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MONDAY 13:50 – 16:40

Posters will be ready by 13:40. Presenters will be around their stands at 13:50 – 14:20 and 16:00 – 16:30.

Exhibition Hall

EuMIC/EuMC04

EuMIC/EuMC Posters

Chair: Mustafa Bakr[1]

[1]University of Oxford

EuMIC/EuMC04-1
Microwave sensing using metal-insulator-metal diodes based on 4-nm-thick hafnium oxide
Martino Aldrigo[1], Mircea Dragoman[1], Sergiu Iordanescu[1], Mazen Al Shanawani[2], George Deligeorgis[3]
[1]National Institute for Research and Development in Microtechnologies (IMT), [2]University of Bologna, [3]FORTH

EuMIC/EuMC04-5
Towards an Excitable Microwave Spike Generator for Future Neuromorphic Computing
Qusay Raghib Ali Al-taai[1], Razvan Morariu[1], Jue Wang[1], Abdullah Al-Khalidi[1], Ali Al-Moathin[1], Bruno Romeira[2], José Figueiredo[3], Edward Wasige[1]
[1]University of Glasgow, [2]International Iberian Nanotechnology Laboratory, [3]Universidade de Lisboa, Campo Grande

EuMIC/EuMC04-9
Doherty Load Modulation Based on Non-Reciprocity
Paul Saad[1], Han Zhou[2], Jose-Ramon Perez-Cisneros[2], Rui Hou[1], Christian Fager[2], Bo Berglund[1]
[1]Ericsson AB, [2]Chalmers University of Technology

EuMIC/EuMC04-13
Effect of Switch Figure of Merit on Frequency-Reconfigurable Power Amplifier Performance
Adam Der[1], William Sear[1], Taylor Barton[1]
[1]University of Colorado, Boulder

EuMIC/EuMC04-2
Automatic Nonlinear Nonquasi-Static Diode Model Extraction from Large-Signal Measurements
Aarón García-Luque[1], Teresa M. Martín-Guerrero[1], Alberto Santarelli[2], Carlos Camacho-Peñalosa[1]
[1]Universidad de Málaga, Andalucía Tech, [2]Università di Bologna

EuMIC/EuMC04-6
Numerical and Experimental Investigations of Selfmixing Effect of a Planar Gunn Diode Oscillator
Mingyan Zhong[1]
[1]University of Glasgow

EuMIC/EuMC04-10
Adopting Supercapacitors in a Single-Stage Marx-Type Multi-level Supply Modulator
Lukas Hüssen[1], Renato Negra[1]
[1]HFE RWTH-Aachen

EuMIC/EuMC04-14
Practical Work for Master2 Students: MMIC Distributed Amplifier Design for High Data Rate Receiver on GaAs-UMS Technology
Catherine Algani[1], Eric Leclerc[2]
[1]Le Cnam, [2]UMS

EuMIC/EuMC04-3
Compact GaN RF-Switches for Power Applications
Samira Driad[1], Charles Teyssandier[1], Laurent Caillé[1], Christophe Chang[1], Laurent Brunel[1], Benoit Lambert[1], Hermann Stieglauer[2], Valeria Brunel[1]
[1]United Monolithic Semiconductors SAS, [2]United Monolithic Semiconductors GmbH

EuMIC/EuMC04-7
An Ultra-Wideband Microstrip-to-WR15 Waveguide Transition for MMIC Applications
Bent Walther[1], Marcel van Delden[1], Thomas Musch[1]
[1]Ruhr-University Bochum

EuMIC/EuMC04-11
A 30-W GaN Quasi-MMIC Doherty Power Amplifier Based on All-Distributed Inductors Load Network
Rui-Jia Liu[1], Xiao-Wei Zhu[1], Jing Xia[2], Peng Chen[1], Chao Yu[1], Lv Zhang[3], Zhi-Yong Chen[3]
[1]Southeast University, [2]Jiangsu University, [3]Guobo Electronics Corporation

EuMIC/EuMC04-4
Analysis of RF Stress Influence on Large-Signal Performance of 22nm FDSOI CMOS Transistors utilizing Waveform Measurement
Dang Khoa Huynh[1], Quang Huy Le[1], Steffen Lehmann[2], Zhixing Zhao[2], Germain Bossu[2], Wafa Arfaoui[2], Defu Wang[1], Thomas Kämpfe[1], Matthias Rudolph[3]
[1]Fraunhofer Institute for Photonic Microsystems (IPMS), [2]Globalfoundries, Germany, [3]Brandenburg University of Technology (BTU)

