A 800- to 3200-MHz Wideband CPW Balun Using Multistage Wilkinson Structure

*Jong-Sik Lim[O], **Ung-Hee Park, *Sungmin Oh, *Jae-Jin Koo, ***Yong-Chae Jeong, and *Dal Ahn

**Division of Information Technology Engineering, Soonchunhyang University, Rep. Of KOREA*
*** Electronics and Telecommunications Research Institute, Rep. Of KOREA*
****Division of Electronics and Information Engineering, Chonbuk National University, Rep. Of KOREA*

***Abstract* — A novel ultra-wide band CPW(Coplanar Waveguide) balun having the structure of multistage Wilkinson power divider is proposed. It has an 180° phase inverting structure between signal line and ground planes of CPW transmission line. The 3-stage Wilkinson power divider is transformed directly into the ultra-wide band balun without any cost of the size and performances. The measurement shows the right S-parameters as a power divider and the proper out of phase as a balun. The measured amplitude and phase unbalances at output ports are ±0.5dB and ±6°, respectively over 800~3200MHz, while the maximum insertion loss is 0.8dB.**

***Index Terms* — Wilkinson dividers, baluns, CPW, coplanar waveguide.**

I. Introduction

One of widely used applications in wireless-related circuits and systems such as antenna, receivers(or mixers), high power amplifiers, and antenna measurement facilities is the power dividing into two output ports with out of phase characteristic, or vice versa. Baluns are used to perform these functional goals. There have been a lot of types of balun, and even recently many new balun topologies are proposed. Out of lots of balun circuit, baluns having the Wilkinson structure (hereinafter "Wilkinson balun") are popular because of simple structure and design, familiarity, and expandability to new application and so on.

Wilkinson divider is greatly extensively used not only as a basic power divider, but various modified power dividers/baluns[1,2]. Because the basic single stage Wilkinson divider has narrow band performances, multi-stage topologies are required for wide band operations. For example, a 3-stage Wilkinson divider guarantees at least octave bandwidth, which means "F_{low}:F_{high}=1:3" [3-5].

By the way when a wide band Wilkinson divider has been realized using CPW (Coplanar Waveguide) elements and if the structural advantage of CPW elements well taken of, it is possible to design an ultra wide band balun having the Wilkinson structure without any cost of size and performance by inserting an 180° phase inverting. The proposed balun in this paper does not require any additional area to form the balun circuit from Wilkinson divider, and holds the performances as a power divider plus to the out of phase characteristic at output ports.

II. Multi-stage Wideband Wilkinson Divider

Wilkinson dividers have simple structure and their applicability is excellent, so they are used for other purposes like balun as well as for inherent power divider. A basic Wilkinson power divider has two in-phase output ports. This means that additional circuit elements should be added to output ports for out of phase characteristic in order to be used as a balun.

However the single stage Wilkinson divider has a relatively narrow bandwidth. Fig. 1 shows the ideal performances of a single stage Wilkinson divider calculated on Agilent Advanced Design System. When -25dB of isolation (S32) between output ports is taken as the criterion of bandwidth, the ideally achieved bandwidth is only 20%. Even though the criterion is mitigated to -15dB of S32, the bandwidth is 50% only.

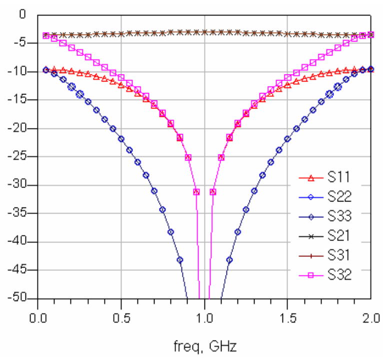

Fig 1. Theoretical characteristics of the basic single stage Wilkinson power divider

A good method to extend the bandwidth is to design a multistage Wilkinson divider. If 100% of fractional bandwidth (FBW) is required, at least 3-stage is chosen because "F_{low}:F_{high}=1:3"[3-5]. Fig. 2 shows the ideal performances of the 3-stage Wilkinson divider. As described just now, more

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than octave bandwidth is shown for the criterion of -25dB of isolation.

