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2018 Asia-Pacific Microwave Conference

APMC 2018

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TECHNICAL SESSIONS (Oral Sessions)

Wednesday, November 7 *10:30 - 12:10*

Room B1

Session WE2-B1

Antennas for Wireless Application

Chairs: Nobuyoshi Kikuma (Nagoya Insititute of Technology, Japan), Keisuke Konno (Tohoku University, Japan)

WE2-B1-1
Circularly Polarization Loop Antenna

Wenting Wu (University Of Sicence And Technology Of China, P.R. China); Cun Wang (University of Science and Technology of China, P.R. China)

WE2-B1-2
Quasi-isotropic radiation by coupled loop antennas without a quadrature phase shifter

Jaechun Lee (Samsung Advanced Institute of Technology, Korea); Sang Joon Kim (Samsung Advanced Institute of Technology, Korea)

WE2-B1-3
Sensitivity Analysis of Input Impedance of a Large Loop Antenna in a Waveguide to Tilt Angle

Nedime Pelin M. H. Salem (New Jersey Institute of Technology, USA); Edip Niver (NJIT, USA); Mohamed A Salem (Sonoma State University, USA)

WE2-B1-4
Realization of Structured Electromagnetic Waves based on Plane Spiral Orbital Angular Momentum Waves using Circular Cylindrical Conformal Microstrip Antenna Array

Qing Ma (Zhejiang University, P.R. China)

WE2-B1-5
Flat Half Maxwell Fish-Eye Lens for High Directivity Applications

Cun Wang (University of Science and Technology of China, P.R. China); Qi Zhu (University of Science and Technology of China, P.R. China)

Room B2

Session WE2-B2

Advances in Theory and Design for Filters and Group Delay Circuits

Chairs: Masataka Ohira (Saitama University, Japan), Yongchae Jeong (Chonbuk National University, Korea)

WE2-B2-1
Compact Quasi-Lumped Element Bandpass Filters for Single-ended High-Purity Frequency Multipliers Applications

Feng-Jun Chen (Microsystem and Terahertz Research Center of CAEP, P.R. China); Liang Zhang (Microsystem and Terahertz Research Center, China Academy of Eegineering Physics & Institute of Electronic Engineering, China Academy of Engineering Physics, P.R. China); Xu Cheng (Mircosystem and Terahertz Research Centre of CAEP, P.R. China); Xin-lin Xia (Mircosystem and Terahertz Research Centre of CAEP, P.R. China); Jiang-An Han (China Academy of Engineering Physics, P.R. China); Xian-jin Deng (Mircosystem and Terahertz Research Centre of CAEP, P.R. China)

WE2-B2-2
Notes on Determination of Frequency-Variant Coupling for High Selectivity In-Line Filters

Yuxing He (Yokohama National University, Japan); Nobuyuki Yoshikawa (Yokohama National University, Japan)

WE2-B2-3
Coupling Matrix Synthesis and Design of a Chained-Function Waveguide Filter

Yuan Ping Lim (Universiti Teknologi PETRONAS, Malaysia); Yew Leong Toh (Universiti Teknologi PETRONAS, Malaysia); Sovuthy Cheab (Universiti Technologi PETRONAS, Malaysia); Stepan Lucyszyn (Imperial College London, United Kingdom (Great Britain)); Peng Wen Wong (Universiti Teknologi PETRONAS, Malaysia)

WE2-B2-4
Arbitrary Prescribed Wideband Flat Group Delay Circuit for Self-Interference Cancellation Circuits

Girdhari Chaudhary (Chonbuk National University, Korea); Phanam Pech (Chonbuk National University, Korea); Junhyung Jeong (Chonbuk National University, Korea); Phirun Kim (Chonbuk National University, Korea); Yongchae Jeong (Chonbuk National University, Korea)

WE2-B2-5
Modified Vector Fitting and Its Application to Simultaneous Characteristics Approximation of Attenuation and Group Delay

Toshikazu Sekine (Gifu University, Japan); Yasuhiro Takahashi (Gifu University, Japan)

Room C1

Session WE2-C1

Metastructures and Microstructures for Terahertz and Microwave Applications

Chairs: Withawat Withayachumnankul (The University of Adelaide, Australia), Jaeyoung Kim (Rohm Co, Ltd., Japan)

WE2-C1-1 [Invited]
Terahertz Metasurfaces for Beamforming and Polarization Conversion

Withawat Withayachumnankul (The University of Adelaide, Australia)

WE2-C1-2
Highly Stable Terahertz Resonant Tunneling Diode Oscillator Coupled to Photonic-Crystal Cavity

