Compact UHF 3 dB MCCT Power Dividers

Hee-Ran Ahn, *Senior Member, IEEE*, Byungjoon Kim, and Sangwook Nam, *Senior Member, IEEE*

***Abstract*—A compact UHF 3 dB power divider (PD) is presented. It consists of two identical asymmetric impedance transformers (MCCTs) and one isolation circuit with resistance and capacitance. The MCCT is composed of two different transmission-line sections and one open stub, and good frequency performance may be achieved by the combination of transmission-line sections and open stub. One PD is fabricated at a design center frequency of 500 MHz, of which total transmission-line sections are only 39.68° long. The measured bandwidth with 15 dB return loss is about 68%.**

***Index Terms*—Asymmetric impedance transformers (MCCTs), compact power dividers (PDs), UHF PDs, Wilkinson power dividers (combiner).**

I. Introduction

THE power dividers (PDs) [1]–[11] have been used for various applications such as balanced amplifiers and antenna arrays. As the terrestrial TV applications or wireless communication systems require substantial reduction in mass and volume, compactness of the PDs has been of high interest. There have been several literatures treating compact PDs [3], [5]–[8], [10]. However, the PD in [5] requires two metal layers, which are suitable for MMICs, and two stages are needed for wideband performance. In [6], three dimensional waveguide structures are needed. In [7], two asymmetric equivalent transmission-line sections connected in cascade are employed, but the phase delay doesn't seem to be 90° [8, Fig. 4]. Due to the reason, the isolation circuit should consist of not only resistance but also capacitance (inductance). In [9], lumped-element equivalent circuits (CRLH TLs) are used, but the bandwidths are small. In [10], an etched pattern on ground plane should be involved, probably being suitable only for MMICs. In [3], two-types of modified asymmetric equivalent circuits are exploited, but the application for the PDs with the equal termination impedances is excluded. In [11], the PDs with complex termination impedances are studied, but no compactness is treated for those with real termination impedances.

Manuscript received September 30, 2013; revised December 21, 2013 and January 22, 2014; accepted March 11, 2014. Date of publication June 05, 2014; date of current version June 20, 2014. This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology 2009-0083495.

The authors are with the School of Electrical and Computer Engineering, Seoul National University, Seoul, Korea (e-mail: hranahn@gmail.com; bjkim@ael,snu.ac.kr; snam@snu.ac.kr).

Color versions of one or more of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LMWC.2014.2316213

TABLE I
COMPARISONS BETWEEN CONVENTIONAL AND THIS WORKS

	Miniaturization methods	15-dB BW ($\|S_{11}\|$)	Total TL lengths
this work	MCCTs with SMTs and L_{S1} −type	68%	39.68°
[3]	MCCTs, MCVTs	80%	67.72°
[7]	Asymmetric TLs		133.28°
[9]	CRLH TLs	17.5%	>78.7°
[10]	DGS	~43%	~54.2°

In this letter, one type of asymmetric impedance transformers, MCCTs (modified constant conductance-type transmission-line impedance transformers) [3] are investigated in a way different from [3], and a compact PD with 50 Ω termination impedances is fabricated at a design center frequency of 500 MHz. For the compact PDs, each 90° transmission-line section should be reduced and the frequency performance is determined, depending on how much and in which direction to reduce it. The conventional and this work are compared in Table I where this work may be regarded as the best, considering the compact size.

To verify the best performance, one PD is fabricated and measured at a design center frequency of 0.5 GHz. The total transmission-line sections are 39.68° long, and the 15 dB bandwidth of $|S_{11}|$ is 68%.

II. Asymmetric Impedance Transformers of MCCTs

The MCCT is depicted in Fig. 1 where two transmission-line sections and one open stub are composed of the MCCT, and the termination impedances are $2R_L$ and R_L with the impedance transformation ratio of 2. The characteristic impedances of the transmission-line sections are Z_a and Z_b and their electrical lengths are Θ_a and Θ_b. Those of the open stub are Z_o and Θ_o. Since the MCCT is asymmetric, the termination impedances of $2Z_L$ and Z_L cannot be interchangeable. The input impedance looking into the transmission-line section with Z_b and Θ_b is designated as $Z_{in\_R_L}$, while that looking into the open stub with Z_o and Θ_o is indicated as $Z_{in\_2R_L}$, from which the design formulas for Z_a and Θ_a are obtained as (1a) and (1b), as shown at the bottom of the next page, where

$$Re\left(Z_{in\_2R_L}\right) = \frac{2R_L Z_o^2}{Z_o^2 + (2R_L \tan\Theta_o)^2} \tag{1c}$$

$$Im\left(Z_{in\_2R_L}\right) = -\frac{(2R_L)^2 Z_o \tan\Theta_o}{Z_o^2 + (2R_L \tan\Theta_o)^2} \tag{1d}$$

$$Re\left(Z_{in\_R_L}\right) = \frac{R_L Z_b (1+\tan^2\Theta_b)}{Z_b^2 + (R_L \tan\Theta_b)^2} \tag{1e}$$

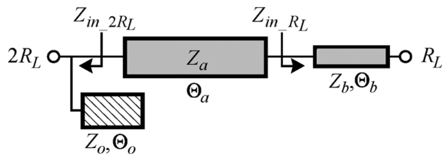

Fig. 1. Asymmetric impedance transformer, MCCT.