EuMIC/EuMC04-8
An Integrated Multiphysics Model for Phase-Change Material Switches
Pierre Blondy[1], Ines Bettoumi[2], Kateryna Kiryukhina[3], Olivier Puig[3]
[1]Xlim - UMR 7252 - CNRS- Universite De Limoges, [2]XLIM-UMR CNRS 7252 - Université de Limoges, [3]Centre National d'Études Spatiales (CNES)

EuMIC/EuMC04-12
A Digital Power Amplifier for 32-QAM
Gavin Watkins[1]
[1]Toshiba Europe Limited

MONDAY 14:20 – 16:00

ROOM	Room 1	Room 6	Room 13	Room 14
	EuMC02 Innovative Microwave Circulators and Phase Shifters Chair: Bart Nauwelaers[1] Co-Chair: Marco Pasian[2] [1]KU Leuven, [2]University of Pavia	**EuMC03** Non-planar Filters I Chair: Giuseppe Macchiarella[1] Co-Chair: Vicente E. Boria[2] [1]Politecnico di Milano[2], Universitat Politecnica de Valencia	**EuMC04** Active Antennas and Architectures Chair: Nils Pohl[1] Co-Chair: Kevin Morris[2] [1]Ruhr University Bochum, [2]University of Bristol	**EuMIC/EuMC03** MMIC Power Amplifiers and Supply Modulation Chair: Jeff Powell[1] Co-Chair: Markus Mayer[2] [1]Teratech Components, [2]Arelis
14:20 – 14:40	**EuMC02-1** Microwave Ferrite Components - an Industry Perspective John Ascroft[1] **INDUSTRIAL KEYNOTE** [1] Honeywell	**EuMC03-1** The Extracted Zero Technique Simone Bastioli[1] **INDUSTRIAL KEYNOTE** [1]RS Microwave	**EuMC04-1** 7.5 GHz-Band Digital Beamforming Using 1-bit Direct Digital RF Transmitter with 10GbE Optical Module Ryo Tamura[1], Mizuki Motoyoshi[1], Suguru Kameda[1], Noriharu Suematsu[1] [1]Research Institute of Electrical Communication, Tohoku University	**EuMIC/EuMC03-1** A 6-18 GHz 13 W and 22% PAE GaN Power Chipset Mehdi DINARI[1], Benoit MALLET-GUY[2], Yves Mancuso[2] **INDUSTRIAL KEYNOTE** [1]Thales DMS France, [2]Thales Defence Mission Systems (TDMS)
14:40 – 15:00	**EuMC02-2** Broadband Ku- and Ka-Band Circulators in LTCC Using Sintered Bulk Ferrites Carsten Weil[1], Tim Hauck[1], Johannes Schur[2], Jens Müller[2] [1]AFT microwave GmbH, [2]TU Ilmenau	**EuMC03-2** Dielectric-loaded Ku-Band Filter for High-power Space Applications based on Barrel-shaped cavities Paolo Vallerotonda[1], Fabrizio Cacciamani[2], Luca Pelliccia[2], Francesco Aquino[2], Cristiano Tomassoni[3], Petronilo Martín-Iglesias[4], Vittorio Tornielli di Crestvolant[4] [1]RF Microtech s.r.l / University of Perugia, [2]RF Microtech s.r.l, [3]University of Perugia, [4]ESA / ESTEC	**EuMC04-2** Quadruple-fed Aperture-coupled Microstrip Patch Antenna for On-antenna Power Combining Timothée Le Gall[1], Anthony Ghiotto[2], Stefan Varault[1], Gwenaël Morvan[1], Bruno Louis[1], Grégoire Pillet[1] [1]Thales DMS France, [2]Bordeaux INP, IMS Laboratory	**EuMIC/EuMC03-2** On-chip Power Combining with 3-Stage75–110 GHz GaN MMIC Power Amplifiers Shane Verploegh[1], Timothy Sonnenberg[1], Mauricio Pinto[2], Akim Babenko[1], Zoya Popovic[1] [1]University of Colorado at Boulder, [2]Raytheon Company
15:00 – 15:20	**EuMC02-3** Quasi-Reflectionless Differential Phase Shifter with Arbitrary Prescribed Group Delay and Flat Phase Difference Girdhari Chaudhary[1], Daehan Lee[1], Muhammad A. Chaudary[2], Yongchae Jeong[1] [1]Jeonbuk National University, [2]Ajman University	**EuMC03-3** LTCC based Ka-Band Diplexer for Miniaturized Ground-Segment User Terminals Davide Tiradossi[1], Paolo Vallerotonda[2], Luca Pelliccia[1], Stefano Moscato[3], Antonio Traversa[3], Giandomenico Cannone[3], Petar Jankovic[4], Fabrizio De Paolis[4] [1]RF Microtech s.r.l, [2]RF Microtech s.r.l / University of Perugia, [3]SIAE Microelettronica S.p.A., [4]ESA / ESTEC	**EuMC04-3** Antenna Mutual-Coupling Mitigation With Analogue Compensation Network Roger Green[1], Tommaso Cappello[1], Geoffrey Hilton[1], Mark Beach[1] [1]University of Bristol	**EuMIC/EuMC03-3** Wideband Phase Modulator MMIC for K-Band Supply-Modulated Power Amplifier Linearization Gregor Lasser[1], Connor Nogales[1], Maxwell R. Duffy[2], Zoya Popovic[1] [1]University of Colorado, Boulder, [2]Northrop Grumman Corporation
