A NOVEL 3-WAY HYBRID COMBINER/DIVIDER FOR HIGH POWER C-CLASS MICROWAVE AMPLIFIERS*

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Abstract – Theoretical and experimental results of a novel 3–way tandem divider/combiner are presented. The device has hybrid properties and can be implemented on a low dielectric constant microwave substrate. The main advantages of the novel design are high power capability, low loss and good active return loss.

1. Introduction

Efficient power combining architectures in a high power microwave transmitter require non binary combining techniques due to the increased power gain of the presently available microwave C-class transistors. A 3:1 hybrid divider/combiner was required for a nonbinary combined 1 KW microwave unit amplifier.

Ideally, this coupler will duplicate the performance of the classic 2:1 overlay 90° hybrid coupler and should be easy to integrate in the amplifier's layout. Used as a combiner in C-class amplifiers, the coupler must have low loss, sufficient bandwidth and good active return loss. It must also be matched at the second harmonic of the operating frequency. When used as a divider, for driving class C transistors, the amplitude imbalance between the output ports of the coupler must be kept to a minimum.

The only known 3 way 90° coupler that has hybrid properties and can be implemented in a microstrip layout is the N-way branch coupler, which is a generalized form of the classic 2-way branch hybrid coupler [1], [2]. This N-way branch coupler can offer a good return loss and isolation over a few percent relative bandwidth only, it is highly reactive at the second harmonic of the operating frequency and has poor active return loss, which is not acceptable for C-class amplifiers.

The Wilkinson 3 way divider/combiner [3] has limited power performance and requires a tridimensional resistive balancing circuit. Good power capability is offered by the Gysel combiner [4], but this design does not have the important property of identical mismatch canceling. The chain combiner [5], [6] can offer good performance but the 3dB and 4.77 dB overlay couplers required, limit the peak power capability and can not be integrated in a microstrip layout.

Various other planar geometry have been explored in [7], [8], [9] to create a 1:N divider/combiner but the performances obtained are not satisfactory when compared to what is necessary in a microwave C-class amplifier.

2. New coupler architecture:

The problem is to find a coupler that is broadband, does provide good active return loss and can be implemented on a soft substrate $\varepsilon_r \leq 3$. This coupler must have a 3:1 combining/division ratio and should retain all hybrid advantages and properties.

What we are looking for is a design that also offers a low enough imbalance and VSWR under expected manufacturing tolerances to be adequate for C-class amplifiers and is easily manufactured using standard procedures. This will make possible the implementation of the 3:1 coupler directly into the amplifier's artwork.

Such a new coupler architecture is shown in fig.1. The new 3:1 coupler is formed by connecting in tandem two six port structures (three-line directional couplers, having a much looser coupling than -4.77dB),

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interconnected with three equal electrical length, 50 ohm lines. The three-line microstrip coplanar coupler was analyzed in the past by Pavlidis and Hartnagel [10] but no attempt was made to apply this structure to a nonbinary hybrid coupler circuit.

The new architecture presented in fig.1 will form a 3:1 hybrid coupler, regardless of the type of sixport coupler used (coax, stripline, microstrip). A much looser coupling is very beneficial, especially in microstrip, to obtain high power capability and a manufacturable circuit.

In order to design the new 3:1 hybrid coupler, we must find the required voltage coupling factor x between the center port and the side port of a three-line sixport, which will give 3-way equal power splitting, when used in tandem. This can easily be done by neglecting the length of connecting lines and the losses and considering the circuit voltages in the ideal case. By solving the equations shown in fig.1 in terms of x^2 (the power coupling coefficient) and discarding the negative solution, as we can not accept negative powers, we get:

$$x=0.3250 \qquad y=0.8880$$

$$K= 10*\text{Log}(x^2) = - 9.76 \text{ dB}.$$

We have obtained a coupling value close to -10 dB. Trying to implement a three-line circuit on a low dielectric substrate using three coplanar microstrip coupled lines will produce a very narrow gap between the conductors (less than 0.1mm) for 10 dB coupling. Last but not least, some sort of air bridge is necessary for connections between the crossing conductors, a highly undesirable situation. The way to eliminate this problem is to use a symmetrical, planar, overlay structure, as shown in fig.1. The crossing problem is solved in this case with a simple via. The result is a three-layer circuit with equal substrate height (H1=H2). Due to the way the two six ports are connected, the coupler has low sensitivity to registration error. As the two 50 ohm loads required are external and connected to ground, the 3:1 coupler has high power capability. Also, due to the increased distance between the overlay-coupled lines, the peak power capability is no longer limited by the substrate thickness.