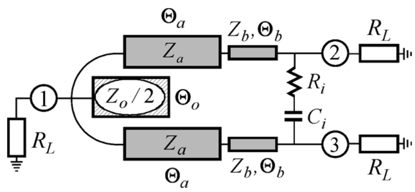

Fig. 2. MCCT PD.

$$Im\left(Z_{in\_2R_L}\right) = Z_b \frac{\left(Z_b^2 - R_L^2\right)\tan\Theta_b}{Z_b^2 + (R_L\tan\Theta_b)^2} \tag{1f}$$

III. MCCT PDs

The impedance transformers of MCCTs may be used for the 3 dB PDs. The schematic diagram is depicted in Fig. 2.

For the design of the PDs, the first condition is that the MCCTs are impedance transformers transforming $2R_L$ into R_L, and the second condition is that the isolation circuit consisting of R_i and C_i should contribute to the perfect isolation between ports ② and ③. If the isolation impedance produced by R_i and C_i is denoted as Z_{IC}, the following relation should be satisfied:

$$\frac{2}{Z_{IC}} + Y_b\frac{-jY_a cot\Theta_a + jY_b tan\Theta_b}{Y_b + (Y_a cot\Theta_a)tan\Theta_b} = \frac{1}{R_L} \tag{2}$$

where $Y_a = Z_a^{-1}$ and $Y_b = Z_b^{-1}$.

Based on the equation in (2), the isolation impedances with $R_L = 50\ \Omega$ were calculated by fixing $\Theta_b = 10°$ and $Z_o = 50\ \Omega$ and varying Z_b and Θ_o, and the calculation results are plotted in Fig. 3 where a design center frequency is 0.5 GHz and all the values are satisfied with the impedance transforming of MCCTs. When $Z_b = 200\ \Omega$, the isolation resistances of R_i are smaller than those with $Z_b = 160\ \Omega$, and the capacitances of C_i are also smaller than those with $Z_b = 160\ \Omega$. Both values of R_i and C_i are inversely proportional to Θ_o of the open stub in Fig. 2.

IV. Measurements

In the fabrication of the MCCT PDs, the first thing is to determine one isolation circuit, because the isolation circuit should be implemented with a set of chip resistor(s) and capacitor(s), and the resistance or capacitance values are limited. In this case,

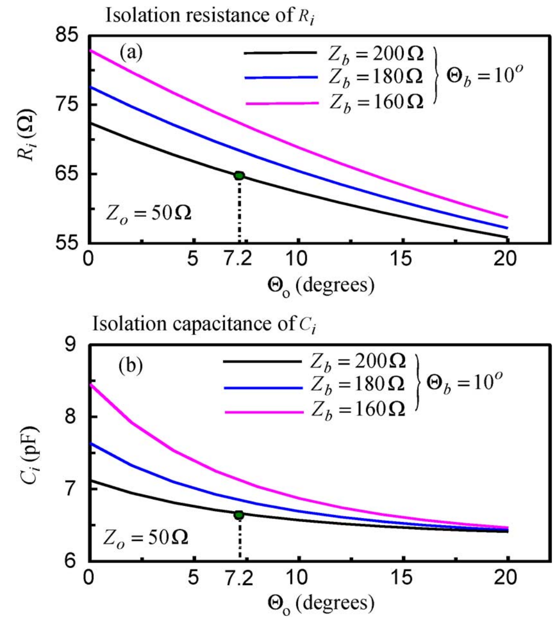

Fig. 3. Isolation Circuits. (a) Resistance. (b) Capacitance.

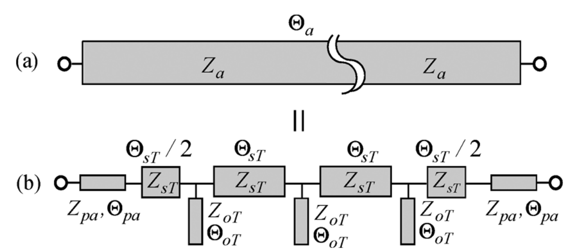

Fig. 4. SMT with $N = 3$ (Stepped-impedance modified T-type).

