A COMPACT 8 - 14 GHZ LTCC STRIPLINE COUPLER NETWORK FOR HIGH EFFICIENCY POWER COMBINING WITH BETTER THAN 82% COMBINING EFFICIENCY

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Abstract

A compact coupler network for combining six high efficiency HBT power MMICs has demonstrated an 82% minimum combining efficiency (0.85 dB), typically greater than 87% (0.6 dB), over an 8.0 to 14.0 GHz frequency band. The combining network is a two-tier "vertically stacked" multilayer Low Temperature Cofired Ceramic (LTCC) stripline assembly and was designed with the aid of electromagnetic simulation and circuit modeling. This paper describes the design, fabrication and test of this combiner assembly.

Introduction

The power combining network described in this paper is a 6-way splitter/combiner network designed to combine the outputs of six high efficiency 25 ohm, 2W, HBT power MMICs [1] to achieve 10 watts output over an 8.0 to 14.0 GHz frequency band. This power amplifier assembly has application in an electronically scanned active array (ESAA) and is described in a separate paper [2]. The amplifier network is three balanced pairs of power MMICs combined in a 3 way serial fashion as shown in Figure 1. This network was chosen over the 6-way serial combining scheme previously described [3] because the balanced serial combiner provides a better return loss at the frequency band edges. Physical constraints in the module layout dictated by antenna element spacing and other module layout issues forced the splitter and combiner portions of the amplifier to be each fitted into a 0.140 inch width. To meet this requirement, a multilayer two-tier "vertically stacked" stripline Low Temperature Cofired Ceramic (LTCC) design was selected.

A preliminary effort to demonstrate the feasibility of the two-tier stripline design was completed and reported earlier [4]. This first effort, although achieving acceptable performance at the lower portion of the band, fell short of its insertion loss goal significantly at the high end of the band. The insertion loss of the combiner varied from about 0.6 dB to about 1.6 dB at the higher frequencies. Through EM field simulation and modeling it was subsequently determined that the design approach was sound and with several circuit modifications and careful modeling, the insertion loss goal could be met. This paper describes the design, modeling, and fabrication of this combiner network.

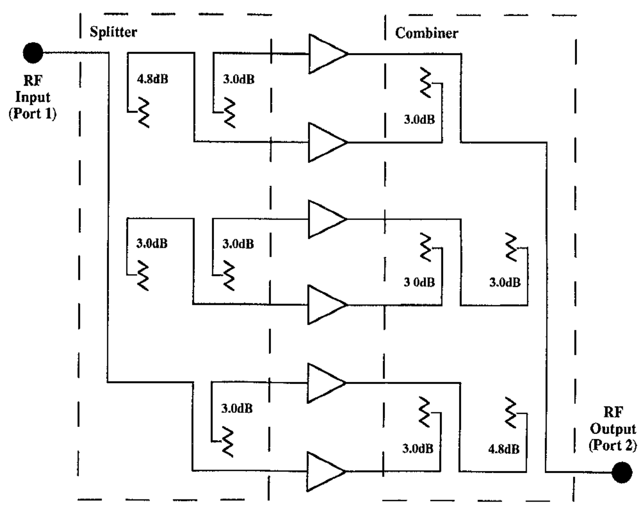

Figure 1. Amplifier Combining Network

Design Implementation

A stripline design using quarter-wavelength overlay couplers was chosen to realize the combining Network of Figure 1. The stripline substrate is a Low Temperature Cofired Ceramic (LTCC) material, Ferro type A6. The Ferro A6 LTCC has a relative dielectric constant of 5.9 and a loss tangent of 0.002. Each combiner (splitter) Network contains 5 couplers, one 4.77 dB coupler and four 3.01 dB couplers. The stripline circuit contains 11 layers, each layer is 0.0037 inches thick. The stripline ground plane spacing is 0.0407 inches. To realize the 3.01 dB coupler, 2 completely overlapping conductors spaced 0.0037 inches apart with conductor widths of 0.016 inches was required. This

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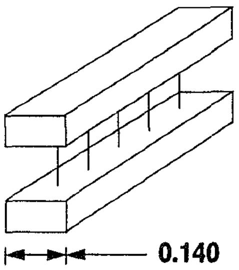
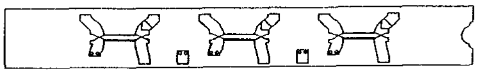
resulted in a coupler characteristic impedance of nominally 32 ohms. To realize the 4.77 dB coupler, two conductors 0.019 inches wide were offset by 0.010 inches. The 32 ohm impedance was maintained throughout the network with transformers at the amplifier ports (32 ohm to 25 ohm) and at the input/output ports (32 ohm to 50 ohm).

