A Novel Compact Uniplanar MMIC Wilkinson Power Divider With ACPS Series Stubs

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ABSTRACT

Short-circuit series stubs realized in the signal conductor of an asymmetric coplanar stripline (ACPS) transmission line are investigated as a circuit element in order to achieve a significant size reduction of a MMIC Wilkinson divider. A simple ideal transmission line equivalent circuit is used to model the ACPS line/stub combination yielding good agreement with EM simulation. The stubs are then utilized to shorten the $\lambda/4$ transmission lines by approximately 35% in a Wilkinson divider application at 23GHz.

I. INTRODUCTION

Uniplanar technologies such as coplanar waveguide (CPW) and coplanar stripline (CPS) possess many well known advantages over microstrip for monolithic microwave and hybrid integrated circuits. These include low dispersion, insensitivity to substrate thickness, easy connection of both shunt and series elements, and elimination of via holes (reducing cost and parasitic inductance). As a result, these technologies are increasingly favoured over microstrip for mm-wave applications. Furthermore novel circuit element structures can be realized with uniplanar technologies which would be difficult if not impossible in microstrip. This provides the designer the opportunity to create new circuit topologies having increased performance over classical implementations [1], [2]. Wilkinson dividers are essential components used in many microwave and mm-wave circuits such as modulators, mixers, amplifiers, and antenna feed networks. The standard Wilkinson divider utilizes $\lambda/4$ transmission lines, which can take up precious real-estate on GaAs MMICs. Reduction in circuit size (and hence cost) is of paramount importance. Examples of size reduction of couplers often employ capacitively loaded transmission lines [3]. Loading the transmission line with inductors has not been as popular probably because spiral inductors have high losses and low resonant frequencies and require accurate models for successful design. Also, short-circuit series stubs are not common because they are difficult to realize in microstrip, which in the past has been much more commonly used than CPW or CPS. In this work, size reduction of a Wilkinson divider is investigated by employing short-circuit asymmetric CPS (ACPS) series stubs (Figure 1).

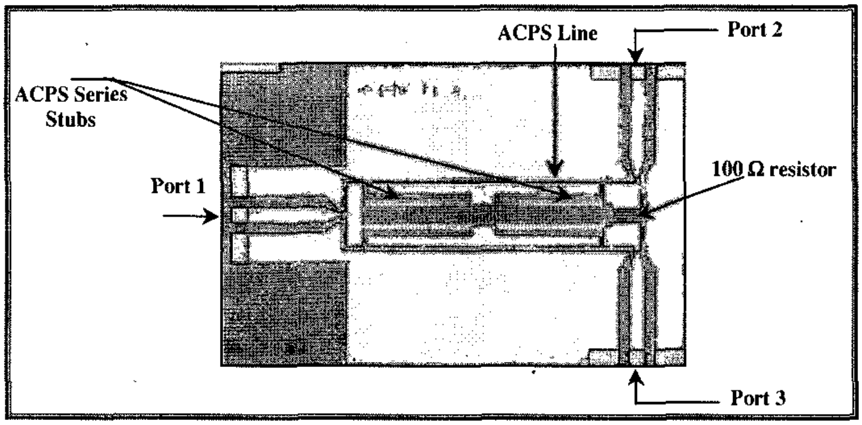

Figure 1: Photograph of size-reduced MMIC Wilkinson divider.

CPS transmission lines have been shown to support excellent signal propagation characteristics in the mm-wave frequency band [4]. CPS lines support a quasi-TEM mode and, unlike CPW, do not require ground plane interconnections (such as air bridges) at discontinuities to suppress the even mode of propagation. The size reduction technique is explained in section II. The physical structure of the ACPS stubs and simulated EM results are presented in III. The design procedure for the combiner/divider is outlined in section IV and, in V, the simulated and measured results are presented.

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II. SIZE REDUCTION

One technique used to reduce the size of transmisson lines is to load each end with a lumped capacitor, C, or an open-circuit shunt stub of impedance Z_{os}, and length θ_s [3] as illustrated in Fig. 2. The shortened line's length and impedance are θ_l, and Z_{ol} respectively.

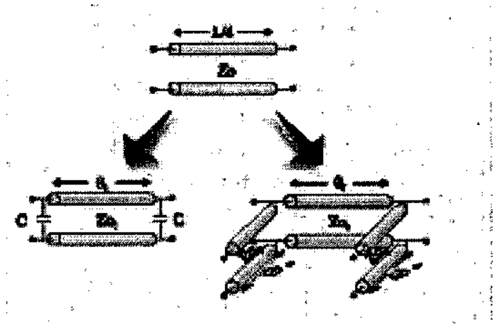

Figure 2: Reduction of λ/4 transmission line using shunt capacitance or shunt open-circuit stubs.