15:20 – 15:40	**EuMC02-4** A Phase Shifter Composed of Reduced-Size Rat-Race Coupler with CRLH Transmission Lines and Resonating Reactance Circuits Masashi Nakatsugawa[1], Fusuke Kurotani[1], Yuya Chiba[1], Tamami Maruyama[1] [1]National Institute of Technology, Hakodate College	**EuMC03-4** Quadrature-Based Approach Used for Improved Fitting of Filter Measured S-parameters Jedrzej Michalczyk[1], Jerzy Michalski[1] [1]SpaceForest	**EuMC04-4** Conformal Antenna with Reconfigurability of Monopole-like and Broadside Patterns Realized with Polymer-Conductive Textile Composite Roy B. V. B. Simorangkir[1], Bahare Mohamadzade[2], Ali Lalbakhsh[2], Sanjeev Kumar[1], John L. Buckley[1], Toni Bjorninen[3], Brendan O'Flynn[1] [1]Tyndall National Institute, [2]Macquarie University, [3]Tampere University	**EuMIC/EuMC03-4** Compact Design of a L-Band 40W 40 MHz Envelope Tracking GaN Power Amplifier for Small Cells Olivier Nonet[1], Wilfried Demenitroux[1], Frederic Ploneis[1], Denis Barataud[2], Michel Campovecchio[2] [1]Thales Group, [2]Xlim - CNRS- Unversite De Limoges
15:40 – 16:00	**EuMC02-5** Simultaneous Electric and Magnetic Two-Dimensional Tuning in Nonlinear Magnetic Transmission Line MuhibUr Rahman[1], Ke Wu[1] [1]Polytechnique Montreal	**EuMC03-5** Narrowband Extracted Pole Filters With Mixed Dielectric and Waveguide Resonators in Ku-Band Patrick Boe[1], Daniel Miek[1], Fynn Kamrath[1], Kennet Braasch[1], Michael Höft[1] [1]Christian-Albrechts-Universität zu Kiel	**EuMC04-5** Design of a Multi-mode Transmission System Based on Vortex Electromagnetic Wave Jialin Zhang[1] [1]Beihang University (BUAA)	**EuMIC/EuMC03-5** A 600-W Enhancement-Mode GaN Multi-Level Dynamic Converter for Supply Modulated PAs Connor Nogales[1], Zoya Popovic[1], Gregor Lasser[1] [1]University of Colorado at Boulder

Quasi-Reflectionless Differential Phase Shifter with Arbitrary Prescribed Group Delay and Flat Phase Difference

Girdhari Chaudhary[#], Daehan Lee[#], Muhammad A. Chaudary[*], Yongchae Jeong[#]

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***Abstract* — This paper presents a design of a quasi-reflectionless differential phase shifter, which can provide arbitrarily prescribed group delay (GD) and flat phase difference. The proposed quasi-reflectionless differential phase shifter consists of quarter-wavelength coupled lines and series resistor-connected open-circuited half-wavelength stubs in the main and references branches. Closed-form design equations are derived to achieve arbitrary prescribed flat phase difference and GD. For flat phase difference within passband, the GD of the main and reference branches must be the same. In addition, the GD and phase difference flatness in passband are controlled by a series-connected resistor. For experimental validation, a microstrip line 90° quasi-reflectionless differential phase shifter with GD of 1.90 ns at a center frequency of 3.50 GHz is designed and fabricated. The measurement results are well agreed with simulation and theoretical predicted results.**