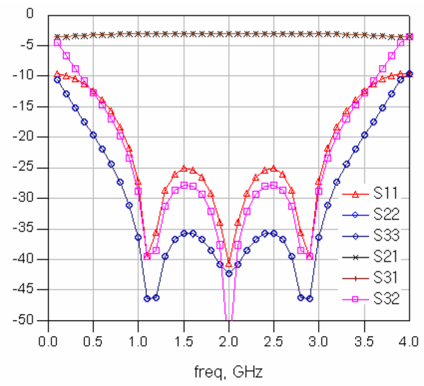


Fig. 2. Theoretical characteristics of a 3-stage Wilkinson divider

III. The Previous Microstrip Wideband Wilkinson Baluns

The circuit topology of the previous Wilkinson balun is shown in Fig. 3. It is consisted of 3-stage Wilkinson divider and additional two couplers which are terminated by open- or short-end for out of phase characteristic at output ports[5,6]. However it should be noted that the size of balun is much larger than the divider because of the additional two couplers. In practice, the additional area for couplers is larger than that of 3-stage Wilkinson divider. So the total size of the Wilkinson balun is much larger than the Wilkinson divider.

Furthermore the bandwidth of the balun is narrower than that of the 3-stage Wilkinson divider because couplers have narrower bandwidth than Wilkinson divider and may act like a limiting factor which reduces the bandwidth of balun.

The used couplers are lange coupler in [5] and twisted-pair coaxial cables in [6]. It is noted that lange couplers should be realized with an extremely precise technique to be free from the performance degradation due to the pattern error, and its size at low frequency is too large to realize. In addition, the twisted-pair coaxial cable must have a fairly large size at low frequency, and it requires a cumbersome manual work to tune the additional proper electrical length.

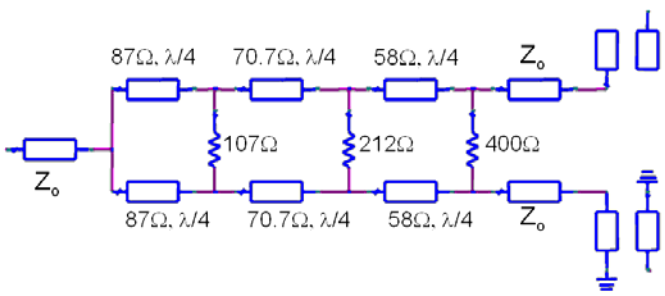


Fig. 3. Balun with the wide band Wilkinson divider and couplers

IV. The Proposed CPW Ultra Wideband Balun

In this paper, a new ultra wideband balun is proposed in order to solve the problem of the previous Wilkinson wideband baluns. The previous ones were realized based on microstrip line, but CPW transmission line is used in the proposed balun.

It is well known that 180^{o} phase inversion is obtained when the signal and ground line are "X"-shaped inter-crossing each other in finite ground CPW or CPS transmission lines [7-9]. Fig. 4 show the phase inverting structures which are realized in finite ground CPW lines. In the phase inverting structure, "B1(=B2)≤W/2" and "A≤G", where W and G are the widths of the center and finite ground conductor, S is the gap between conductors. A minor modification for the phase inverting structure like Fig. 4(c) is acceptable.

It is noted that the used phase inverting structure is frequency independent, and unlikely the previous Wilkinson baluns, is not the factor of frequency limiting. This is one of great advantage of the proposed balun, especially for ultra wideband balun. However, in the previous balun adopting the phase inverting structure composed by couplers, the operating frequency are limited by the bandwidth of couplers as has been described.