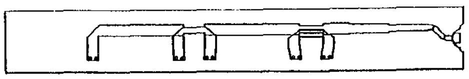
The packaging approach and circuit layout is shown in Figure 2. An LTCC two-tier stripline design was chosen for each splitter/combiner section to fit the required circuitry into the allotted 0.140 inches. The bottom stripline tier contains the three way serial combining portion of the network. The top stripline tier contains the remaining three 3.01 dB couplers. Specially designed stripline/stripline transitions using metal filled vias connect the top and bottom stripline circuits. The three stripline ground planes are connected with vias located along the perimeter of the substrate. The LTCC assembly is cofired to form a single integral substrate.



Two Tier LTCC Stripline



Top Stripline Circuitry



Bottom Stripline Circuitry

Figure 2. Stripline Assembly

Circuit Design and Modeling

The stripline network was designed with the aid of both circuit modeling using HP EESofs Touchstone (version 3.0) and EM field simulation using HP's High Frequency Structure Simulator (HFSS). The initial dimensions of the couplers were computed using Touchstone. Next, a HFSS model was created for each coupler design to include junction effects. The coupler line widths, line lengths and overlay offsets were varied in the HFSS model to optimize the coupler response for each design. Each coupler design was intentionally over-coupled at the band center frequency to benefit the coupling response of the band edges. The return loss at each of the coupler outputs was optimized by using capacitive tuning at the coupler junctions. The capacitive elements are metal vias extending from the top and bottom stripline ground planes to metal pads located over the coupler junctions. The HFSS model of one of the 3.01 dB coupler designs is shown in Figure 3. Figure 4 shows the modeled response of this coupler. All three coupler models achieved better than -25 dB return loss over the 8.0 to 14.0 GHz frequency band.

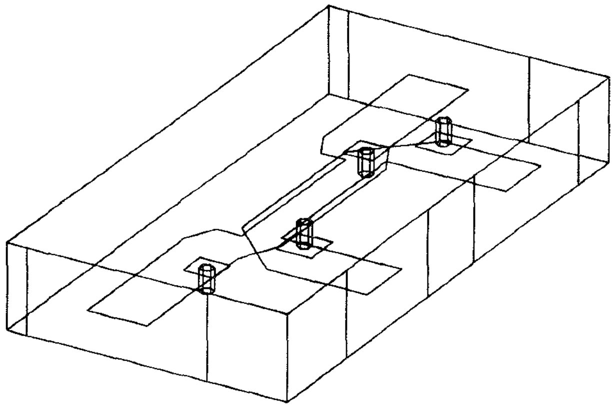


Figure 3. HFSS Coupler Model

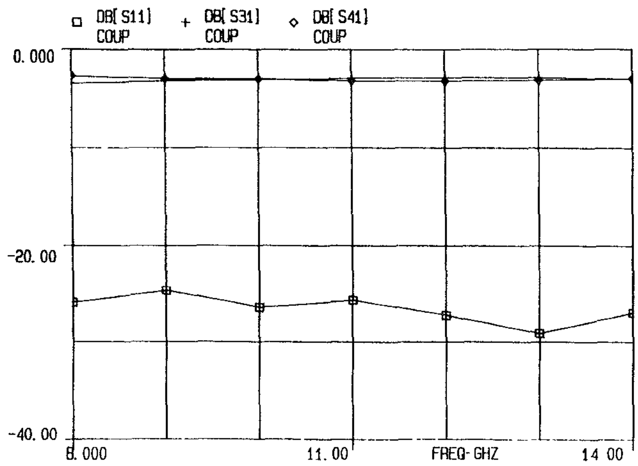


Figure 4. Coupler Modeled Response

Figure 5 shows a HFSS model of the stripline/stripline transition. The connection from one stripline to the other is made with two 0.008 inch dia vias which pass through an opening in the middle stripline ground plane. The dimensions of the opening, the distance between the transition vias and the row of ground vias located at the substrate edge, and the length of a narrow section of stripline near the transition vias were optimized for minimum reflection. The optimized return loss of the transition is better than -30 dB over the frequency band. The response is shown in Figure 6.