***Keywords* — Arbitrary group delay, differential phase shifter, microstrip line, quasi-reflectionless.**

I. Introduction

Differential phase shifter are indispensable components for phased array antennas, beamforming networks, and antenna feeding networks for modern wireless communication [1]. For realizing flat phase difference over the wideband between two output ports, different configurations of conventional differential phase shifters have developed by employing phase-adjusting line and uniform transmission line [3]-[7]. As a classical type, the Schiffman phase shifter is widely used, which have utilized an edge-coupled section in main branch as phase-adjusting technique for achieving flat phase difference [3]. To realize ultra-wideband differential phase shifter, multilayer structures have been adopted, which increases cost and complexity in fabrication [4]. To improve selectivity, filtering differential phase shifters have proposed by controlling fractional bandwidth of bandpass filter (BPF) between main and reference branch [5], [6]. Unfortunately, the conventional differential phase shifters have a reflective in nature in stopband.

In recent years, reflectionless BPF and power dividers have become attractive to prevent interblock signal interference from unwanted RF signal power reflections and improve the stability of adjacent RF active circuits in RF front-end [7], [8]. Different topologies of reflectionless BPFs have investigated in literature, however, these reflectionless circuits are limited to filter design or power divider and suffer from arbitrary prescribed GD analysis. Microwave circuits with arbitrarily prescribed GD response with respect to frequency have various applications in communication systems such as real-time analog radio-signal processing (R-ASP), phased array antenna, RF self-interference cancellation in-band full-duplex radio, and signal cancellation in the feed-forward amplifier [9], [10].

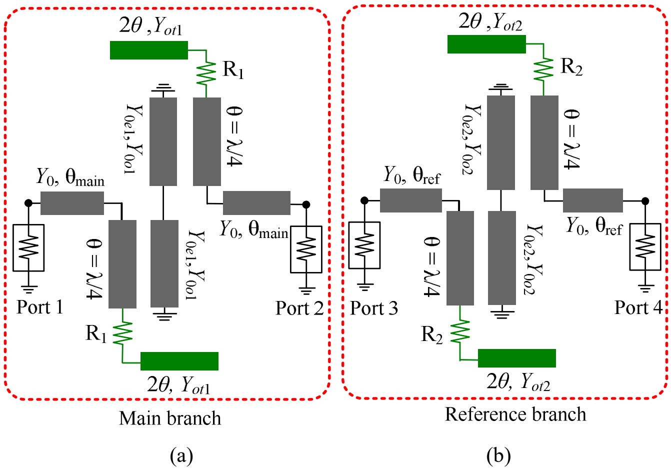

Fig. 1. Proposed structure of quasi-reflectionless differential phase shifter (a) main branch and (b) reference branch.

In this paper, we propose a quasi-reflectionless differential phase shifter using coupled lines and series resistor-connected stubs. An analytical design method has been developed to design a quasi-reflectionless filtering differential phase shifter with arbitrarily prescribed GD and flat phase difference. The arbitrarily prescribed GD and filtering response are realized by controlling a coupled line section and stubs. The half-wavelength open-circuited stubs contribute to the quasi-reflectionless characteristics at out-of-band signals. In addition, series resistors connected to the subs for achieving a flat GD response as well as the flat phase difference between the main and reference branch.