$Z_b = 200\ \Omega$, $\Theta_b = 10°$ and $\Theta_o = 7.2°$ are chosen to have the isolation impedance of $(64.725 - j47.78)\ \Omega$ in Fig. 3. The isolation circuit may be implemented with two chip resistors of 62 and 2.7 Ω and two capacitors of 5.6 and 1.2 pF at 0.5 GHz. In this case, $Z_a = 55.79\ \Omega$ and $\Theta_a = 28.77°$ are, based on (1), calculated. The transmission-line section with Z_a and Θ_a in Fig. 2 may be reduced more by use of a symmetric equivalent circuit of SMT [12, Fig. 6(b)], and the relation is described in Fig. 4 where only three stages $(N = 3)$ are shown.

Letting $\Theta_{pa} = 0°$ in Fig. 4(b) [13, Fig. 6(b)], the characteristic impedance of Z_{sT} and the total electrical length of $3\Theta_{sT}$ are computed as $Z_{sT} = 114.858\ \Omega$ and $3\Theta_{sT} = 14°$.

The transmission-line section with $Z_b = 200\ \Omega$ and $\Theta_b = 10°$ in Fig. 2 may also be reduced by an equivalent circuit of L_{S1}-type [14, Fig. 6(d)] where the L_{S1}-type consists of N_s number of L_{S1} inductance and two identical transmission-line

$$Z_a = \sqrt{\frac{Re\left(Z_{in\_R_L}\right)\left|Z_{in\_2R_L}\right|^2 - Re\left(Z_{in\_2R_L}\right)\left|Z_{in\_R_L}\right|^2}{Re\left(Z_{in\_2R_L}\right) - Re\left(Z_{in\_R_L}\right)}} \tag{1a}$$

$$\tan\Theta_a = Z_a\frac{Re\left(Z_{in\_R_L}\right) - Re\left(Z_{in\_2R_L}\right)}{Re\left(Z_{in\_R_L}\right)Im\left(Z_{in\_2R_L}\right) - Re\left(Z_{in\_2R_L}\right)Im\left(Z_{in\_R_L}\right)} \tag{1b}$$

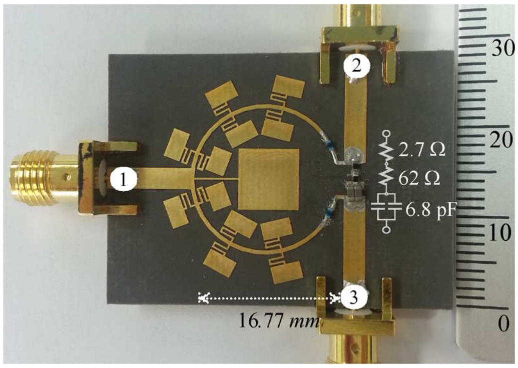

Fig. 5. Fabricated MCCT PD.

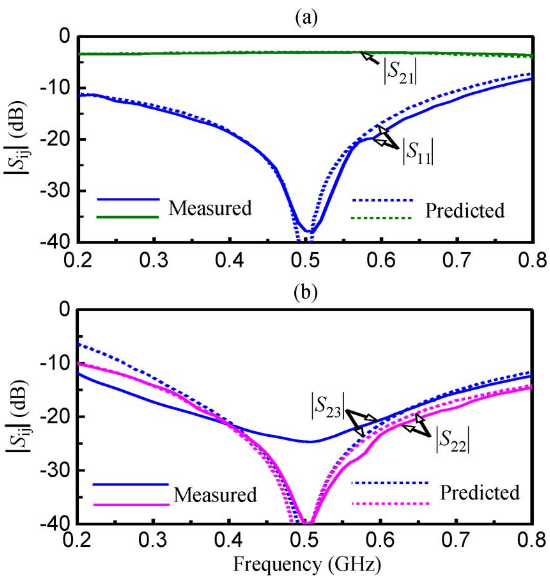

Fig. 6. The results measured and predicted are compared. (a) Power division and matching at port 1; (b) Isolation and matching at port 2.

sections with the characteristic impedance of Z_{LS1} and electrical length of $\Theta_{LS1}/2$. For that with $Z_b = 200\ \Omega$ and $\Theta_b = 10^\circ$, $N_s = 1$ was chosen, which results in $Z_{LS1} = 116.56\ \Omega$, $\Theta_{LS1} = 5.84^\circ$ and $L_{S1} = 7.3$ nH at 0.5 GHz. The fabricated MCCT PD is shown in Fig. 5 where the total transmission-line sections are 39.68° long. That is, a 90° transmission-line sections is reduced to a 19.84° one.

