High Efficiency 80W X-Band Power Amplifier using Coaxial Waveguide Spatial Power Combining Technique

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***Abstract* — As the commercially available microwave monolithic integrated circuit (MMIC) amplifiers improve in output power and bandwidth a compact platform to combine a large number of these MMICs becomes very desirable. A reduced size version of a coaxial waveguide combiner structure using an antipodal finline antenna array is investigated. The reduced size coaxial waveguide combiner structure is used to demonstrate an 80 Watt power amplifier at X-Band by combining 16, 6 Watt MMIC devices and the scalability of the overall combiner platform. Around 30% efficiency has been achieved for most of the band.**

***Index Terms* — Antipodal finline, high efficiency, MMIC, power amplifiers, spatial power combining, X-Band.**

I. INTRODUCTION

CAP Wireless has used a coaxial waveguide spatial power combining structure to combine 16 MMIC amplifiers over the full 2 to 20 GHz bandwidth in its first generation, patented “Spatium” power amplifiers. The first generation spatial power combiner is currently in production, and used as a platform for both a 2 to 20 GHz 10 Watt power amplifier and a 6 to 18 GHz 35 Watt power amplifier, by combining 16 commercially available MMIC amplifiers. The 2 to 20GHz 10 Watt power amplifier has demonstrate high output power and extremely good gain flatness (less than +/-1 dB) across the entire 2 to 20 GHz range [1]-[2]. The performance proves the coaxial waveguide spatial power combining structure is ideal for large scale power combining over multi-octave bandwidths. Fig. 1 shows the overall combining structure.

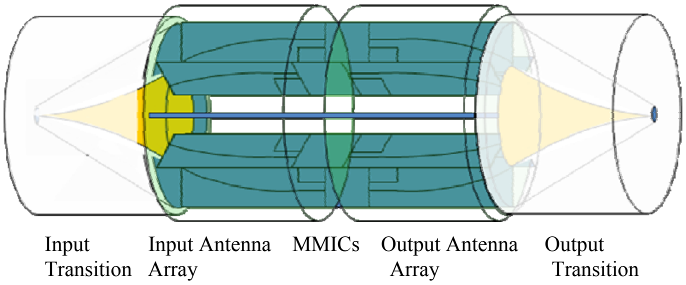

Fig. 1. Coaxial Waveguide Spatial Power Combining Structure.

But demand for reduced size drove the development of the second generation coaxial waveguide spatial power combiner targeted at X-Band applications. There are two transitions that are the main factors in the length of the combining structure. The first is the transition from a microstrip line at the output of the MMIC amplifier to an antipodal finline antenna on each of the 16 wedge shaped trays. Next the oversized coaxial waveguide output must be transitioned down to a standard 50 Ω connector. The two transitions are mirrored on the input as a 16 way divider and on the output as a 16 way combiner. Both of these transitions increase in length as the bandwidth increases, especially as the low end cutoff frequency reduces. The outer dimension of the first generation Spatium power amplifiers is 2.81” x 3.00” x 9.90”, and achieves a usable bandwidth from 2 to 20 GHz. The second generation Spatium has dimensions of 2.40” x 2.40” x 5.00”, and has a usable bandwidth of 4.5 to 20 GHz, both are shown side by side in Fig. 2. The major size reduction moving from the first to the second generation Spatium power amplifiers was in the length, since the low end cutoff frequency in the second generation is over a full octave in bandwidth higher in frequency. The diameter of the coaxial structure was reduced but by a much smaller factor than the length because the overall diameter in the center of the structure is constrained by the size of the packaged MMIC amplifier and appropriate biasing components.

Fig. 2. First and Second Generation Spatium Power Amplifiers.

II. Coaxial Waveguide Spatial Power Combining Structure

The coaxial waveguide spatial power combining structure consists of 16 wedge shaped trays, as shown in Fig. 3, arranged in a radial pattern around a center post. Each assembled tray consists of an wedge shape aluminum carrier that creates the coaxial structure to confine the electromagnetic field. Mounted on each tray is a duroid PCB that has the antipodal finline to microstrip transition shown in Fig. 4. The transition rotates the radially directed electric field from the coaxial waveguide structure at point (a) in Fig. 4 by 90 degrees to be compatible with the microstrip by the time it reaches point (c) in Fig. 4. The other element of each tray is an HTCC package that is resonance free from DC to 20 GHz, shown in Fig. 5. The package is solder attached to the PCB and has a 50 Ω microstrip line on an alumina substrate to take a passive measurement and the same package will be used to package the active MMIC amplifiers.