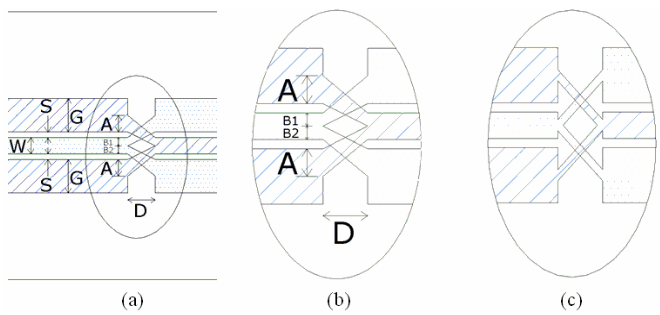
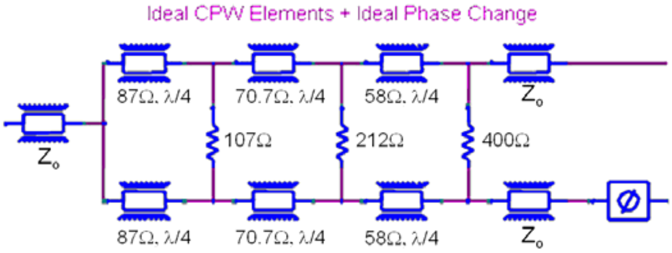


Fig. 4 CPW structure for 180^{o} phase converting
(a) Top view (b) Magnified "X"-crossing structure (c) A modified "X"-crossing structure

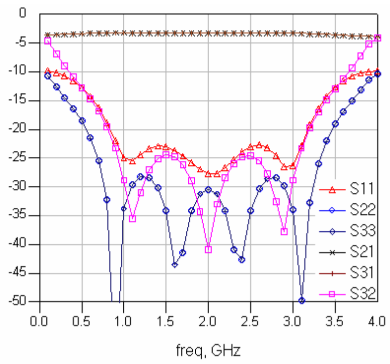
Fig. 5(a) shows the ideal schematic of the proposed CPW Wilkinson balun. In the mid of the path to port 3, the ideal phase inverting element is inserted. Because the ideal phase inverting is added to the transmission line to port 3, the wide band performance of the Wilkinson divider is directly guaranteed in the Wilkinson balun. Fig. 4(b) shows the wide band performances of the balun shown in Fig. 4(a). In the power dividing point of view, it just looks like a Wilkinson divider. However in Fig. 5(c), the out of phase characteristic is very clear, and this is definitely different from regular Wilkinson dividers. It should be noted again that the out of phase characteristic of the proposed balun does not depend on the frequency band of the phase inverter if it is ideal. In other words, the broadband characteristic of the wideband

Wilkinson divider is not degraded even after it is applied to the proposed Wilkinson balun.

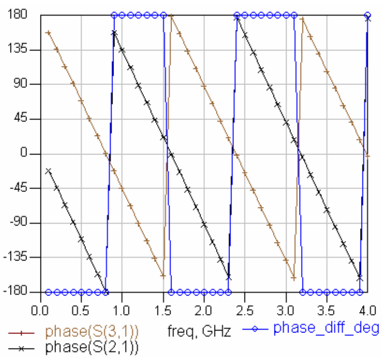
The bandwidth of the proposed ideal balun covers 800MHz to 3200MHz for the criteria of -15dB of isolation and matching, which corresponds to "F_{low}:F_{high}=1:4" at least or more.



(a)



(b)



(c)

Fig. 5. (a) 3-stage ultra-wide band CPW balun (b) Ideal S-parameters (c) Ideal phase characteristics

V. Fabrication and Measurement

Fig. 6 shows the layouts of the broadband 3-stage Wilkinson divider and proposed Wilkinson balun, and Fig. 7 the fabricated balun. Differently from the ideal balun schematic shown in Fig. 5(a), many of discontinuity elements such as Tee- or radical bending elements are inevitably used. So a lot of air-bridge element should be realized over the discontinuities. In this work, bottom bridges are patterned on the bottom of the substrate with lots of via-hole instead of air-bridges for the convenience. Of course the practical performances might be degraded mildly because of the inevitable bridge elements.

