A POWER AMPLIFIER YIELDS 10 WATTS OVER 8 - 14 GHZ USING GAAS MMICS IN AN LTCC SERIAL COMBINER/DIVIDER NETWORK

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Abstract

The main thrust of this work was to develop a high efficiency N-way combining scheme consistent with the physical geometries associated with X and Ku band active apertures. A 12-way combiner utilizing stripline serial feed networks in Low Temperature Cofired Ceramic (LTCC) was designed, fabricated and tested over an 8-14 GHz bandwidth. This combiner was integrated with 6 dual channel 1 watt MMICs to achieve 10 watts peak output power with greater than 86% combining efficiency at center band. The results of this work are described within this paper.

Introduction

Electronically scanned active array antenna applications such as weather monitoring, windshear/microbursts, terrain avoidance/ground mapping and high resolution imaging radar call for very wideband performance of both the transmit (Tx) and the receive (Rx) functions. The large numbers of T/R channels comprising these active arrays drives the designer to the lowest cost solutions for the Tx power amplifier functions. Concomitant with the requirement of low cost is the requirement for attaining very high performance within physical constraints dictated by operating frequency, antenna element spacing, prime power availability and system heat removal (cooling) capacity. The simultaneous solution to low cost and high performance power amplifiers is achieved by utilizing high yielding low power MMICs with low loss combining techniques.

Approach

The amplifier herein presented attains very broadband performance combining six dual channel MMICs with a 12-way serial combiner in a configuration which supports the transmit function of an active array with element spacings of less than 0.50 inches. Typically, these power amplifiers have used several transistors combined in parallel by several binary levels of microstrip Lange couplers to achieve the required output power. This arrangement is shown in figure 1. This "pyramid" structure which results is extremely disadvantageous because the resulting aspect ratio of the surface area deviates drastically from that required for a "behind the element" location. The signal divider/combiner scheme just described is usually called the "corporate" structure.

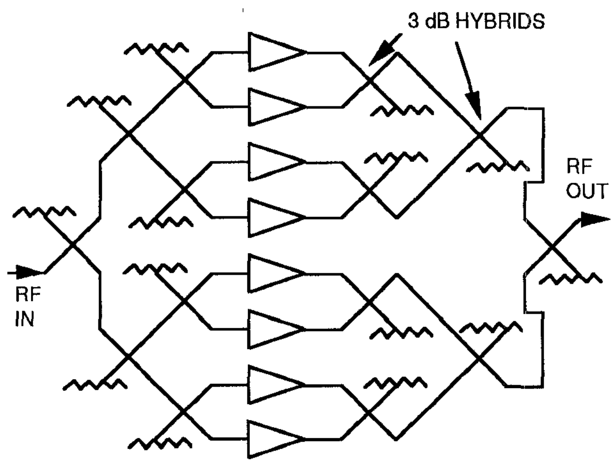

Figure 1. Corporate Splitter/Combiner

Figure 2 presents an amplifier layout more appropriate to the "behind the element" location because the width is unaffected by the number of combined MMICs. The figure shows the associated coupler structure which uses the "serial" divider/combiner scheme for an 8 way network comparable to the corporate scheme shown in figure 1. This configuration has somewhat lower loss than the corporate structure of figure 1 because the mean path length for the amplifier MMICs is less resulting in lower I^2R losses. In addition, the serial structure is not forced to meander into a central feed point as the corporate structure. This meander often leads to radiating discontinuities which result in additional losses.

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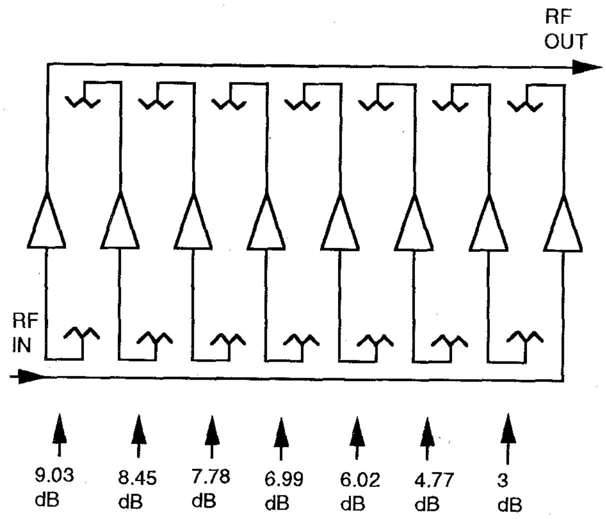

Figure 2. Serial Splitter/Combiner

A wide band power amplifier was designed, fabricated and tested using this series feed technique in conjunction with GaAs MMIC power amplifiers. The GaAs MMIC chosen for the wideband power amplifier was the Raytheon RMM 2060 Power Amplifier Chip. The 2060 is a broadband (6-18 GHz) fully matched dual channel amplifier integrated on a single GaAs substrate. Each channel is comprised of 4 stages of amplification with a gain of 18 dB and an output power of +29 dBm at the 2 dB compression level. Over the 8-14 GHz bandwidth, each channel typically provides an output power greater than 1 watt. To achieve 10 watts of power output, six dual channel chips are combined using the serial divider/combiner network. The high gain nature of the power amplifier minimizes the effect of the splitter losses on the power added efficiency of the overall 10W power amplifier. The distributed nature of the first two stages in the 2060 provide an excellent input VSWR to the chip. The low input VSWR coupled with the uniformity of S parameters, in particular an insertion phase uniformity of $\pm$10 degrees among the 6 chips, reduces the interaction of the chips with the splitter/combiner and enhances the overall combining efficiency.