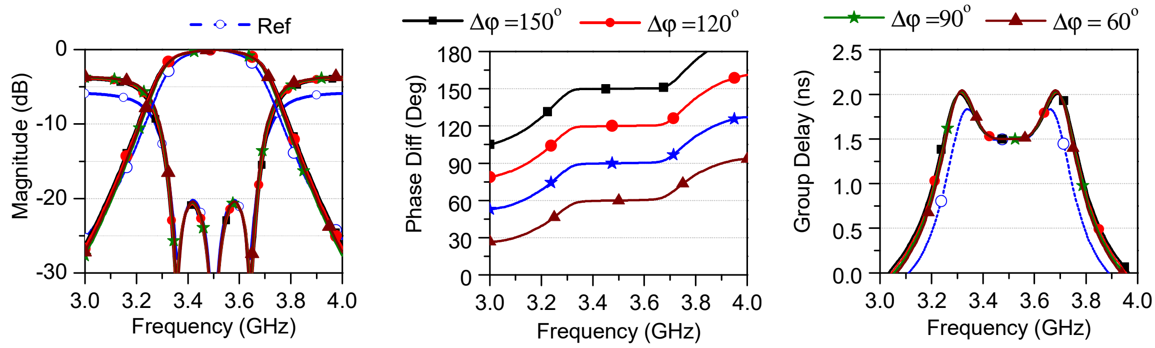

Fig. 2. Simulated results of quasi-reflectionless differential phase shifter with arbitrarily prescribed group delay of 1.50 ns at f_0 = 3.50 GHz.

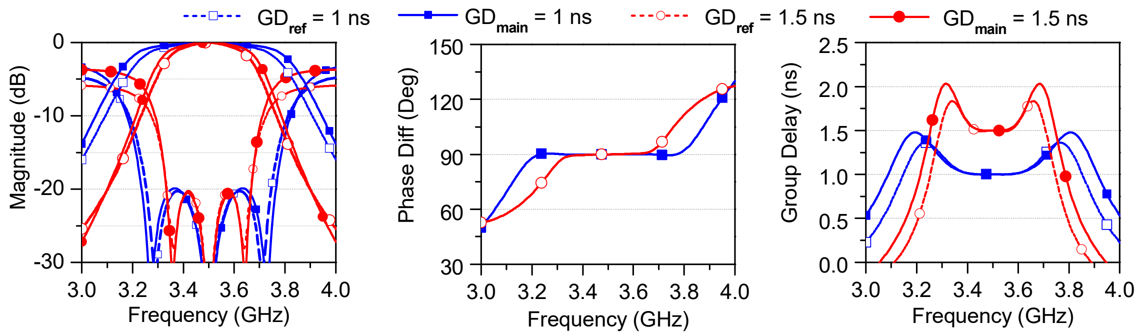

Fig. 3. Simulated results of quasi-reflectionless differential phase shifter with a phase difference of 90° and different arbitrarily prescribed group delays.

Table 1: Circuit parameters for different phase difference

$Z_{ot1} = Z_{ot2}$ = 25 Ω, θ_{ref} = 45°, and GD = 1.5 ns at f_0 = 3.50 GHz					
Branch	$\Delta\varphi$	Z_{0ei} (Ω)	Z_{0oi} (Ω)	R_i (Ω)	θ_{main}
Reference		110.67	63.73	50	
Main	150°	107.44	59.77	30	120°
	120°	108.16	60.59	30	105°
	90°	108.83	61.40	30	90°
	60°	109.48	62.19	30	75°

Table 2: Circuit parameters for different group delay

θ_{main} = 90°, θ_{ref} = 45°, and $\Delta\varphi$ = 90°					
Branch	GD (ns)	Z_{0ei} (Ω)	Z_{0oi} (Ω)	R_i (Ω)	Z_{oti} (Ω)
Reference	1	127.71	66.34	50	50
	1.5	110.67	63.73	50	25
Main	1	125.78	62.65	15	50
	1.5	108.83	61.40	30	25

II. DESIGN METHOD

Fig. 1 shows the proposed structure of a quasi-reflectionless differential phase shifter. The proposed circuit consists of the main branch and its respective reference branch. Each branch comprises of λ/4 coupled lines (Y_{0ei}, Y_{0oi}) terminated with a series resistor (R_i) connected λ/2 open-circuit stubs (Y_{oti}). Since the structure is symmetrical, the S-parameters of each branch is expressed as (1) by using even and odd-mode analysis.

$$S_{ii}^r = S_{ii}^r = \frac{Y_0^2 - Y_{even}^r Y_{odd}^r}{\left(Y_0 + Y_{even}^r\right)\left(Y_0 + Y_{even}^r\right)}, i = 1,2 \quad (1a)$$

$$S_{ij}^r = \frac{\left(Y_{odd}^r - Y_{even}^r\right)Y_0}{\left(Y_0 + Y_{even}^r\right)\left(Y_0 + Y_{even}^r\right)}, \; j = 1,2 \text{ and } i \neq j \quad (1b)$$

where r represents the main and reference branches. Similarly, $Z_0 = 1/Y_0$ is a port impedance. The detailed derivation of even- and odd-mode admittances (Y_{even}^r, Y_{odd}^r) of main and reference branch are given in [11]. The values of Y_{even}^r, Y_{odd}^r are expressed as (2).

