fabricated at center frequency of 2.14 GHz. Measurement results have a good agreement with simulation and predicated theoretical values.**

Keywords*— *Branch-line, tunable power division ratio, negative group delay, transmission line, unequal power divider.

I. INTRODUCTION

Power dividers are essential blocks in microwave and millimeter systems and have been applied for power combining and splitting in various applications [1]. One of the power divider's application example is a feeding network in the beamforming of series-fed antenna arrays. However, the beamforming in series-fed antenna arrays can inherently suffer from beam-squinting, which can leads to an unwanted change in the direction and shape of radiation pattern with a frequency. This design challenge should be overcome with properly designed power distribution (power divider) network [2]. Therefore, tunable power divider with positive and negative group delays will be beneficial in such case to minimize the beam-squinting problem in series-fed antenna arrays.

In recent years, there has been an increasing amount of research on negative group delay (NGD) networks at microwave frequencies. In a medium of refractive index $n(\omega)$, the dispersion relation [3] can be written as (1)

$$k = \frac{\omega n}{c} \tag{1}$$

where ω, k, and c is angular frequency, wave number, and speed of light, respectively. The group velocity (v_g) known as the speed of the envelope signal [3], can be given as shown in (2).

$$v_g = \frac{c}{n + \omega \operatorname{Re}\left(dn/d\omega \right)} \tag{2}$$

From (1) and (2), it is inferred that if the refractive index n and its derivative with respect to ω are negative (i.e. $dn/d\omega<0$), v_g and consequently the group delay can become negative. This happens near absorption line or in media with a signal attenuation where 'anomalous' wave propagation effect can occur [3]. Typically, the NGD phenomena in RF circuits can be observed within the limited frequency band through signal attenuation (SA) condition. This NGD phenomena does not violate a causality, since the initial transient of the pulse is still positively delayed and propagates at speed not exceeding the speed of light in vacuum [4].

Various approaches have been applied to designing two-port active/passive microwave NGD circuits using *RLC* resonators [5]-[10]. To overcome the limited availability problem of lumped elements in radio and microwave frequencies, the distributed elements NGD circuits have also been presented in several works. The NGD circuits have been applied to various practical applications in communication systems, such as shortening or reducing delay lines, enhancing the efficiency of feedforward linear amplifiers, and enhancing bandwidth of feedback linear amplifiers [5]. Moreover, research onto the design of tunable power divider with the predefined PGD and NGD characteristics is lacking. Research that can demonstrate the possibility of a tunable power divider with these characteristics through different transmission paths would be promising.

In this paper, tunable unequal power divider with high power division ratio and predefined NGD characteristics is presented. The proposed circuit provides tunable NGD characteristics between transmission path 3 and 1 whereas the fixed positive group delay (PGD) between transmission paths 2 and 1.

II. ANALYSIS AND DESIGN EQUATIONS

Fig. 1 shows a block diagram of proposed tunable NGD power divider with PGD and NGD characteristics. It consists of 1:1 Wilkinson power divider (WPD) and tunable branch-line NGD circuit.

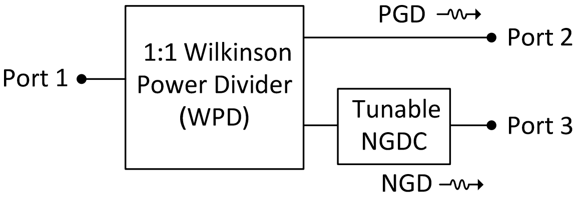


Fig. 1. Block diagram of proposed tunable negative group delay power divider.

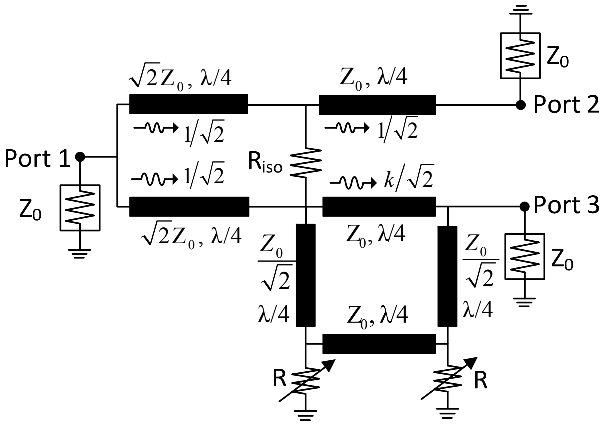


Fig. 2. Proposed structure of tunable power divider with positive and negative group delays.