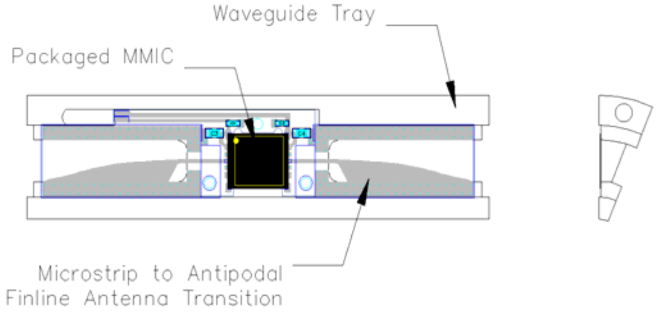

Fig. 3. Assembled Tray.

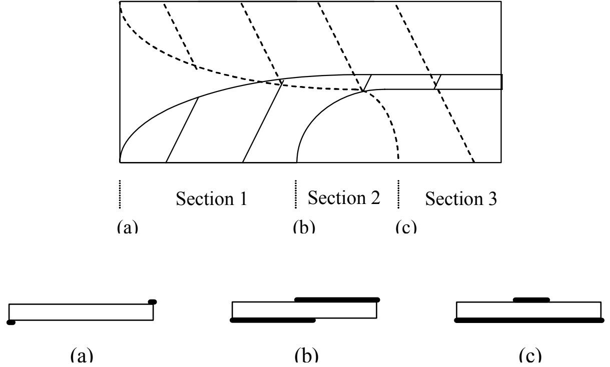

Fig. 4. Antipodal Finline to Microstrip Transition.

A tapered cone is then attached to either end of the center post, starting at the inner diameter of the oversized coaxial waveguide and narrowing down to the pin that becomes the center conductor for the 50 Ω connector. The taper on this cone is optimized to provide the transition from the coaxial waveguide to the 50 Ω connector over the desired bandwidth. A larger end cap is then placed over the tapered inner cone to provide the outer conductor for the coaxial structure. Two clamps are then used to hold the trays together to ensure good electrical contact between adjacent trays, and also to provide a flat surface to which heatsinks can be attached to cool the amplifier. Fig. 6 shows the second generation of the Spatium with the outer cone removed to showing the inner cone.

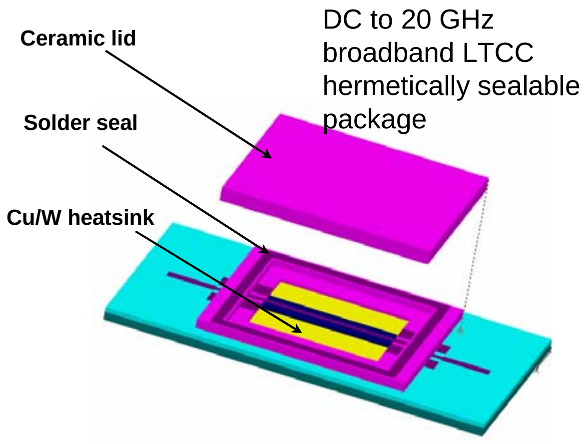

Fig. 5. DC to 20 GHz LTCC Hermetically Sealable Package.

Fig. 6. Assembled Second Generation Spatium with End Cap Removed.