$$Y_{even}^r = Y_0 \frac{Y_{aa}Y_{bb} - Y_{ab}^2 + jY_0 Y_{bb}\tan\left(\theta_r f / f_0\right)}{Y_0 Y_{bb} + j\left(Y_{aa}Y_{bb} - Y_{ab}^2\right)\tan\left(\theta_r f / f_0\right)} \quad (2a)$$

$$Y_{odd}^r = Y_0 \frac{Y_{aa} + jY_0 \tan\left(\theta_r f / f_0\right)}{Y_o + jY_{aa}\tan\left(\theta_r f / f_0\right)} \quad (2b)$$

where

$$Y_{aa} = \frac{n_1 Y_{0oi}^2}{m_1\left(1+k_i\right)^2} - j\frac{Y_{0oi}}{1+k_i}\left\{\cot\frac{\pi f}{2f_0} - \frac{n_2 Y_{0oi}}{m_1\left(1+k_i\right)}\right\} \quad (3a)$$

$$Y_{ab} = \frac{n_1 k Y_{0oi}^2}{m_1\left(1+k_i\right)^2} - j\frac{k_i Y_{0oi}}{1+k_i}\left\{\cot\frac{\pi f}{2f_0} - \frac{n_2 Y_{0oi}}{m_1\left(1+k_i\right)}\right\} \quad (3b)$$

$$Y_{bb} = \frac{n_1 k_i^2 Y_{0oi}^2}{m_1\left(1+k_i\right)^2} - j\frac{Y_{0o}}{1+k_i}\left\{\cot\frac{\pi f}{2f_0} - \frac{n_2 k_i^2 Y_{0oi}}{m_1\left(1+k_i\right)}\right\} \quad (3c)$$

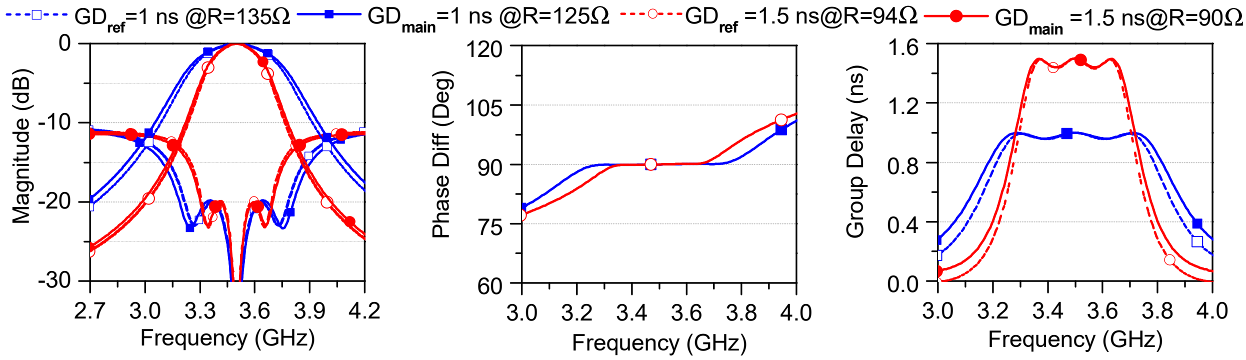

Fig. 4. Simulated results of quasi-reflectionless differential phase shifter with a phase difference of 90° and different arbitrarily prescribed group delay.

$$m_1=\left(\frac{1}{Z_{\lambda i}}+\frac{Y_{0oi}}{1+k_i}\cot\frac{\pi f}{2f_0}\right)^2+\frac{R_i^2Y_{0oi}^2}{Z_{\lambda i}^2(1+k_i)^2}\cot^2\frac{\pi f}{2f_0} \tag{3d}$$

$$n_1=\frac{R_i}{Z_{\lambda i}^2}\csc^2\frac{\pi f}{2f_0},\ Z_{\lambda i}=-\frac{1}{Y_{oti}}\cot\frac{\pi f}{f_0} \tag{3e}$$

$$n_2=\left\{\frac{1}{Z_{\lambda i}}+\frac{R_i^2Y_{0oi}}{Z_{\lambda i}^2(1+k_i)}\cot\frac{\pi f}{2f_0}+\frac{Y_{0oi}}{1+k_i}\cot\frac{\pi f}{2f_0}\right\}\csc^2\frac{\pi f}{2f_0} \tag{3f}$$

$$Y_{0ei}=\frac{1-k_i}{1+k_i}Y_{0oi} \tag{3g}$$

and i = 1, 2. The phase difference between the main and reference branch is determined as (4).