The overall-circuit diagram of proposed circuit is shown in Fig. 2. The WPD consists of λ/4 transmission lines with characteristic impedance of $\sqrt{2}Z_0$. Similarly, tunable NGD circuit consists of a branch-line where direct and coupled ports are terminated with variable resistors R.

The S-parameters of the proposed structure at center frequency $f = f_0$ can be found as (3) using modified even- and odd-modes [11].

$$S_{11}\big|_{f=f_0} = S_{22}\big|_{f=f_0} = S_{33}\big|_{f=f_0} \tag{3a}$$

$$S_{21}\big|_{f=f_0} = \frac{1}{\sqrt{2}} \tag{3b}$$

(3c)

where Z_0 is a port reference impedance. For the perfect isolation ($S_{32} = 0$ at $f = f_0$) between output ports, the value of isolated resistor (R_{iso}) can be found as (4).

$$R_{iso} = 2Z_0 \tag{4}$$

Furthermore, group delays (GDs) between transmission paths evaluated at $f = f_0$ are given as (5).

$$\tau_{21}\big|_{f=f_0} = \frac{1}{2\pi}\frac{d\angle S_{21}}{df}\bigg|_{f=f_0} = \frac{0.5152}{f_0} \tag{5a}$$

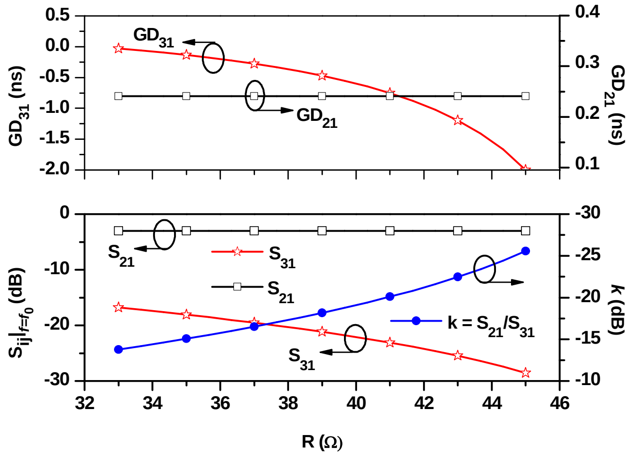


Fig. 3. Calculated group delay and magnitude at center frequency of 2.14 for different value of R.

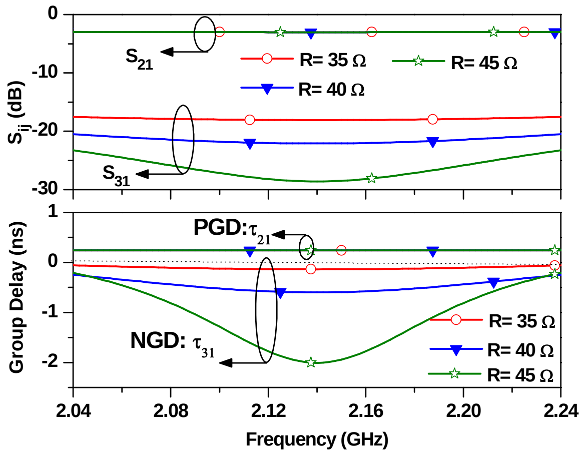


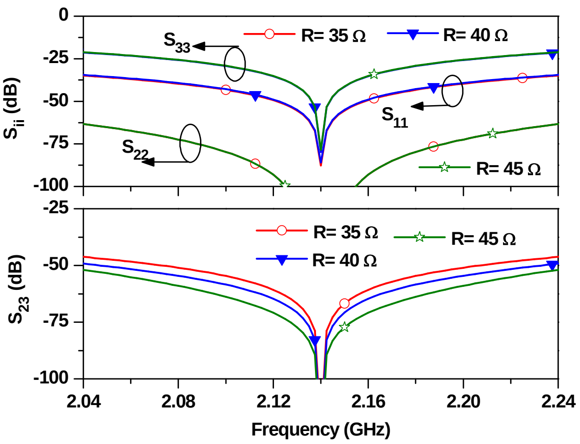
Fig. 4. Synthesized magnitude/group delay characteristics using ideal circuit parameters.

