A Compact 1.7–2.1 GHz Three-Way Power Combiner Using Microstrip Technology with Better Than 93.8% Combining Efficiency

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Abstract—**This letter presents the design and measured performance of a microstrip three-way power combiner. The combiner is designed using the conventional Wilkinson topology with the extension to three outputs, which has been rarely considered for the design and fabrication of N-way combiners. It is shown that with an appropriate design approach, the main drawback reported with this topology (nonplanarity of the circuit when $N > 2$) can be minimized to have a negligible effect on the circuit performance and still allow an easy MIC or MHMIC fabrication.**

I. Introduction

Power dividers/combiners are key components in the design of power amplifiers with high power efficiency. Using these components, it is possible to connect several devices in parallel, which will increase the output power of the amplifier. The cascading technique (sometimes referred to as the *corporate method* or *tree method*) of Wilkinson two-way power dividers [1] has become popular in the design of microstrip N-way dividers/combiners. However, there are three main drawbacks that limit this approach for effective power combining: 1) the number of devices combined in this type of structure is restricted to powers of two (i.e. must equal 2^N where N is a positive integer); 2) the combining efficiency decreases rapidly as the number of outputs increases because of its strong dependence on the losses within the combiner [2]; and 3) the size of the combiner increases drastically as the number of outputs increases.

To overcome these limits, several alternatives using microstrip technology have been studied by different authors [3]–[6]. Surprisingly, the extention to N outputs of the two-way Wilkinson power divider is rarely considered; the main problem reported with regards to the Wilkinson topology when $N > 2$ is the nonplanarity of the circuit due to the presence of a floating node connecting all isolation resistors together, making the fabrication difficult based on the microstrip technology. The topology of the Wilkinson N-way combiner is presented in Fig. 1.

Nevertheless, the Wilkinson N-way divider/combiner topology still remains attractive for the following reasons: the possibility of designing an odd number of outputs, a compact size (only $\lambda/4$ long), and a theoretical ideal performance. In this letter, a robust design of a compact microstrip Wilkinson three-way power combiner is presented. The circuit has been fabricated in MIC technology at 1.9 GHz and the measurements are in very good agreement with the simulation. A combining efficiency of 95.0% at 1.9 GHz has been measured, with better than 93.8% over the 1.7–2.1 GHz frequency band.

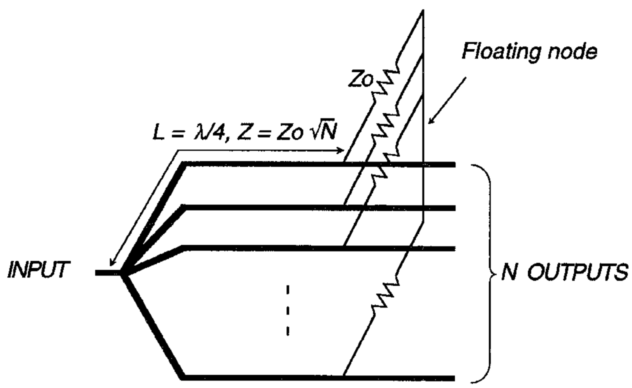

Fig. 1. Wilkinson N-way combiner.

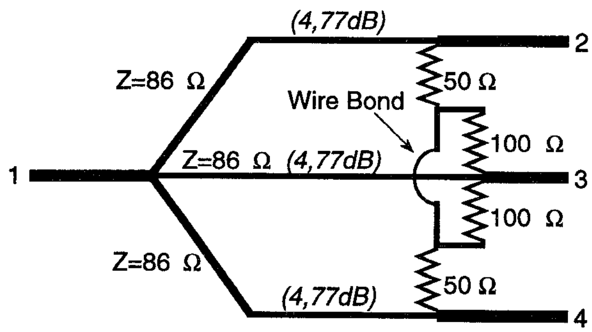

Fig. 2. Schematic of the fabricated three-way combiner.