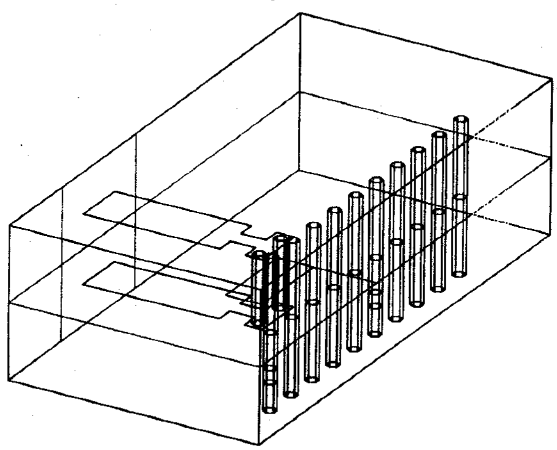


Figure 5. HFSS Model of SL/SL Transition

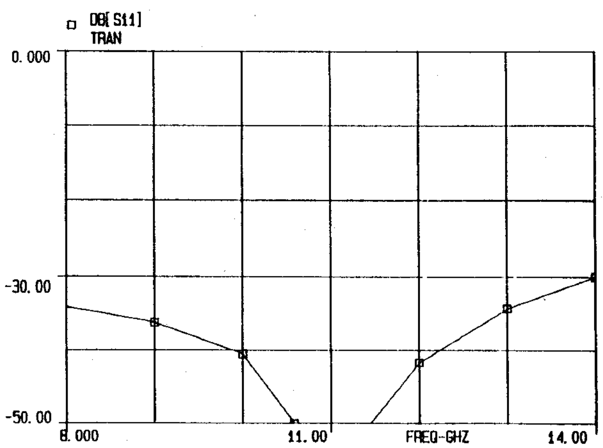


Figure 6. SL/SL Transition Modeled Response

Upon completion of the coupler and transition models the rest of the circuit was HFSS modeled. The model was built step by step. First a model of the serial combiner circuitry was built. Next, the stripline/stripline transitions were added, followed with the addition of the remaining 3 dB couplers. This process was continued until the final assembly was completed. At each step along the way the response was computed and corrections were made where needed. The HFSS model of the completed combiner assembly is shown in Figure 7.

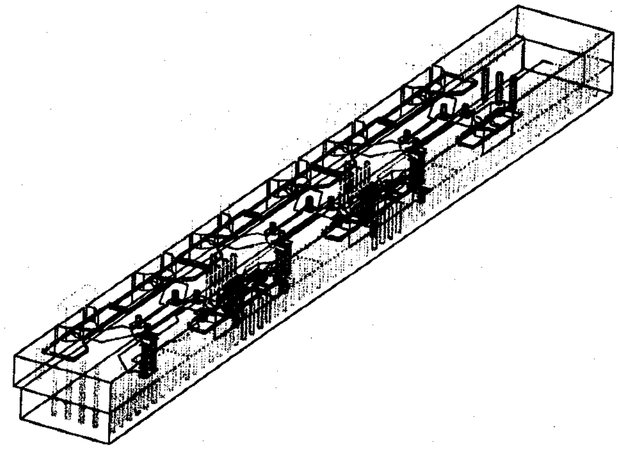


Figure 7. HFSS Stripline Combiner Model

Modeled Results

To predict the performance of the design, two combiner networks were modeled "back to back" with the outputs of the 1st network (splitter) tied directly to the inputs of the 2nd network (combiner). A Touchstone model, using the S-parameters generated by HFSS, computed the insertion loss response over frequency. The modeled response is shown in Figure 8. The computed insertion loss is about 0.25 dB over the center portion of the band falling to 0.8 dB at 8.0 GHz and 1.0 dB at 14 GHz. Adding an estimated 0.6 dB for the stripline dielectric and conductor losses, the splitter/combiner network losses vary between 0.85 dB and 1.6 dB. Assuming that one-half at this loss is in the combiner alone, the modeled combiner loss is 0.43 dB to 0.8 dB.

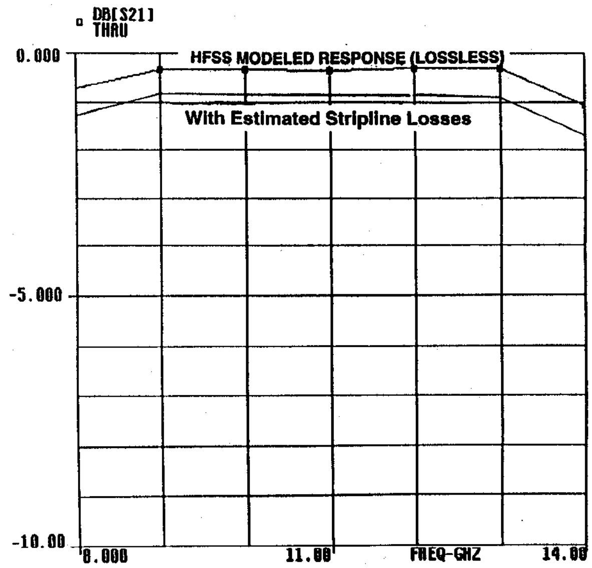


Figure 8. Splitter/Combiner Modeled Response

Measured Results

Two combiner (splitter) substrates were mounted back to back and measured over the 8.0 to 14 GHz frequency band. A photograph of the assembly mounted in its test fixture is shown in Figure 9. The measured response is shown in Figure 10. The insertion loss measured from 1.7 dB at the low end of the band and varied from 1.0 to 1.3 dB over the remaining frequencies. The measured response was within 0.5 dB of the modeled at the low end of the band and was within 0.2 to 0.3 dB over the middle and upper end of the band. The combiner loss is therefore less than 0.85 dB maximum and better than 0.6 dB over most of the band.

