Enhanced Miniaturized Wilkinson Power divider

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***Abstract*—An enhancement technique for miniaturized Wilkinson Power divider is proposed in this paper. The design uses capacitance loading at the input and output ports of the device to achieve size reduction. Broadband characteristics are obtained through the addition of a compensation capacitor between the two output ports. The 11 GHz enhanced Wilkinson power divider is fabricated using a planar micro-strip process on GaAs substrate. The occupied area of the device is 0.28 mm × 0.76 mm. The measured bandwidth for which the input return loss is better than 15 dB is 60.8 % with an insertion loss on this bandwidth not greater than 0.43 dB and a phase deviation less than 0.12 degree.**

***Index Terms*—Wilkinson power divider, miniaturization, capacitance compensation, broadband characteristics.**

I. INTRODUCTION

Power dividers and combiners play an important role in the design of microwave circuits and applications are various. So far, quite a lot of power divider/combiner structures with equal or unequal power division have been proposed. In almost all those structures, quarter wavelength long transmission lines are used as the basic building section resulting in a significant circuit size. Consequently, continuous efforts were carried on to reduce the device size while keeping the original performances [1], [2].

To reduce the size of passive 3 dB Wilkinson power divider, lumped element version was already proposed [3] but suffers from very narrow-band characteristics. Distributed-lumped approach that uses capacitance loading at each of the input and output ports was proposed as an alternative [4], [5]; but as we will discuss in this paper, the bandwidth performance is still limited.

This paper proposes a simple but efficient approach to enhance the bandwidth performance of miniaturized Wilkinson power divider using capacitive loading. The concept is demonstrated by simulation and experimental results at 11 GHz.

II. ENHANCED WILKINSON POWER DIVIDER ANALYSIS

A. *Size Reduction and limitation*

Capacitive loading is well known to help reducing the size of Wilkinson power divider. The schematic of such a reduced size divider is shown in Fig.1 where Z_{01} is the characteristic impedance of the transmission lines, l the physical length of the lines and Z_0, the termination impedance.

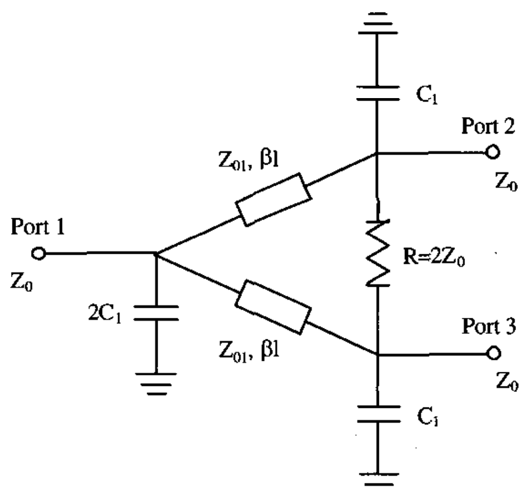

Fig. 1. Miniaturized Wilkinson power divider using capacitance loading.

The even-odd mode analysis [6] performed on this topology leads to ideal matching at the three ports and infinite isolation between the two output ports if,

$$Z_{01} = \frac{\sqrt{2}Z_0}{\sin(\beta_0 l)}$$
$$C_1 = \frac{\sqrt{2}\cos(\beta_0 l)}{\omega_0 Z_0} \quad (1).$$

Where $\beta_0 l$ is the electrical length of the micro-strip transmission line at the design frequency $f_0 = \omega_0/2\pi$.

The equivalence with the original size Wilkinson Power divider is exact only at the design frequency f_0. At higher frequency, each transmission line loaded by a capacitor

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operates as a low pass filter and both return loss and insertion loss degrade quickly with the increasing frequency.

This effect is even more sensitive that the power divider is miniaturized and the load capacitance increased. The normalized bandwidth f_n of the miniaturized divider corresponding to S11<-15 dB is shown Fig. 2 versus the electrical length of the reduced transmission line. Fig.3 shows the normalized frequency bandwidth $f_{0.5dB}$ corresponding to a degradation of the insertion loss of 0.5 dB as regard to its maximum value when the frequency increased. Both normalized frequency bandwidth f_n and $f_{0.5dB}$ are computing assuming loss-less transmission lines and ideal lumped capacitor given by equation 1.

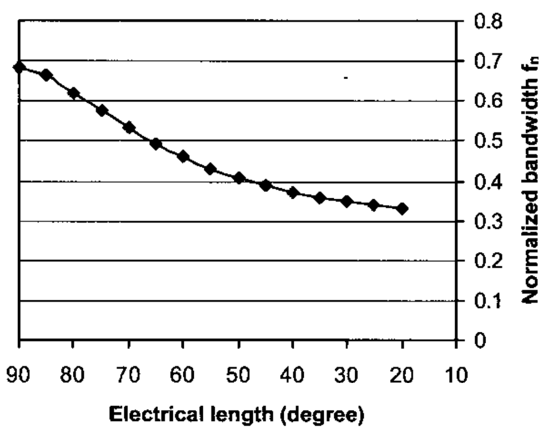

Fig. 2. Normalized frequency bandwidth f_n corresponding to S11<-15dB.