II. Design of a Wilkinson Three-Way Power Combiner

In addition to the resistive losses, the other sources of degradation of the combining efficiency are the variations in the amplitude and phase of the signals to be combined. These variations may take place in the devices themselves (in the case of nonidentical devices) or in the divider/combiner. To avoid

Manuscript received September 26, 1995. This work was supported by the Québec provincial government (Synergie program) with the partnership of the companies Advantech Inc. and Network Science International.

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Publisher Item Identifier S 1051-8207(96)00908-7.

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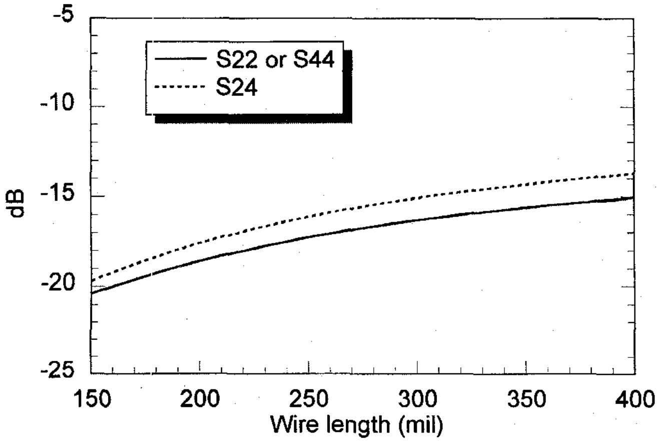

Fig. 3. Simulated variation of S22 (or S44) and S24 in dB versus the length of the wire bond at 1.9 GHz.

any amplitude and phase imbalances between the outputs of the divider/combiner, an electrically symmetric design is the most effective solution. For this reason, the resistor connected to the middle branch of the combiner in Fig. 1 has been split into two equal parallel resistors. Then, to obtain a floating node as ideal as possible, the resistors have been connected together with narrow microstrip lines as short as possible. Finally, the resistors of both sides of the middle branch have been connected by using a 7-mil-diameter copper wire. A schematic of the circuit is presented in Fig. 2.

To evaluate the robustness of this approach, particular attention has been paid to the wire bond by simulating the performance variations of the circuit with the length of the wire. Fig. 3 shows the sensitivity of the amplitude of S22 and S24 versus the wire length. Compared to the other S-parameters, the amplitude of S22 and S24 are the most sensitive parameter to the wire length. The low dependence of the circuit performance on the wire bond length has been verified experimentally by soldering/unsoldering several wire bonds of different lengths on the circuit. Negligible deviations of the S-parameters have been observed for lengths between 150 and 300 mils.

The circuit response will be more sensitive to the wire bond if designed at high frequencies (>10 GHz). However, in such a case it would be advantageous to design the circuit using a more compact technology such as MHMIC (Miniature Hybrid Microwave Integrated Circuit). In this technology, the wire bond could be replaced by an air bridge that will reduce the parasitic effects.