The coupler geometry was analyzed using a planar EM simulator and the results obtained by simulation and measurement are presented in fig.2, 3. The agreement between the CAD data and the measurement is good and the second harmonic matching requirement is fulfilled. The three 50 ohm lines which interconnect the two dual directional couplers are chosen to be $\lambda/4$. Four vias are used to bring all ports on the top microstrip layer. This architecture can be used with a wide range of dielectric constants and substrate thickness.

The measured mismatch canceling is presented in fig.4 and the measured active return loss is presented in fig.5. Considering that the active return loss measured at one port is the result of vectorial summation of all possible contributions for that port (finite isolations, finite directivity, parasitic cross-coupling, etc), when all 3 input ports are excited with 3 properly phased, equal RF signals, the typical 26 dB value obtained, for the frequency band of interest, is outstanding. The above results are obtained for a 3:1 hybrid coupler made on 0.020”+0.020” Rogers 3003 dielectric substrate. The hybrid and the two 50 ohm loads occupy less than one square inch substrate area at S-band.

3. **Conclusions**

A new 3:1 hybrid coupler fit for microwave C-class amplifiers power combining / dividing was described. The new 3:1 coupler has the unique property of retaining all the classic 2:1 hybrid overlay coupler advantages, including the second harmonic match, and the ease of manufacturability. The coupler has been implemented on a soft dielectric substrate (Rogers 3003) and tested. The results are in excellent agreement with the CAD data. The coupler was successfully used in a 1KW C-class S-band unit amplifier developed for RADAR applications.

4. **References**

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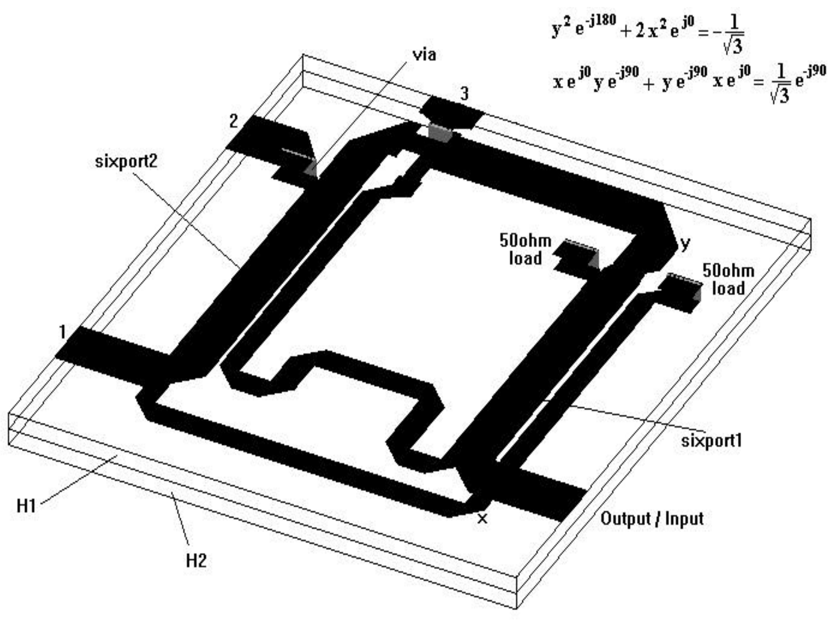

Fig.1

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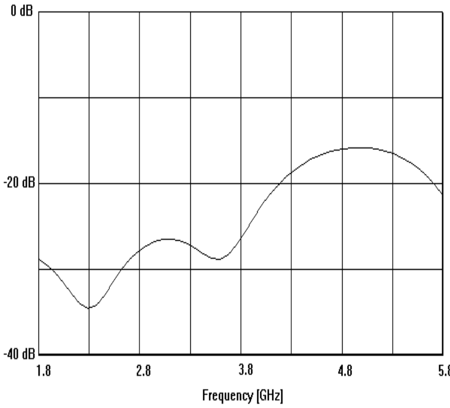