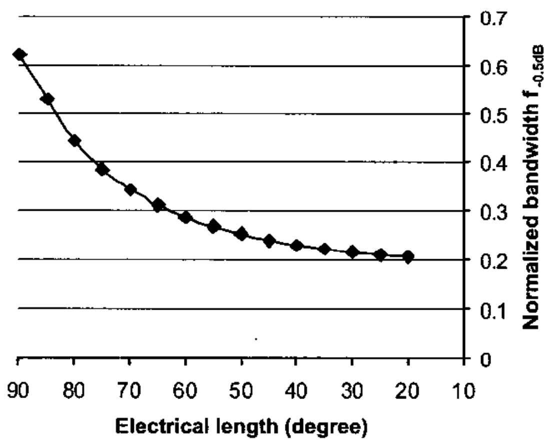

Fig. 3. Normalized frequency bandwidth $f_{0.5dB}$ corresponding to an insertion loss degradation of 0.5 dB when the frequency increased as regard to the design frequency.

A maximum useable frequency bandwidth of 68.1 % is demonstrated for the original size Wilkinson Power divider ($\theta = \pi/2$). For a miniaturized power divider using $\lambda/8$ length transmission lines ($\theta = \pi/4$), the normalized useable frequency is quickly degraded to 38.8 %. Same observation can be done for the normalized frequency $f_{0.5dB}$, demonstrating a quick degradation of the insertion loss of miniaturized power divider with the increasing frequency, and therefore demonstrating the limitation of miniaturized Wilkinson power divider using capacitive load.

B. Capacitance Compensation

To partially overcome the previous issue, we propose the enhanced circuit schematic of Fig. 4.

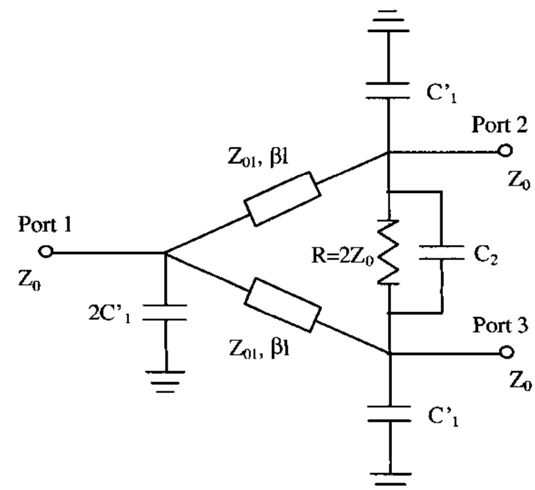

Fig. 4. Enhanced miniaturized Wilkinson power divider.

The design uses the concept of size reduction by capacitive loading but with a reduced capacitance $C'_1<C_1$ to minimized the low-pass filter effect. A capacitor C_2 is introduced between the two output ports of the device to compensate for isolation and return loss degradation. This additional capacitor C_2 does not affect the even-mode but increases the odd-mode phase length. This compensation provides good isolation at the design frequency f_0 and broadband characteristics.

III. CIRCUIT FABRICATION AND RESULTS

The 11 GHz enhanced miniaturized Wilkinson power divider was fabricated on semi-insulation GaAs substrate using a planar micro-strip process. The microphotograph of the divider is shown in Fig. 5. The occupied area of the device is 0.28 mm 0.76 mm.

The two sections of the power divider are implemented by $\lambda/8$ length micro-strip transmission lines of characteristic impedance $Z_{01} = 100\ \Omega$ and width w = 8 μm. The load capacitor 2 C'_1 at the input port and the compensation capacitor C_2 between the two output ports are Metal-Insulator-Metal (MIM) capacitors. The small load capacitors at the output ports are implemented by inter-digital capacitors to benefit from a low sensitivity to process deviation. Eventually, to fully benefit from the size reduction, only one via-hole, central to the device, is used to connect all load capacitors to ground.

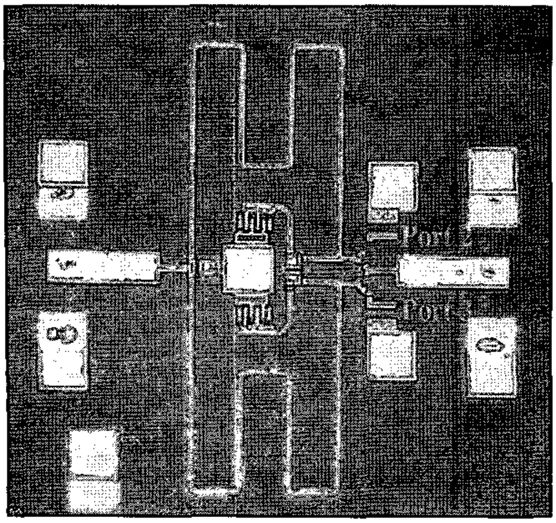

Fig. 5. Fabricated miniaturized Wilkinson power divider.