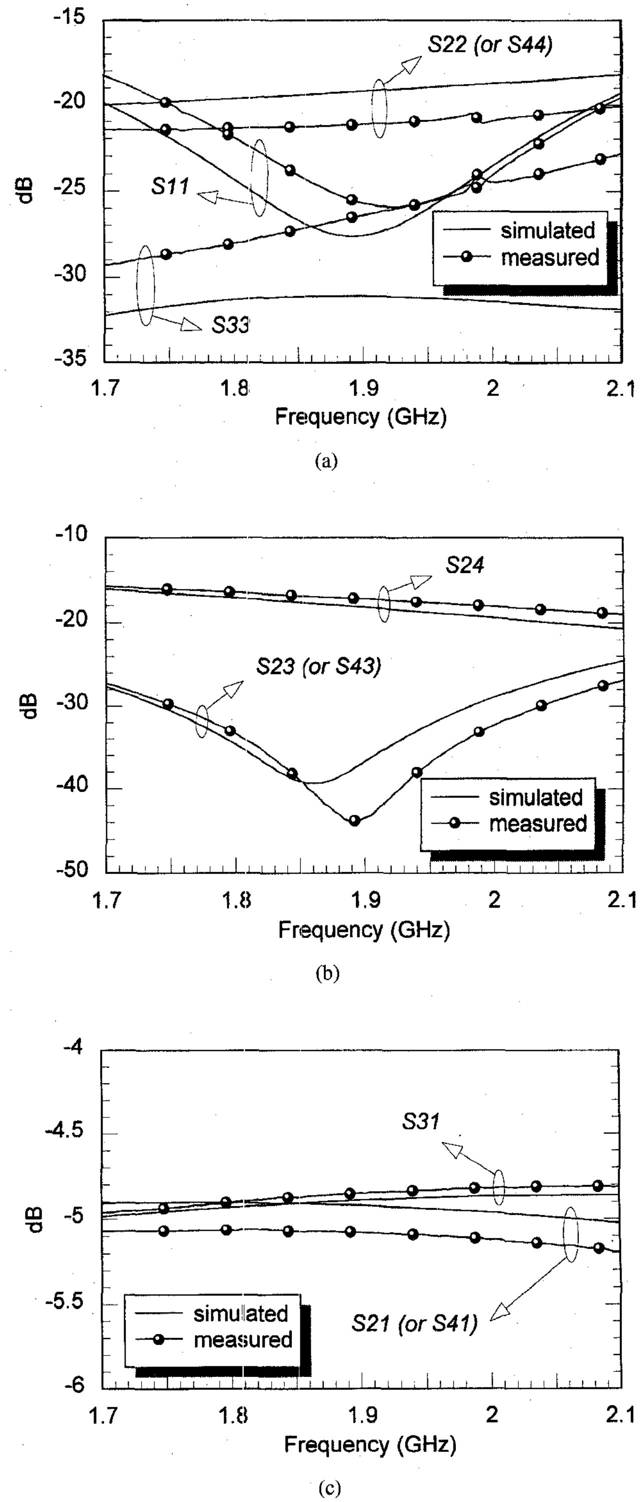

Fig. 4. S-parameters of the Wilkinson three-way combiner. (a) Adaptation. (b) Isolation. (c) Transmission.

III. MEASUREMENT RESULTS

The MDS simulator from Hewlett-Packard has been used for the simulation and layout generation of the circuit. The circuit has been fabricated on RT/duroid 6010 ceramic substrate from Rogers ($\varepsilon_r = 10.2, h = 50$ mil) at 1.9 GHz. The dimensions of the circuit are $1'' \times 0.5''$. The S-parameters of the Wilkinson three-way combiner are presented in Fig. 4. Since port 2 and 4 in Fig. 2 are symetrical, some pairs of S-parameters are identical and only one has been plotted in Fig. 4. A good agreement between simulation and measurement can be observed. The most critical parameter is the isolation between port 2 and 4. As presented in Fig. 3, it could be improved by shortening the wire bond length. However, the measured isolation is already better than -15 dB over the 1.7–2.1 GHz band. At 1.9 GHz, a very good performance has been measured with a combining efficiency of 95.0% (simulation: 96.9%) and a maximum amplitude imbalance of 0.22 dB (simulation: 0.02 dB). In the 1.7–2.1 GHz band, a minimum combining efficiency of 93.8% has been measured (simulation: 95.6%) with a maximum amplitude imbalance of 0.35 dB (simulation: 0.16 dB).

IV. Conclusion

A Wilkinson three-way divider/combiner has been designed and fabricated. This $\lambda/4$-long divider/combiner presents a good matching to all ports, and a good isolation between the outputs with high combining efficiency (better than 93.8%, i.e. insertion loss better than -0.28 dB) over the 1.7–2.1 GHz band. Furthermore, it can be easily designed using a commercial quasi-static simulator and fabricated in standard MIC technology.

Acknowledgment

The authors would like to thank J. Gauthier for the circuit fabrication and mounting.

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