It is one of important feature of the proposed balun that there is no additional area from the Wilkinson divider, while the previous Wilkinson balun require large area for the section of out of phase characteristic [5,6]. The area of the balun is exactly same as the Wilkinson divider and no other elements such as coupler and twisted-wire coaxial line is required. This is another great advantage of the proposed balun.

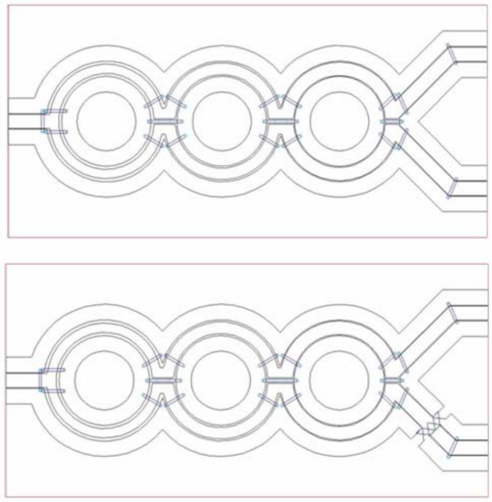
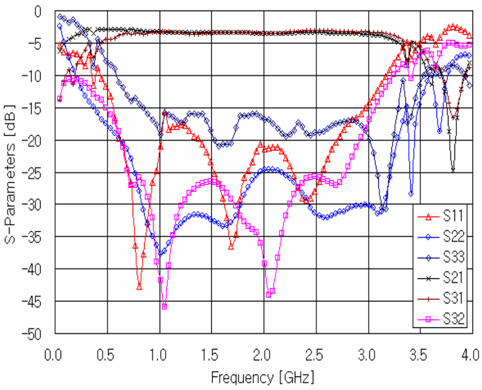


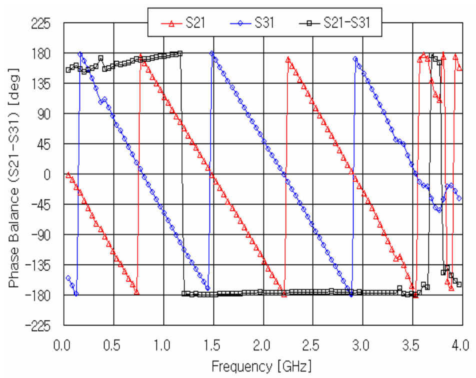
Fig. 6. Layouts of the CPW 3-stage ultra-wide band Wilkinson divider and balun (substrate thickness = 31mils, dielectric constant=2.2)

Fig. 7. Fabricated CPW ultra-wide band balun.

Fig. 8 shows the measured performances of the proposed ultra wideband balun. The matching at ports and isolation are -10 ~ -43dB and -12 ~ -45dB, respectively, over 800MHz ~ 3200MHz. The magnitude and phase unbalance between output ports are ± 0.5dB and ± 6 degrees, respectively. The maximum insertion loss is 0.8dB. Even though there exist a lot of discontinuity elements, bottom-bridge, and via-holes, which are inevitable in CPW transmission line, ultra wideband performances were achieved.



(a)



(b)

Fig. 8. Measured data of the 3-stage ultra-wide band CPW balun (a) S-parameters (b) phase

VI. CONCLUSION

An ultra wideband Wilkinson balun has been designed and measured. The proposed balun consisted of 3-stage wideband Wilkinson divider and CPW 180° phase inverting structure. The measured maximum insertion loss over the ultra wideband was only -0.8dB only, and the magnitude and phase unbalance between output ports were ± 0.5dB and ± 6 degrees, respectively. The measured power dividing performances were similar to those of the Wilkinson divider, and measured out of phase characteristic was the right one of typical balun over 800MHz ~ 3200MHz.

Furthermore there was no required additional area in the proposed balun from the Wilkinson divider. So a relatively smaller and ultra wideband Wilkinson balun was obtained compared to the precious Wilkinson baluns. It is expected that very high frequency applications are possible through the MMIC, RFIC process technology in the future because the proposed balun basically adopts CPW elements.

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