The substrate selected for microwave signal, as well as DC bias and drain power distribution was a Low Temperature Cofired Ceramic (LTCC) substrate made of multi-layered laminations. The microwave signal layers are well shielded and isolated within the LTCC substrate. The GaAs MMICs are mounted in pockets (cutouts) in the LTCC. The use of the LTCC provides exceptional isolation in critical areas and results in absolute stability of the module (no tendency to oscillate under any condition of termination at any operational temperature).

The LTCC microwave signal distribution circuitry is shown in Figure 3. The LTCC material chosen for this design is the DuPont type 845 which has a dielectric constant of 4.8 and a loss tangent of .004. The divider/combiner networks are 12 way power split circuits using six-way serial distribution and two-way parallel combining. The six-way networks are five overlay stripline directional couplers arranged in a serial fashion to provide six equal amplitude signals at the outputs. The couplers were designed for a .042 inch ground plane separation and a .0039 inch conductor spacing. The amount of coupling for each coupler was controlled by the amount of offset from the main coupler line.

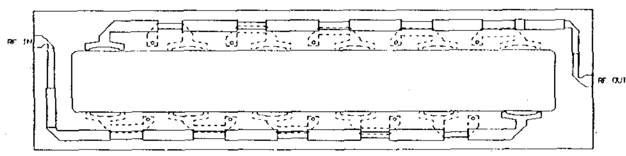

Figure 3. LTCC Stripline Splitter/Combiner

Figure 4 shows the multilayer LTCC assembly. The substrate contains 15 layers of ceramic, each layer is .0039 inch thick. The bottom of the substrate is metallized and serves the bottom stripline ground plane. The top of the fifth layer contains the main line feeding the coupler network. The coupler circuitry is located above on the top of the sixth layer. The top stripline ground plane is located on the eleventh layer. The next four layers contain the gate lines, a ground plane for isolation, the drain lines, and a top ground plane respectively. Cofired vias connect the buried DC bias and power lines to the top surface where connections to the GaAs chips are made. Decoupling capacitors are mounted to the top surface. The amplifier chips which are mounted on CM-15 carriers for thermal spreading, are mounted onto chassis ground through a cutout in the LTCC substrate.

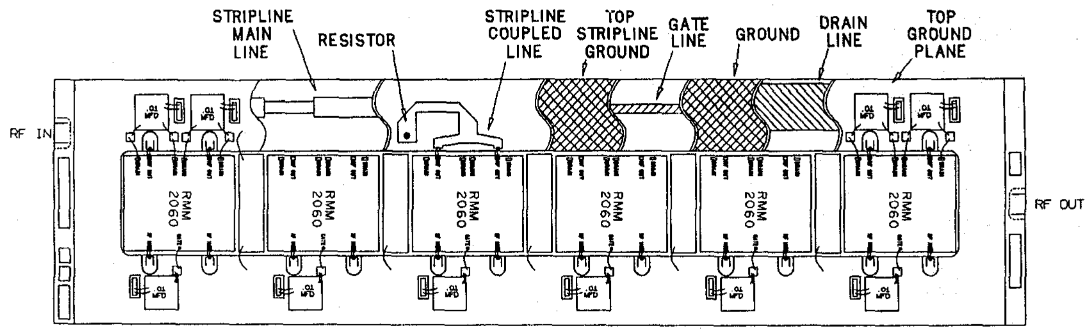

Figure 4. LTCC Multilayer Assembly

Results

The divider/combiner network was tested prior to insertion of the amplifier chips to determine the combining efficiency. 50 ohm microstrip lines were placed in the locations of the amplifier chips. The insertion loss was measured for the "back to back" divider/combiner network as a function of frequency. The measured insertion loss was less than 1.3 dB of the band center and about 1.8 dB at the edges of the 8-14 GHZ band. The combiner loss (assumed to half of the total loss) is .65 dB and .90 dB at the center and band edges respectively. The Measured losses agree well with the predicted losses modelled using Touchstone. The measured results are shown in figure 5.