$$\Delta\varphi=\angle S_{21}^{main}-\angle S_{21}^{ref}=2\left(\theta_{main}-\theta_{ref}\right) \tag{4}$$

Using phase of S_{21} in (1b), the GD of main and reference branch are determined as (5).

$$\tau\Big|_{f=f_0}^{main}=\frac{a_1Y_{0o1}^3+Y_{0o1}c_1+d_1}{4f_0bY_{0o1}^2}+\frac{\theta_{main}}{\pi f_0} \tag{5a}$$

$$\tau\Big|_{f=f_0}^{ref}=\frac{a_2Y_{0o2}^3+Y_{0o2}c_2+d_2}{4f_0bY_{0o2}^2}+\frac{\theta_{ref}}{\pi f_0}, \tag{5b}$$

where

$$a_i=\frac{1-k_i^2}{Y_0^2(1+k_i)^3},\ b_i=\frac{k_i^2}{Y_0(1+k_i)^2},\ i=1,2 \tag{6a}$$

$$c_i=\frac{k_i^2}{1+k_i},\ d_i=2k_i^2Y_{oti},\quad i=1,2 \tag{6b}$$

An arbitrarily specified GD and magnitude response of each branch can be obtained by selecting the appropriate Y_{0oi} and k_i if Y_{oti} are specified by the designer. Therefore, Y_{0oi} in terms of specified GD at f_0, k_i, and Y_{oti} can be found as (7).

$$a_iY_{0oi}^3-4f_0b_i\left(\tau\Big|_{f=f_0}^{\text{main or ref}}-\frac{\theta_{\text{main or ref}}}{\pi f_0}\right)Y_{0oi}^2+Y_{0oi}c_i+d_i=0 \tag{7}$$

As noted from (7), Y_{0oi} has three roots and one of these roots is the optimum circuit parameter. To achieve flat phase difference, the GD of main and reference branch must be chosen same value.

To validate the analytical analysis, Fig. 2 shows the simulated results with different flat phase difference and arbitrarily prescribed GD of 1.5 ns at center frequency f_0 = 3.50 GHz. Table 1 depicts the calculated circuit parameters. The proposed phase shifter provides three reflection zeros and flat phase difference of 150°, 120°, 90° and 60° within passband frequency. Moreover, the GD remains constant at f_0 even though phase difference is changed from 60° to 150°. The return loss (RL) is quasi-reflectionless, where RL is higher than 6 dB in all frequency ranges.

To illustrate the arbitrary prescribed GD, Fig. 3 shows the simulation results. In this design example, the phase difference is chosen as 90° whereas GD is selected as 1 ns and 1.50 ns at f_0. The calculated circuit parameters are shown in Table 2. As observed from this figure, transmission magnitude 3dB bandwidth as well as flat phase difference bandwidth are decreased while increasing the GD. Therefore, trade-off occurs between flat phase difference bandwidth and GD.

Fig. 4 shows the simulation results for demonstrating the flat GD characteristics. The arbitrarily prescribed flat GD (equiripple GD) in passband can achieved by controlling the series connected resistors. However, the transmission magnitude 3-dB bandwidth and flat phase difference bandwidth are decreased with an increase of GD. In addition, when GD ripple in passband edge is small, the input/output port return losses (RLs) are higher than 11 dB in all frequency range.

III. Simulation and Measurement Results

For experimental validation, a $\Delta\varphi$ = 90° quasi-reflectionless differential phase shifter with GD of 1.90 ns at f_0 = 3.5 GHz is designed and fabricated on Taconic substrate with dielectric constant of 2.20 and thickness of 0.787 mm. The calculated circuit parameters of are given as main branch: $Z_{0e1}=1/Y_{0e1}$ = 119.38 Ω, $Z_{0o1}=1/Y_{0o1}$ = 74.03 Ω, $Z_{ot1}=1/Y_{ot1}$ = 25 Ω, R_1 = 30 Ω, θ_{main} = 90° and reference branch: $Z_{0e2}=1/Y_{0e2}$ = 119.96 Ω, $Z_{0o2}=1/Y_{0o2}$ = 75.66 Ω, $Z_{ot2}=1/Y_{ot2}$ = 25 Ω, R_2 = 50 Ω, θ_{ref} = 45°. The simulation was performed using ANSYS HFSS 2021.