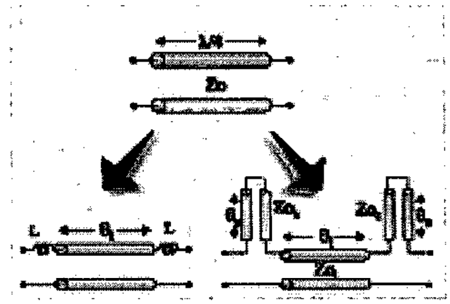

Figure 3: Shortening of λ/4 transmission line using series inductors or short-circuit stubs

The two structures are equivalent at one frequency if:

$$Zo_1 = Zo / \sin(\theta_1) \quad (1) \qquad C = \frac{\cos(\theta_1)}{\omega \cdot Zo} \quad (2) \qquad \frac{Zo_s}{Zo_1} = \tan(\theta_1) \cdot \tan(\theta_s) \quad (3)$$

Similarly, line length reduction can be obtained by using series inductors, L, or short-circuit series stubs of length θ_s and impedance Z_{os} as shown in Figure 3. For this topology it is required that:

$$\sin(\theta_l) = \frac{Z_{ol}}{Z_o} \ (4) \qquad L = \frac{Z_{ol}}{\omega \cdot \tan(\theta_l)} \ (5) \qquad \tan(\theta_l) \cdot \tan(\theta_s) = \frac{Z_{ol}}{Z_{os}} \ \mathbf{(6)}$$

It is much easier to implement shunt capacitive loading than series inductive loading in microstrip because of the difficulty in fabricating series stubs. Shunt stubs or MIM capacitors are easy to realize in microstrip. With uniplanar technologies both types of loading can easily be accomplished. When using capacitive loading, the shortened line has a Zo greater than that of the 90 line (eqn. (1)). However, using inductive loading results in a shortened line with a lower Zo than the 90 line as indicated by eqn. (4). Therefore a designer can choose the most feasible topology depending on the realizability of the required line impedance and circuit elements. A line reduction of 50% can be achieved by altering the original impedance by a factor of 2 .

III. ACPS SERIES STUB TOPOLOGY

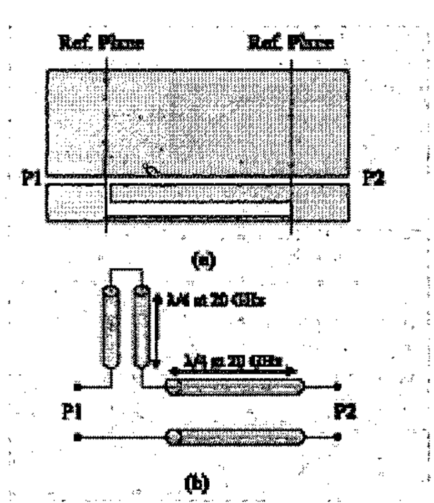

Figure 4: (a) ACPS short-circuit series stub (b) Ideal equivalent circuit.

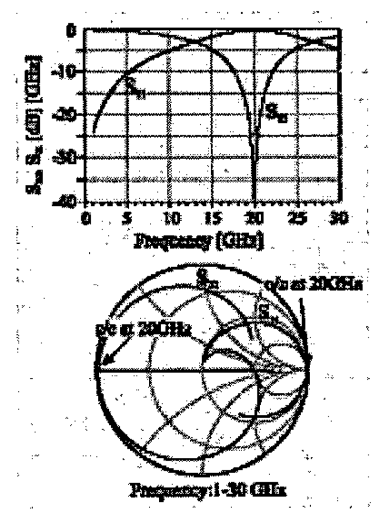

Figure 5: S-parameter response of ACPS short-circuit series stub.

CPS lines consist of two metal strips of width W, separated by a slot of width S. ACPS lines are similar to CPS lines except that the two metallic strips are of different width. This extra degree of freedom allows for flexibility in the characteristic impedance and effective permittivity [5]. In order to apply the inductive loading technique for size reduction described above, a physical realization of a short-circuit series stub in ACPS is required. ACPS series and shunt stubs along with other discontinuities have been studied in [6] and [7].
Here the topology of Fig. 4a (often referred to as a spur-slot discontinuity) will be used. In Fig. 4b, the ideal transmission line equivalent circuit used to model the structure of Fig. 4a is shown.
In order to determine the frequency response of the ACPS series stub and the validity of using the simple equivalent circuit of Fig. 4b, the ACPS stub was simulated using Agilent ADS Momentum TM [8]. The results are shown in Fig. 5. It can be seen from s_{11} that the $\lambda/4$ short-circuit stub transforms the impedance to an open circuit at 20 GHz. Looking into port 2 the structure looks like a short-circuit at 20 GHz because of the $\lambda/4$ transmission line cascaded with the stub. This response agrees well with the simple model of Fig. 4b. It is important to note that the Zo of the series stub is much lower than would be the case for an isolated ACPS line of the same dimensions. This limits the size reduction which can be achieved using this method.