Xiongbin Yu (Osaka University, Japan); Jaeyoung Kim (Rohm Co, Ltd., Japan); Masayuki Fujita (Osaka University, Japan); Tadao Nagatsuma (Osaka University, Japan)

WE2-C1-3
An Equidistantly Stepped Waveguide TE11-TE01-Mode Converter for Millimeter Wave Radar Applications

Birk Hattenhorst (Ruhr-University Bochum, Germany); Christian Schulz (Ruhr-Universität Bochum, Germany); Christoph Baer (Ruhr-Universität Bochum & Institute of Electronic Circuits, Germany); Thomas Musch (Ruhr-Universität Bochum, Germany)

WE2-C1-4
Transformation of OAM waves to Plane Spiral OAM waves Based on Gradient-index Meta-surface

Lin Hua (Zhejiang University, P.R. China)

Room: C2

Session WE2-C2

Rectifiers and Rectennas

Chairs: Tsunayuki Yamamoto (Yamaguchi University, Japan), Jiafeng Zhou (University of Liverpool, United Kingdom (Great Britain))

WE2-C2-1
SOI-CMOS high power rectifier IC with the cross coupled CMOS pair

Shunya Tsuchimoto (Kanazawa Institute of Techology, Japan)

WE2-C2-2
Waveform-Based Design of a 2.8-GHz Self Synchronous Class-E RF-DC Rectifier with GaN Transistor

Fei You (University of Electronic Science and Technology of China, P.R. China); Ying Wang (China Academy of Space Technology(Xi'an), P.R. China); Shi-Wei Dong (National Key Laboratory of Space Microwave Technology, P.R. China); Xumin Yu (National Key Laboratory of Space Microwave Technology, P.R. China); Chuan Li (University of Electronic Science and Technology of China, P.R. China)

WE2-C2-3
Development of Sub-Terahertz Rectenna using Gyrotron

Sei Mizojiri (University of Tsukuba, Japan)

WE2-C2-4
A High Efficiency Differential Rectenna Employing Two-Parasitic-Element Stacked Antenna

Kenta Yasuda (Saga University, Japan); Eisuke Nishiyama (Saga University, Japan); Ichihiko Toyoda (Saga University, Japan)

WE2-C2-5
A 2.5D Wafer-level CMOS-IPD Rectenna Using Wide-Range Efficiency and Self-biasing Topology for a RF Wireless Power Harvesting System

Kuei-Cheng Lin (National Applied Research Laboratories, Taiwan)

Arbitrary Prescribed Wideband Flat Group Delay Circuit for Self-Interference Cancellation Circuits

Girdhari Chaudhary #1, Phanam Pech#, Junhyung Jeong#, Phirun Kim#, and Yongchae Jeong#2

#*Division of Electronics Engineering, Chonbuk National University, Jeonju-si, Republic of Korea*
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Abstract — **This paper presents a design of arbitrary specified wide flat group delay (GD) circuit without any cross-coupling among non-adjacent resonators. The proposed structure consists of short-circuited coupled lines along with transmission lines (TLs) at input and output. The additional TL provides an extra degree of freedom to obtain higher wideband flat GD without fabrication difficulty in microstrip technology. The close-form analytical design equations are derived to obtain arbitrary wideband flat GD response. For experimental validation, a prototype circuit was designed and fabricated for GD of 3.6 ns at the center frequency of 2 GHz.**

Index Terms — **Coupled line, self-interference cancellation, wideband flat group delay.**

I. INTRODUCTION

Wideband RF self-interference cancellation is highly required for in-band full duplex systems [1], where a precise group delay (GD), amplitude and phase matchings are critical. In addition, wideband flat GD circuits also have various applications in modern RF/microwave communication systems containing real-time analog radio-signal processing (R-ASP) [2]. The flat GD response in linear phase filters can be achieved by two approaches. The first approach is to use external all-pass GD circuit cascaded with filter, which increases circuit size and insertion loss. The second approach is to impose linear phase and amplitude requirement characteristics for realizing flat GD response in filters [5]-[7]. However, these conventional techniques require more than one signal transmission path using cross-coupling between non-adjacent resonators or posting the transmission zero on a right-half plane by handling sign of cross-coupling. In addition, the arbitrary flat GD response in bandpass filter is difficult to specify with these conventional techniques.

This paper shows an alternative very simple way to realize arbitrary specified flat GD circuit. The proposed technique does not require any cross-coupling among adjacent resonators or controlling sign of cross-coupling or any kind of transformation to obtain required circuit parameters. In this work, closed-form analytical design equations are derived to obtain circuits parameters for arbitrary specified wideband flat GD response.