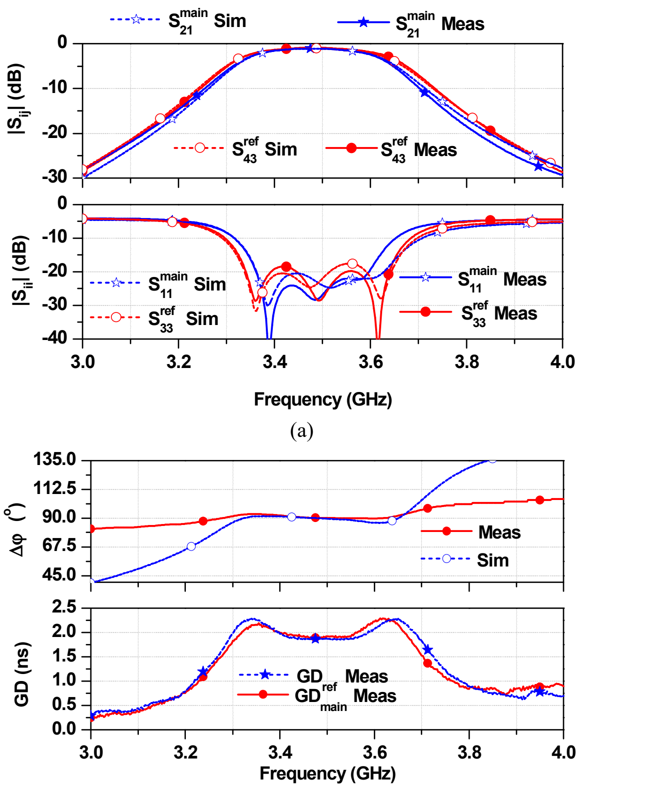

Fig. 5. Simulated and measurement results: (a) magnitude and (b) phase and group delay.

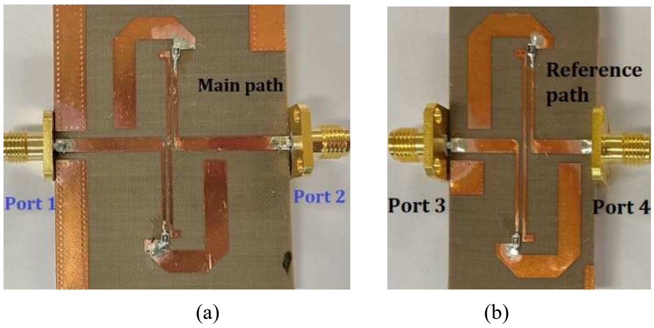

Fig. 6. Photographs of fabricated quasi-reflectionless differential phase shifter: (a) main branch and (b) reference branch.

Fig. 5 shows the simulation and measurement results. The measurement results are well agreed with simulation results. From experiment, the insertion loss of main and reference branch are found to be 1.10 dB and 0.9 dB at f_0 = 3.50 GHz, respectively. The measured phase difference is determined as 89.9 ± 1° within bandwidth of 350 MHz (3.30 GHz to 3.65 GHz). Similarly, the measured GDs of main and reference branch are 1.92 ns and 1.88 ns at f_0 = 3.50 GHz. The measured RL is higher than 18 dB within 350 MHz (3.30 GHz to 3.65 GHz) passband frequency and higher than 6.5 dB in all frequency range. Photograph of fabricated circuits are shown in Fig. 6.

IV. Conclusion

This paper demonstrated the quasi-reflectionless differential phase shifter with arbitrarily prescribed group delay and flat phase difference. The proposed phase shifter is designed by using group delay analysis method. The flat phase difference between main and reference branch is achieved by calculating design parameters by equating the group delay of both branches. The passband group delay flatness as well as differential phase shift flatness can be controlled by series connected resistor. The proposed method can be easily extended for higher order by cascading number of 1-stage phase shifter. For experimental demonstration, a 90° phase shifter with group delay of 1.9 ns is designed and measured. The measured results well agreed with simulation and theoretically predicted results.

Acknowledgment

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