IV. DESIGN PROCEDURE

The topology of the Wilkinson divider/combiner is based on that presented in [9],[10]. The centre frequency for the design is 23GHz. The first step in the design procedure is to use equations (4), (5), and (6) to determine the parameters of the line and stub. In this case, θ_l was chosen to be approximately 60 which represents a reduction in length of 33%. A further reduction was not attempted because it would require larger inductive loading. This in turn would require a higher stub Zo which was difficult to achieve using the ACPS series stub structure. From (4) and (5) we Zo_l=61.2 Ω and L=0.25 nH. A Wilkinson divider using these parameters was then simulated in Agilent ADS [8] using ideal elements to verify performance. This topology is shown in Fig. 6. The next step involved replacing the ideal elements indicated in each of the boxes of Fig. 6 with the structure shown in Fig. 4a. Since all four boxes are identical, only one had to be designed. These were then cascaded together to form the complete circuit. Initial dimensions for the line and stub were estimated from standard equations [5] and an EM simulation was then performed.

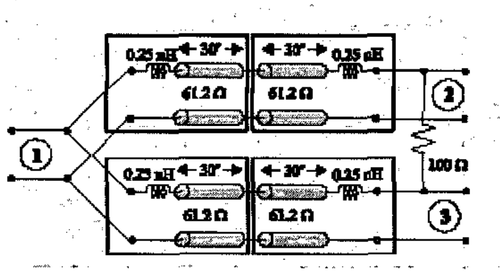

Figure 6: Ideal size-reduced Wilkinson divider.

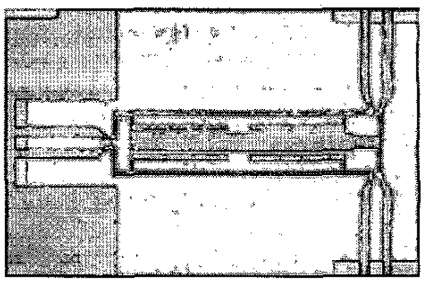

Figure 8: The final circuit of Wilkinson divider.

The resulting s-parameters were converted to ABCD parameters from which the element values could be ascertained using the following equations:

$$\frac{\theta_l}{2} = \cos^{-1}(\Re e(D)) \quad (7) \qquad Zo_l = \frac{\sin(\theta_l)}{\Im m(C)} \quad (8) \qquad L = \frac{\Re e(D-A)}{\omega \cdot \Im m(C)} \quad (9)$$

The widths, gaps, and lengths of the ACPS structure were then adjusted manually and another EM simulation was performed. This iterative procedure allowed optimum values for θ_l, Zo_l, and L to be determined. The final circuit is shown in figure 1. Note that in this design no effort was made to compensate for the parasitics introduced by the bends, resistor or Y connection dividing the CPW input into the two ACPS arms of the circuit.

V. Fabrication and results

The circuit shown in figure 8 was was manufactured with the 0.18 μm OMMIC foundry process. The circuit was measured using a Wiltron 360 VNA and G-S-G probes. The TRL calibration technique was employed and CPW standards were printed on-wafer for this purpose. The simulated and measured results are shown in figures 8&9. At mid-band the return loss and isolation is better than 30dB, while the insertion loss is approximately 0.5dB. Good agreement between simulation and measurement was obtained.

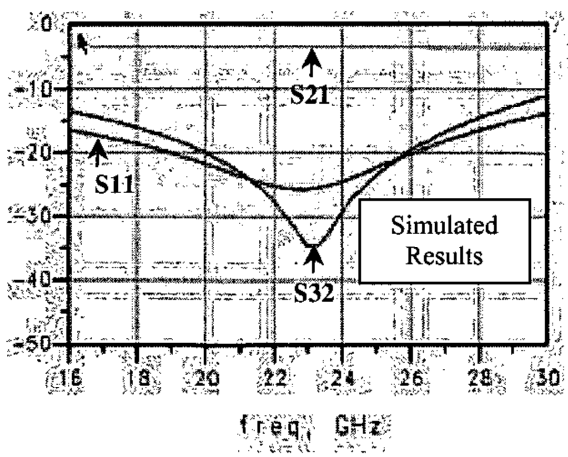

Figure 8: Simulated return losses coupling and isolation.

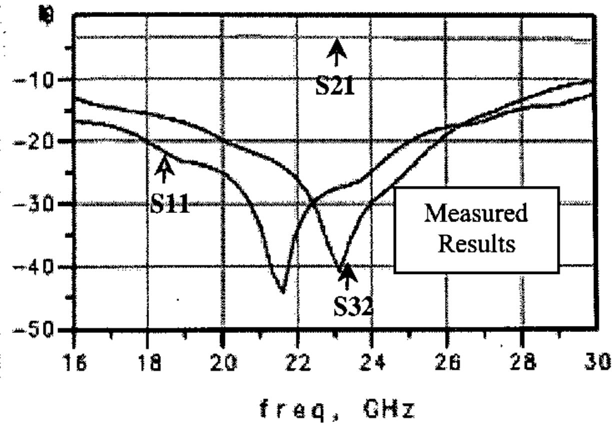

Figure 9: Measured return losses, coupling and isolation.

VI. CONCLUSION

In this work, the use of ACPS series stubs was investigated for size reduction of a Wilkinson combiner/divider. It was found that the design could be carried out using ideal transmission line models with good success. In this first attempt, approximate line length reduction of 35% was achieved but this may be possible to improve by adding additional series stubs in the ground plane.

VIII. REFERENCES

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