The frequency responses measured and predicted are compared in Fig. 6 where the power division and the matching at port ① are in Fig. 6(a), and the isolation and the matching at port ② in Fig. 6(b). The measured results are in good agreement with the predicted ones, and the bandwidth with 15 dB return loss at port ① is 68% (0.32–0.66 GHz). That at port ② is 96% (0.31–0.79 GHz) and the 15 dB isolation is 94% (0.25–0.72 GHz). Since the bandwidth is determined by the worst performance, the bandwidth of the MCCT PD in Fig. 5 is 68%, which may be considered as a good result for the compact size.

V. Conclusion

In this letter, a compact UHF MCCT PD is presented. The MCCT consists of two different transmission-line sections and one open stub, and the frequency performance better than that of any other symmetric one is generated by the combination of three elements in MCCTs. Therefore, even though the total transmission-line sections of the MCCT PD are only 39.68 ° long, quite being compact, the measured bandwidth is 68%. As the results of their desirable property for the compact size, the MCCT PDs can be used in a UHF frequency region.

References

[1] E. J. Wilkinson, "An N-way hybrids," *IEEE Trans. Microw. Theory Tech.*, vol. MTT-8, no. 1, pp. 116–118, Jan. 1960.
[2] H.-R. Ahn and I. Wolff, "General design equations, small-sized impedance transformers, their application to small-sized three-port 3-dB power dividers," *IEEE Trans. Microw. Theory Tech.*, vol. 49, pp. 1277–1288, Jul. 2001.
[3] H.-R. Ahn, "Modified asymmetric impedance transformers (MCCTs and MCVTs) and their application to impedance-transforming three-port 3-dB power dividers," *IEEE Trans. Microw. Theory Tech.*, vol. 59, pp. 3312–3321, Dec. 2011.
[4] H.-R. Ahn and I. Wolff, "Three-port 3-dB power dividers terminated by different impedances and its application to MMIC's," *IEEE Trans. Microw. Theory Tech.*, vol. 47, pp. 786–794, Jun. 1999.
[5] Y.-S. Lin and J.-H. Lee, "Miniature ultra-wideband PD using bridged T-coils," *IEEE Microw. Wireless Compon. Lett.*, vol. 22, no. 8, pp. 391–393, Aug. 2012.
[6] J.-K. Chuang, R.-Y. Fang, and C.-L. Wang, "Compact and broadband rectangular waveguide power divider/combiner using microstrip-fed antisymmetric tapered probe," *IEEE Trans. Compon., Packag. Manufact. Tech.*, vol. 4, no. 1, pp. 109–116, Jan. 2014.
[7] C.-L. Chang and C.-H. Tseng, "Compact Wilkinson power divider using two-section asymmetrical T-structures," *Elctron. Lett.*, vol. 49, no. 8, Apr. 2013.
[8] H.-R. Ahn, "Comments on a rigorous design methodology for compact planar branch-line and rat-race couplers with asymmetric T-structures," *IEEE Trans. Microw. Theory Tech.*, vol. 61, no. 4, pp. 1728–1729, Apr. 2013.
[9] H.-L. Zhang, B.-J. Hu, and X.-Y. Zhang, "Compact equal and unequal dual-frequency power dividers based on composite right-/left-handed transmission lines," *IEEE Trans. Microwave Theory Tech.*, vol. 59, no. 9, pp. 3464–3472, Sep. 2012.
[10] J. Yang, C. Gu, and W. Wu, "Design of novel compact coupled microstrip power divider with harmonic suppression," *IEEE Microw. Wirelss Compon. Lett.*, vol. 18, no. 9, pp. 572–574, Sep. 2008.
[11] H.-R. Ahn and S. Nam, "3-dB power dividers with equal complex termination impedances and design methods for controlling isolation circuits," *IEEE Trans. Microw. Theory Tech.*, vol. 61, pp. 3872–3883, Nov. 2013.
[12] H.-R. Ahn and S. Nam, "Compact microstrip 3-dB coupled-line ring and branch-line hybrids with new symmetric equivalent circuits," *IEEE Trans. Microw. Theory Tech.*, vol. 61, pp. 1067–1078, Mar. 2013.
[13] H.-R. Ahn and S. Nam, "New design formulas for impedance-transforming 3-dB Marchand baluns," *IEEE Trans. Microw. Theory Tech.*, vol. 59, pp. 2816–2823, Nov. 2011.
[14] H.-R. Ahn and S. Nam, "Wideband microstrip coupled-line ring hybrids for high power-division ratios," *IEEE Trans. Microw. Theory Tech.*, vol. 61, pp. 1768–1780, May 2013.