Once the second generation Spatium structure was fabricated the passive structure was tested to verify the performance met the simulation data and that the combining efficiency would be around 90% across the full 8 to 12 GHz X-Band. In measuring the passive performance of the structure each of the 16 wedge shaped trays was assembled with a package with a 50 Ω thru line on an alumina substrate instead of the MMIC amplifier. The loss of this structure was then measured along with the loss of a package with a 50 Ω thru line on a fixture. The fixture is just the center portion of the PCB that is mounted on each of the 16 wedges with 50 Ω microstrip input and output. This PCB is mounted to and aluminum block and edge mount SMA connectors are attached to the input and the output for the measurement. Fig. 7 shows the thru loss of the complete Spatium structure with the active MMIC amplifiers replaced with the thru packages on the trays along with the loss of a thru package on a fixture. It is shown that the loss of the passive structure is very flat across the full 8 to 12 GHz X-Band with less than 1 dB of variation.

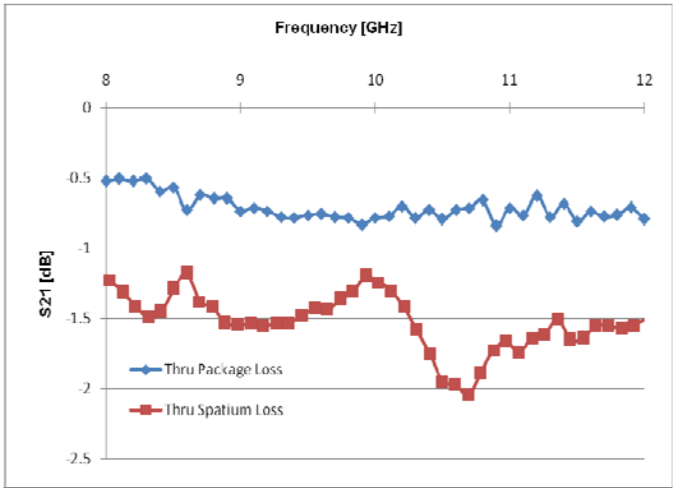

Fig. 7. Loss of Passive Spatium Structure and Fixtured 50 Ω Package.

Using the measurements shown in Fig. 7 the combining loss and the combining efficiency can be calculated for the Spatium structure. It must be pointed out that the measurement of the thru Spatium loss in Fig. 7 is a combination of both, splitting of the power at the input and recombining on the output, as well as the losses associated with the thru package mounted on each tray in place of a MMIC. The calculation of the output combining loss is done by subtracting the measured loss of the thru package on a fixture from the measured loss on the complete Spatium with thru packages on each of the 16 trays and then dividing that result in half. The result is divided in half because the Spatium structure is symmetrical on the input and the output so half the loss will be due to the 16 way splitter on the input and the other half will be due to the 16 way combiner on the output. The results are shown in Fig. 7.

Fig. 8 shows the loss associated with combining the output power of 16 MMIC amplifiers in the second generation Spatium structure. Nominally the structure can provide 90% combining efficiency and only has +/- 0.25 dB of ripple in the combining loss across the full X-Band, 8 to 12 GHz. This is very close to what was expected from the passive structure. The structure must also be verified to maintain this performance when the thru packages are replaced with active devices.

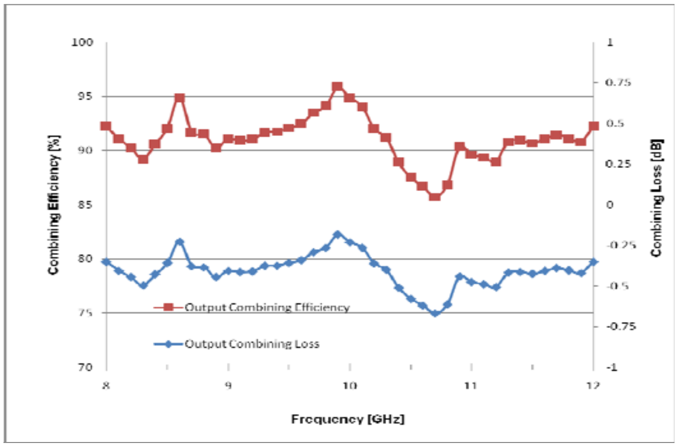

Fig. 8. Spatium Combining Efficiency and Combining Loss.