$$\tau_{31}\big|_{f=f_0} = \frac{1}{2\pi}\frac{d\angle S_{31}}{df}\bigg|_{f=f_0} \approx -2.0759\frac{\left(R^2 - 0.4184Z_0^2\right)}{f_0\left(Z_0^2 - R^2\right)} \tag{5b}$$

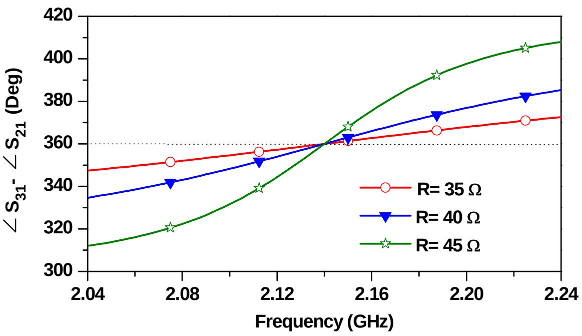
The power division ratio (k) is defined as (6).

$$k = \frac{S_{31}}{S_{21}}\bigg|_{f=f_0} = \left|\frac{Z_0 - R}{Z_0 + R}\right| \tag{6}$$

For illustrative explanation of these equations, the S-parameters and GDs between different transmission paths are shown in Fig. 3 for different values of R. As seen from (3c) and (5b), the magnitude and GD between transmission path 3 and 1 is purely controlled by resistor R. As R increases toward Z_0, the GD and magnitude S_{31} are increased towards high value. Therefore, for NGD, the region of variable resistor R should be $32.34 < R < 50\ \Omega$. Similarly, the power division ratio k and NGD can be varied only by R. However, the magnitude and PGD between paths 2 and 1 is constant and independent of R as presented in (3b) and (5a).



(a)



(b)

Fig. 5. Synthesized results using ideal circuit parameters: (a) return loss/isolation characteristics, and (b) phase difference characteristics.

On the basis of design equations (3)-(6), the calculated responses of the proposed circuit are shown in Fig. 4 and 5 with different values of *R*. As seen from Fig. 4, *S*-parameters and GD between transmission paths 3 and 1 are changed with different values of *R*. As value of *R* approaches to Z_0, the values of S_{31} and GD are moved toward high value. However, the GD and transmission coefficient between transmission paths 2 and 1 remain almost constant value and PGD. The input/output return losses are perfectly matched at f_0. Moreover, the isolation between output ports is infinite as shown Fig. 5.

In this work, the variable resistors are implemented with PIN diodes HSMP-4810 from Avago which functions as a current-controlled variable resistor at microwave frequencies. To compensate the parasitic components of the PIN diode such that their input impedance is purely resistive, the PIN diode is terminated in offset transmission line (TL) with electrical length of Θ_1 and characteristic impedance Z_1 as shown in Fig. 6. The design equations are presented in [9].

Fig. 7 shows simulated reflection characteristics of TL terminated PIN diode. The characteristic impedance and electrical length of TL are given as 82 Ω and 72.2° at f_0 = 2.14 GHz. This result shows that the variable resistance of the TL terminated with a PIN diode is obtained with almost zero imaginary parts.

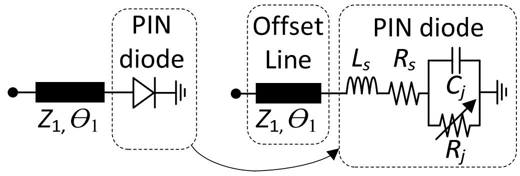


Fig. 6. Parasitic compensated PIN diode with offset line and its equivalent circuit.