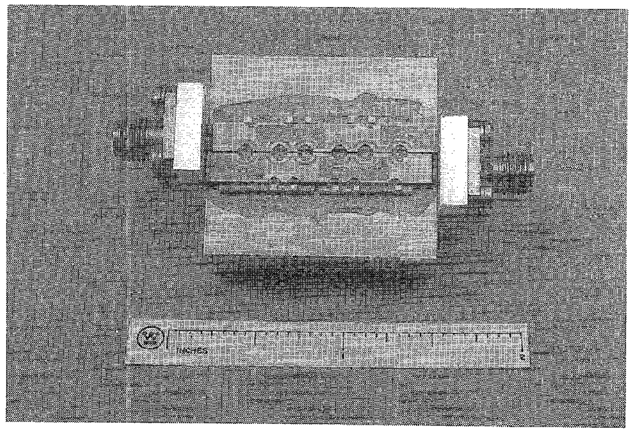


Figure 9. Splitter/Combiner Assemblies Mounted Back to Back in Test Fixture

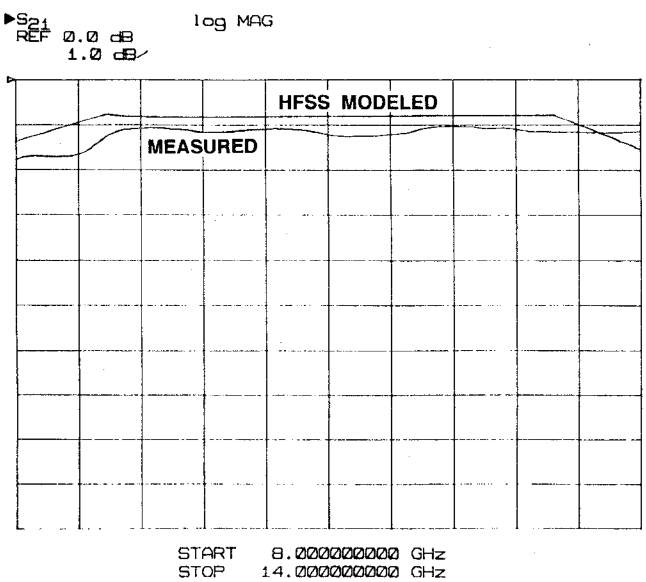


Figure 10. Splitter/Combiner Back to Back Measured Performance

Summary and Conclusions

A compact two-tier multilayer stripline combining network using LTCC was designed and fabricated. The combiner was designed with the aid of EM simulation and modeling using HP's HFSS. Good agreement was found between the measured and modeled performance. A combining loss of 0.85 dB or better, typically 0.6 dB or less, was achieved for a six-way power combiner over an 8.0 to 14.0 GHz frequency band. The technique is well suited for combining high efficiency power MMICs.

References

[1] F. Ali, A. Gupta, M. Smith, B. Veasel, D. Dawson "A 25 ohm 2W, 8-14 GHz HBT Power Amplifier MMIC with 20 dB Gain and 40% Power Added Efficiency". IEEE 1994 Microwave and Millimeterwave Monolithic Circuits Symposium Digest pp 113-115.

[2] G. Ferrell, L. Dickens, J. Gipprich, R. Hayes and F. Sacks "A High Efficiency 10 Watt Power Amplifier Assembly Using Combining Techniques" 1995 IEEE MTT-S International Microwave Symposium Digest

[3] J. Gipprich, L. Dickens, and J. Faulkner "A Power Amplifier yields 10 watts over 8-14 GHz using GaAs MMIC's in a LTCC serial combiner/divider network." 1993 MTT-S International Microwave Symposium Digest Vol. 3 pp 1369-1372.

[4] Gipprich, L. Dickens, R. Hayes, M. Restivo "A Compact LTCC Multilayer Multiport Stripline Coupler Network for Low Loss Power Combining/Splitting" IEEE 3rd Topical Meeting on Electrical Performance of Electronic Packaging, Nov. 2-4, 1994, pp 167-169.