II. ANALYTICAL ANALYSIS

The schematic of the proposed circuit with wideband flat GD response is shown in Fig. 1. The proposed structure consists of λ/4 short-circuited coupled line addition to transmission lines (TLs). The characteristic impedance of TLs and even- and odd-mode impedances of coupled lines are normalized with port impedance Z_0 and denoted as z_1, z_{0e}, and z_{0o}, respectively. Using the equivalent sub-circuits under even- and odd-mode excitations [8] shown in Figs. 1(b) and 1(c), the S-parameters of the proposed circuit are derived as (1) where f_0 and f are the design center frequency and operating frequency, respectively.

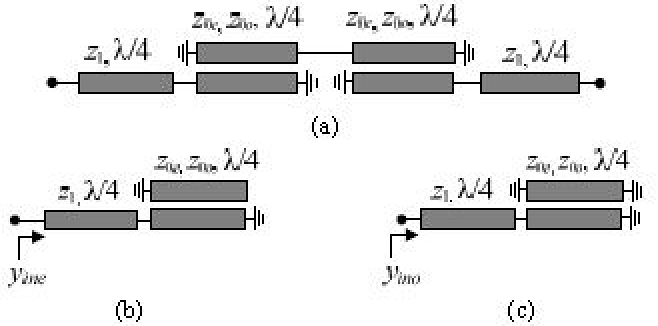


Fig. 1 Proposed structure of wideband flat group delay circuit and its equivalent circuits: (a) proposed structure, (b) even-mode and (c) odd-mode equivalent circuits

$$S_{11} = S_{22} = \frac{1 - y_{ine} y_{ino}}{(1 + y_{ine})(1 + y_{ino})} = \frac{x_2 x_4 + x_1 x_3}{(x_2 + jx_1)(x_4 + jx_3)} \tag{1a}$$

$$S_{12} = S_{21} = \frac{y_{ino} - y_{ine}}{(1 + y_{ine})(1 + y_{ino})} = \frac{j(x_2 x_3 - x_1 x_4)}{(x_2 + jx_1)(x_4 + jx_3)}, \tag{1b}$$

where

$$x_1 = \frac{1}{z_1^2} \sin\frac{\pi f}{f_0} - \frac{2}{z_c z_1 \sqrt{1 - C^2}} \cot\frac{\pi f}{2 f_0} \left(\cos^2 \frac{\pi f}{2 f_0} - C^2 \right) \tag{2a}$$

$$x_2 = \frac{2}{z_1} \cos^2 \frac{\pi f}{2 f_0} + \frac{2}{z_c \sqrt{1 - C^2}} \left(\cos^2 \frac{\pi f}{2 f_0} - C^2 \right) \tag{2b}$$

$$x_3 = \frac{1}{z_1^2} - \frac{1}{z_c z_1 \sqrt{1 - C^2}} \cot^2 \frac{\pi f}{2 f_0} \tag{2c}$$

$$x_4 = \left(\frac{1}{z_1} + \frac{1}{z_c \sqrt{1 - C^2}} \right) \cot\frac{\pi f}{2 f_0}. \tag{2d}$$

Likewise, z_c and C are characteristic impedance and the coupling coefficient of short-circuited coupled line, respectively, and these values are expressed in terms of z_{0e} and z_{0o} as (3).

$$z_{0e} = z_c\sqrt{\frac{1+C}{1-C}},\ z_{0o} = z_c\sqrt{\frac{1-C}{1+C}} \tag{3}$$

Using the phase of S_{21} from 1(b), the expression of GD can be derived using (4)

$$\tau = -\frac{1}{2\pi}\frac{d\angle S_{21}}{df}, \tag{4}$$

The required value of z_c with the specified flat GD can be found by solving (4) at f_0 as (5).

$$z_c = \frac{2z_1}{\sqrt{1-C^2}\left(b \pm \sqrt{b^2 - \frac{4}{z_1^2 C^2}}\right)} \tag{5}$$

where

$$b = \frac{4z_1 f_0 \left.\tau\right|_{f=f_0} - z_1^2 - 1}{z_1^2} \tag{6}$$

From (5) and (6), z_c has two unique solutions depending positive and negative signs. For positive real value of z_c, the value of C should be (7).

$$C(dB) = 20\log\left(\frac{2z_1}{4z_1 f_0 \left.\tau\right|_{f=f_0} - z_1^2 - 1}\right) + \alpha \tag{7}$$

where α is a positive factor that provides an extra degree of freedom to controls C and in-band GD ripple.