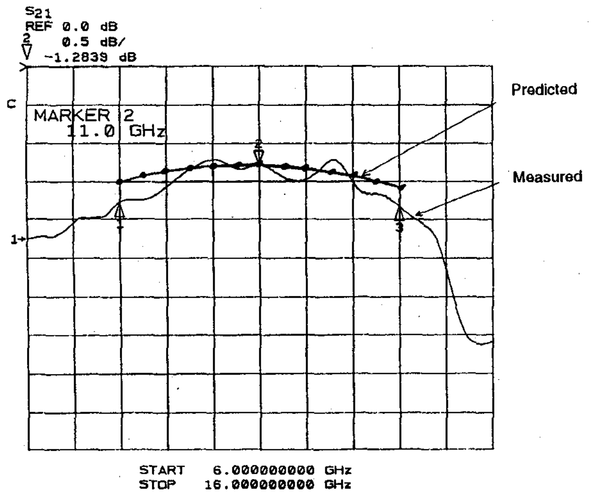

Figure 5. Measured Stripline Back to Back Insertion Loss

Figures 6 and 7 show the amplifier assembly mounted on a test fixture and mounted in a conventional X-ku band module package. The test fixture includes in addition to the power amplifier, a driver stage, gate regulators, drain regulator/modulators, and storage capacitors for pulse operation. The tests were run at 25°C for peak input levels of -5 dbm to +8 dbm. The RF signals were pulsed at a duty cycle of 1% and a pulse width of 10 microseconds. The performance shown in Figure 8 was achieved with no RF tuning. Greater than 10 watts (+40 dbm) was achieved over most of the band from 9 to 13 GHz dropping slightly below 10 watts at the 8-14 GHz band edges. The measured power at 8 and 14 GHz was 39.8 dbm and 39.6 dbm respectively.

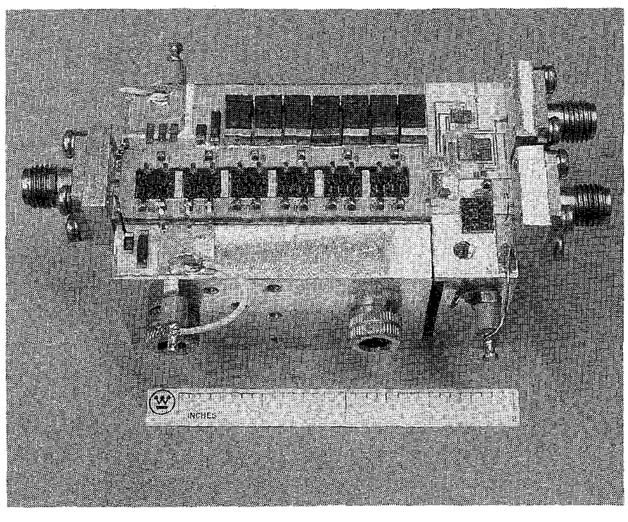

Figure 6. 10w Power Amplifier Assembly

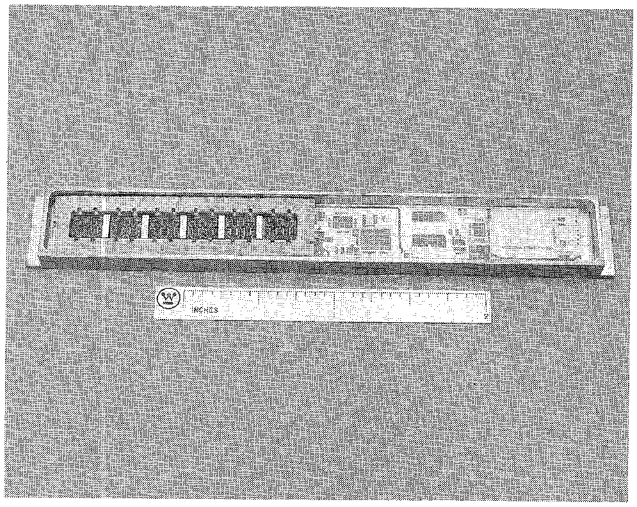

Figure 7. 10w Power Assembly in X-Ku T/R Package

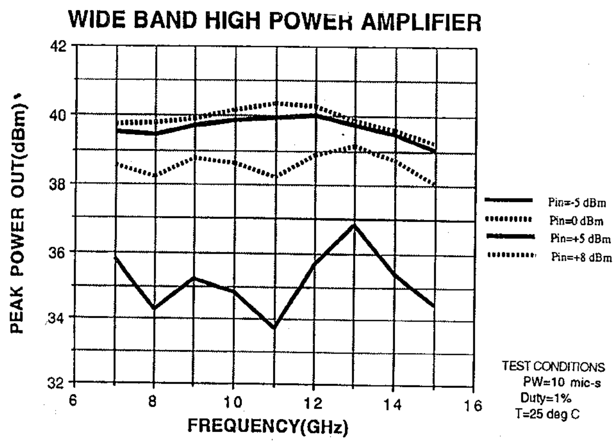

Figure 8. Measured 10w Power Output

Summary

A 10 watt power amplifier with greater than 81% combining efficiency was demonstrated over the 8-14 GHz bandwidth. The amplifier required no RF tuning and met the physical dimensions required for an X-Ku band active array module.