The S-parameters of the fabricated device measured on wafer are in good agreement with the electro-magnetic (em-) simulation and are within the yield of our process.

The measured coupling loss (S_{21}, S_{31}) and return loss (S_{11}, S_{22}, S_{33}) compared to em-simulation are shown in Fig. 6 and Fig. 7, respectively. As expected the limiting performance for the use of the power divider is the input return Loss S_{11}. The measured bandwidth for which S_{11} is lower than -15 dB is 60.8 % from 8 GHz to 15 GHz. Within this bandwidth, the insertion loss is less than 0.43 dB. Fig. 8 shows a phase deviation in the frequency range 8-15 GHz less than 0.12 degree. Isolation could not be measured on the fabricated samples but em-simulation shows in-band isolation better than 15 dB.

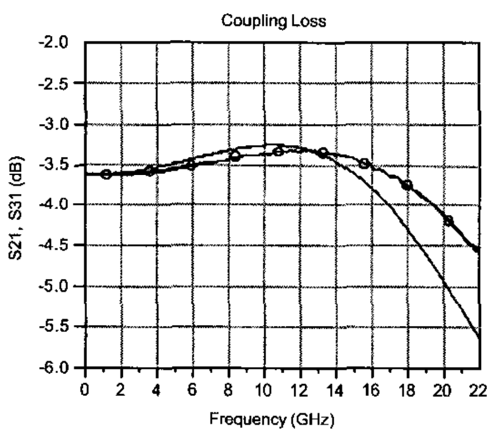

Fig. 6. Measured (circled blue line) and em-simulated (red line) coupling Loss of the fabricated Wilkinson power divider.

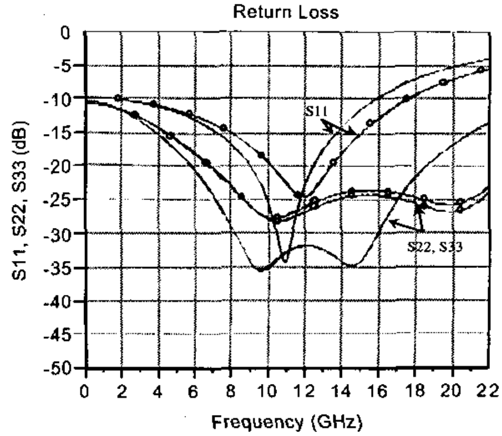

Fig. 7. Measured (circled blue line) and em-simulated (red line) return Loss of the fabricated Wilkinson power divider.

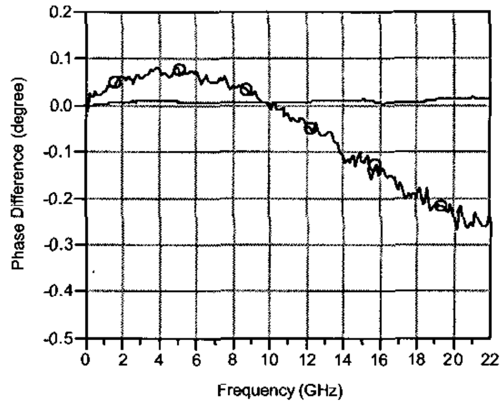

Fig. 8. Measured (circled blue line) and em-simulated (red line) phase difference of the fabricated Wilkinson power divider.

The 60.8 % useable bandwidth of the device is greatly enhanced as regard to the predicted 38.8 % bandwidth (see sec. II-A), and therefore fully demonstrated the interest of the proposed concept.

IV. Conclusion

A technique to enhance the bandwidth characteristics of miniaturized Wilkinson power divider is proposed and demonstrated at 11 GHz. This technique is simple and applicable to higher frequency.

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REFERENCES

[1] K. Nishikawa, T. Tokumitsu, and I. Toyoda, "*Miniaturized Wilkinson power divider using three-dimensional MMIC technology*," *IEEE Microwave and Guided Wave Lett.*, vol. 6, no. 10, pp.372-374. Oct. 1996.

[2] T. Hirota, A. Minakawa, and M. Muraguchi, "*Reduced-size branch-lineand Rat-race hybrids for uniplanar MMIC's*," *IEEE Trans. Microwave Theory Tech.*, vol. 38, no. 3, pp.270-275, March 1990.

[3] I. D. Robertson, and S. Lucyszyn, *RF and MMIC design and Technology*. The Institution of Electrical Engineers, United Kingdom, 2001.

[4] S. Pampichai, N. Siripon, M. Chongcheawchamnan, S. Bunnjaweht, and I.D. Robertson, "*A 3-dB lumped distributed miniaturized Wilkinson divider*,"*23rd Electrical Engineering Conference*, pp. 329-332, Nov 2000.

[5] M.C. Scardelleti, G.E. Ponchak, and T.M. Weller, "*Miniaturized Wilkinson power divider utilizing capacitive loading*," *IEEE Microwave and Wireless Components Lett.*, vol. 12, no. 1, pp.6-8. Jan. 2002.

[6] J. Reed, and G.J. Wheeler, "*A method of analysis of symmetrical four-port networks*," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-4, pp.246-252, Oct. 1956.