Fig. 2 shows the calculated magnitude and GD responses of the proposed circuit with positive and negative signs in (5). As can be observed from Fig. 2(a), the solution of z_c with a positive sign provides wide return loss characteristics with three poles, however, GD peaks occur at band edge frequencies. These in-band GD ripples can be minimized by obtaining a solution of z_c with a negative sign as shown in Fig. 2(b). However, only one pole occurs at f_0 when GD is flat. In general, the negative sign is preferable for wideband flat GD response with minimum ripple. The responses of the proposed circuit can be compared with conventional Butterworth and Chebyshev filter responses for the same GD at f_0 and return loss bandwidth specification. The GD of the proposed circuit is flatter and wider than the conventional filters.

In addition, the in-band GD ripple of the proposed circuit is decreased and approached toward maximally flat characteristics as α increases. The in-band GD ripple ($\Delta\tau_{\text{ripple}}$) can be calculated as (8) where $\tau_{\max}$ and $\tau_{f=f0}$ are maximum GD at band edge frequency and minimum GD at f_0, respectively.

$$\Delta\tau_{ripple} = \frac{2\left(\tau_{\max} - \tau_{f=f_0}\right)}{\tau_{\max} + \tau_{f=f_0}} \times 100\% \tag{8}$$

To investigate the effect of selecting α, Fig. 3 shows calculated $\Delta\tau_{\text{ripple}}$ with different z_1. As seen from the figure, the $\Delta\tau_{\text{ripple}}$ can be minimized by increasing α. In general, higher α is preferable for minimum $\Delta\tau_{\text{ripple}}$. Fig. 4 (a) depicts the calculated the circuit parameters the with the specified GD. The practical realizable circuit parameters of coupled lines can be obtained by appropriately selecting z_1. Specifically, the higher z_1 is preferable for high GD and practical realizable coupled line.

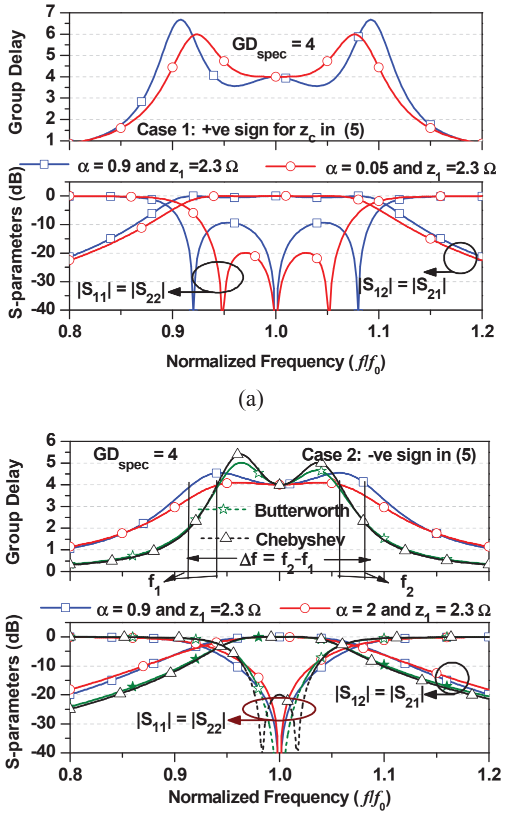


Fig. 2 Calculated responses of the proposed filter: (a) positive sign in (6) and (b) negative sign in (5).

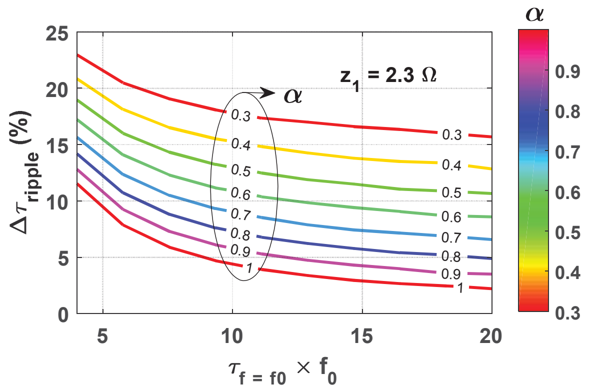
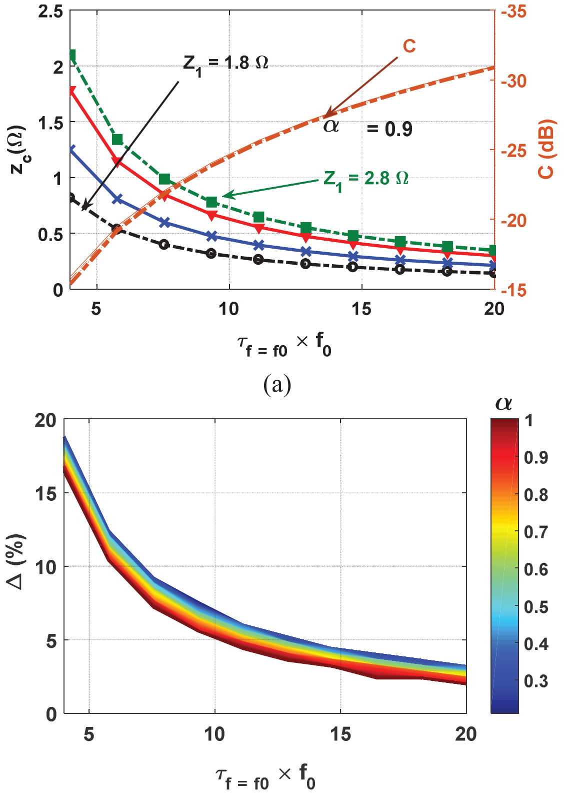