Fig.2a Simulated S22

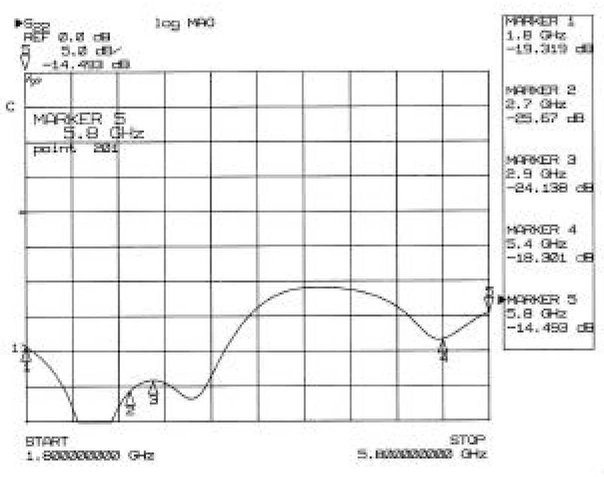

Fig.2b Measured S22

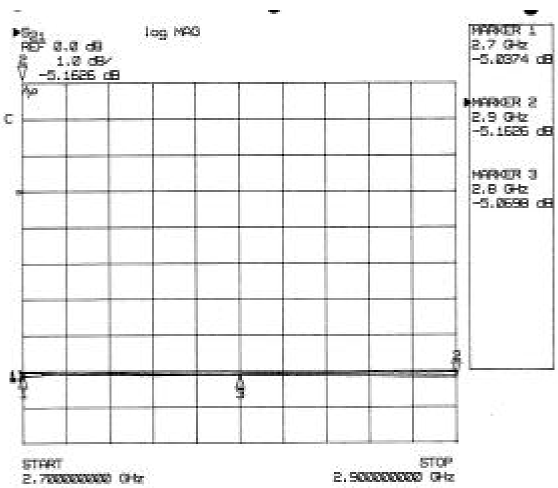

Fig.3. Measured S21, S31 and S41 superposed.

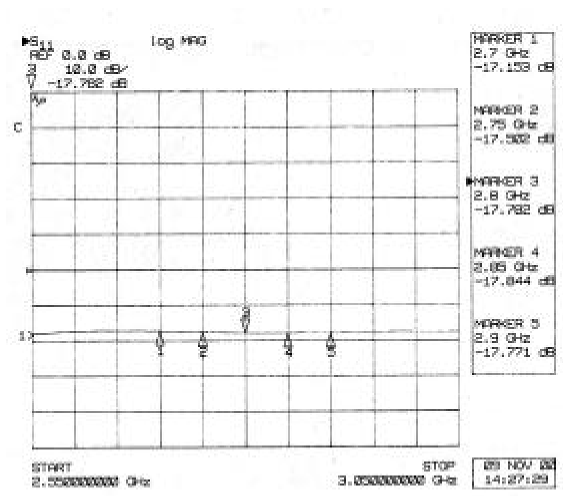

Fig. 4. Measured S11 (mismatch canceling, all 3 ports open)

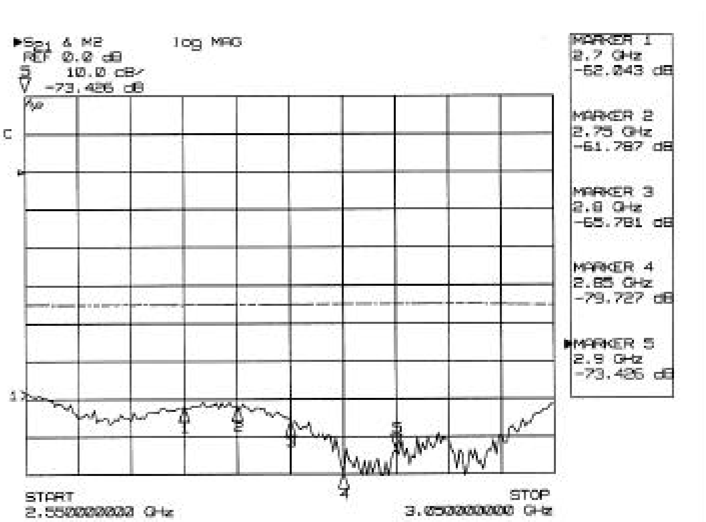

Fig.5 Measured active return loss (0 dB reference line at – 35 dB)