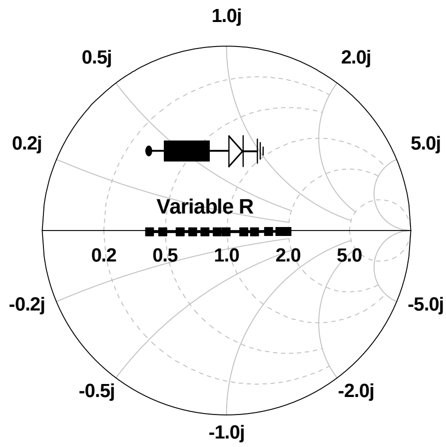


Fig. 7. Simulation results of parasitic compensated PIN diode for variable resistor at center frequency 2.14 GHz

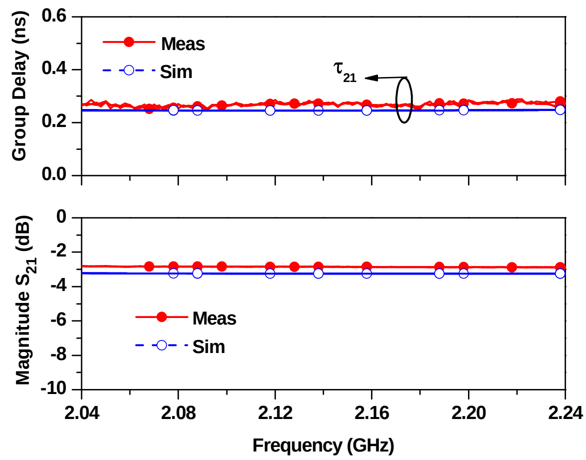


Fig. 8. Simulated and measured group delay/magnitude between paths 2 and 1.

III. Simulation And Measurement Results

For experimental verification, we designed and fabricated the proposed tunable NGD power divider at f_0 of 2.14 GHz. The circuit was fabricated on a Rogers RT/Duriod 5880 substrate with a dielectric constant (ε_r) of 2.2 and a thickness (*h*) of 31 mils. The circuit was simulated and optimized using Ansys HFSS 2014 and Advanced Design System (ADS) 2013.

The simulated and measured the magnitudes and GDs are shown in Fig. 8 and 9. The measured $|S_{21}|$ and τ_{21} between paths 2 and 1 are remained almost constant at value of -2.96 dB and

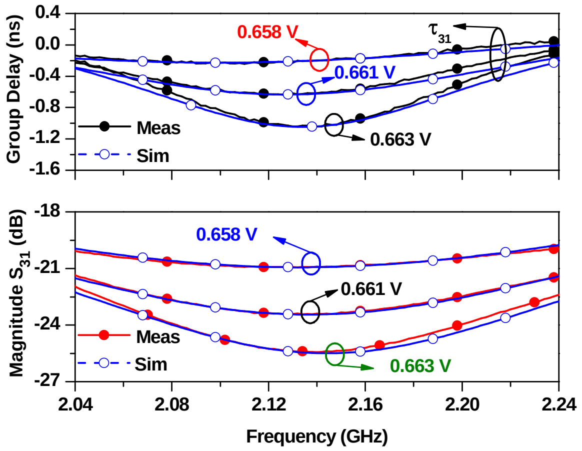


Fig. 9. Simulated and measured group delay/magnitude between paths 3 and 1.

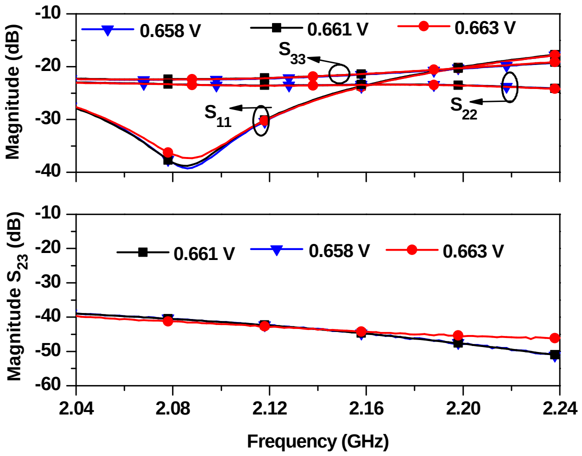


Fig. 10. Simulated and measured return losses and isolation characteristics.