Fig. 3. Calculated in-band group delay ripple with different α.

Once z_c, C, and z_1 are determined for the specified GD and minimum $\Delta\tau_{\text{ripple}}$, the in-band flat GD fractional bandwidth (Δ) can be approximately found by as (9).

$$\Delta = \frac{f_2 - f_1}{f_0} \times 100\% \tag{9}$$

where f_1 and f_2 are lower and upper cut-off frequencies (refer to Fig. 2) in between which the GD is equal to specified GD at f_0.



(a)

(b)

Fig. 4. Calculated parameters of the proposed filter: (a) z_c and C with a negative sign in (6) and α =0.9 and (b) flat group delay fractional bandwidth (Δ).

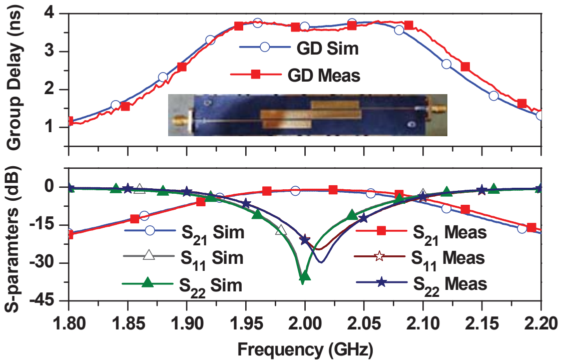


Fig. 5. Simulated and measured results of the proposed group delay circuit.

Fig. 4(b) depicts the computed Δ for various z_1 and α which is calculated from (4) and (9) using MATLAB. The value of Δ is decreased as GD increases, however, Δ is slightly higher with small α.

III. SIMULATION AND MEASUREMENT

For experimental demonstration, the prototype circuit is designed and fabricated at f_0 = 2 GHz with GD of 3.6 ns and $\Delta\tau_{\text{ripple}}$ = 5.5%. The circuit parameters for the given specification are calculated as $z_1 = 2.12\ \Omega$, $z_c = 0.5835\ \Omega$, and C = -21.5482 dB. The renormalized circuit parameters of designed prototype are $Z_1 = 106\ \Omega$, $Z_{0e} = 31.7288\ \Omega$, and $Z_{0o} = 26.8290\ \Omega$. The experimented and simulated GDs and S-parameters are shown in Fig. 5 where measurement results well agreed with the simulations. The measured GD is 3.59 ns at f_0 and the flat GD extends from 1.93 to 2.10 GHz with Δ = 8.5%. Similarly, the measured S-parameters at f_0 = 2 GHz are determined as $|S_{21}|$ = -0.97 dB, $|S_{11}|$ = -24.58 dB and $|S_{22}|$ = -29.39 dB.

IV. CONCLUSION

In this paper, a design of group delay circuit with arbitrary defined wideband flat group delay response is demonstrated with analytical close-form design equations. The proposed topology shows an alternative way to realize the flat group delay response without requiring any cross-coupling with adjacent resonators or controlling sign of coupling. The proposed technique does not necessitate any transformation to obtain circuit parameters. The proposed circuit provides wideband flat group delay response and is significant to different RF/microwave circuits such as a wideband RF self-interference cancellation circuit, RF amplifier linearization, and analog radio signal processing.

ACKNOWLEDGMENT

This research was supported by the Korean Research Fellowship Program through the National Research Foundation (NRF) of Korea, funded by the Ministry of Science and ICT (2016H1D3A1938065) and the Basic Science Research Program through the NRF of Korea, funded by Ministry of Education, Science and Technology (2016R1D1A1B03931400).

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