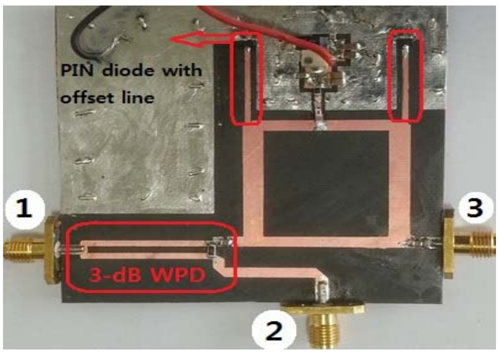


Fig. 11. Photograph of fabricated circuit.

0.27 ns at 2.14 GHz, respectively. Similarly, the measured values of $|S_{31}|$ between paths 3 and 1 are varied from -20.90 dB to -25.45 dB with GDs variations of -0.2 ns to -1.04 ns at 2.14 GHz. Therefore, the measured power division ratio is varied from 17.94 dB to 22.49 dB. The GD and power division ration can be varied further. However, NGD and magnitude band width will be decreased. Therefore, there is a trade-off between GD and bandwidth.

From Fig. 10, the measured $|S_{11}|$, $|S_{22}|$, and $|S_{33}|$ are -24.73 dB, -20.58 dB, and -20.62 dB, respectively. The return loss characteristics of fabricated circuit are slightly degraded as compared to ideal results because of junction capacitance of branch-line structures. The measured isolation ($|S_{23}|$) at f_0 is - 42.18 dB. A photograph of fabricated circuit is shown in Fig. 11.

IV. Conclusion

In this paper, tunable power divider with high power division ratio and predefined negative group delay characteristics is proposed and fabricated. Both theoretical and experimental results have been presented for verification. The group delay and power division ratio were controlled by varying bias voltage of PIN diodes. In addition, the proposed power divider is promising for application as feed network in series fed antenna arrays for minimizing beam-squint.

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References

[1] M. J. Chik and K. K. M. Cheng, "Group delay investigation of rat-race coupler design with tunable power division ratio," *IEEE Microw. Wireless Compon. Letters,* vol. 24, no. 5, pp. 324-326, May 2014.

[2] H. Mirzaei and G. V. Eleftheriades, "Arbitrary-angle squint-free beamforming in series-fed antenna arrays using non-Foster elements synthesized by negative group delay networks," *IEEE Trans. Antennas and Propagation,* vol. 63, no. 5, pp. 1997-2010, May, 2015.

[3] L. Brillouin and A. Sommerfeld, *Wave propagation and group velocity*, New York: Academic press Network, pp. 113-137, 1960.

[4] M. W. Mitchell and R. Y. Chiao, "Causality and negative group delays in simple bandpass amplifier," *Am. J. Physics*, vol. 70, no. 11, pp. 1117-1121, Nov. 2002.

[5] 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.

[6] G. Chaudhary, Y. Jeong, and J. Lim, "Microstrip line negative group delay filters for microwave circuits," *IEEE Trans. Microw. Theory Tech.*, vol. 62, no. 2, pp. 234-243, Feb. 2014.

[7] G. Chaudhary and Y. Jeong, "Distributed transmission line negative group delay circuit with improved signal attenuation," *IEEE Microw. Wireless Compon. Letters*, vol. 24, no. 1, pp. 20-22, Jan. 2014.

[8] G. Chaudhary and Y. Jeong, "Transmission line negative group delay networks with improved signal attenuation," *IEEE Antenna and Wireless Propag. Letters*, vol. 13, pp. 1039-1042, 2014.

[9] J. Jeong, S. Park, G. Chaudhary, and Y. Jeong, "Design of tunable negative group delay circuit for communication systems," *Proc. of IEEE Radio-Frequency Integrated Tech.*, pp. 59-61, Nov. 2012.

[10] G. Chaudhary, Y. Jeong, and J. Im, "A design of reconfigurable negative group delay circuit without external resonators," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 883-886, 2015.

[11] H. R. Ahn, Asymmetric passive components in Microwave Integrated Circuits, New York, NY, USA: Wiley, 2006.

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