III. Power Amplifier Small Signal Performance

The MMIC chosen for this application is tuned primarily for the 9.0 to 10.5 GHz portion of the X-Band, but it has usable gain and power from 8.0 to 11.0 GHz. It has about 19 dB small signal gain and 6 watts of output power over the tuned bandwidth. The small signal performance of both the Spatium with a MMIC on each of the 16 trays and a fixtured MMIC are shown in Fig. 9. The small signal measurements show that the passive losses of the Spatium structure are less than 1 dB, which is consistent with the measurements taken with a completely passive structure.

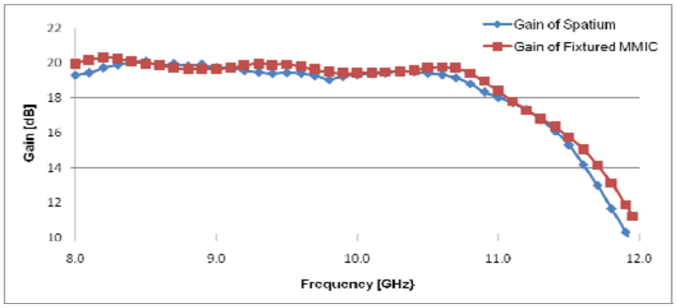

Fig. 9. Small Signal Gain of Fixtured MMIC and Spatium.

IV. Power Amplifier Large Signal Performance

The large signal measurement was taken using a driver with greater bandwidth than the MMIC chosen for the Spatium to ensure that there will be plenty of driving power to measure the saturated power outside of the 9.0 to 10.5 GHz bandwidth that the MMIC is primarily tuned for, as the gain of the MMIC amplifier decreases outside of this bandwidth especially above 11 GHz. Fig. 10 shows the saturated output power and drain efficiency of the Spatium amplifier over the full 8 to 12 GHz

X-Band. The amplifier was driven 3 dB into compression to reach full saturation. The Spatium has a saturated output power of greater than 80 watts from 9.1 to 10.8 GHz peaking at 9.2 GHz with 88.5 watts of output power. The low end rolling off to 64.9 watts at 8 GHz and the high end rolls off to 50 watts by 11.3 GHz and down just over 20 watts by the time the high end of X-Band is reached. The drain efficiency of the Spatium is greater than 30% for the tuned 9.1 to 10.8 GHz bandwidth.

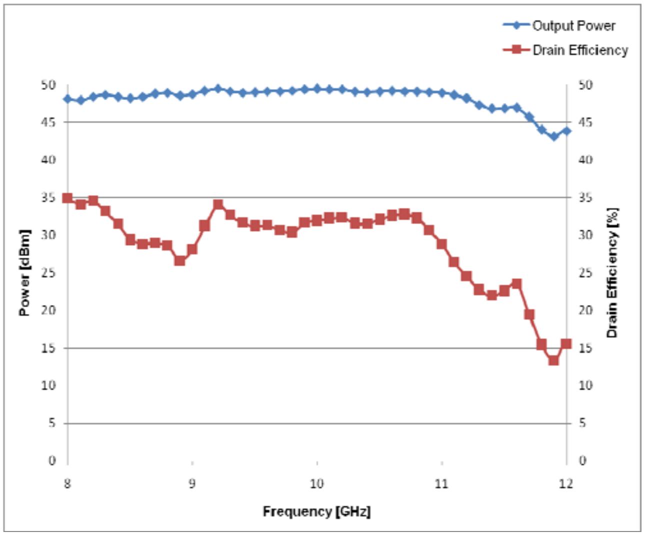

Fig. 10. Saturated Output Power and Drain Efficiency of the Spatium.

V. SPATIUM COMBINER PLATFORM FLEXIBILITY

The Spatium structure provides a very flexible combiner platform to work with and can continue to be reused or scaled as newer MMIC devices become available, with increased bandwidth and power. The second generation Spatium demonstrates a broadband coaxial combining structure that has a usable bandwidth from 4.5 to 20 GHz, and demonstrates that the Spatium structure can be scaled down in size as long as a reduction in bandwidth is acceptable. This presents a basic platform from which many variations of bandwidth and power can be produced with just a change of the MMIC used in the combiner structure.

The main challenge in going to higher power levels comes in the thermal management of the Spatium. The increase in output power means an increase in the amount of heat that must be dissipated to keep the junction temperatures of the MMIC devices at a level to not compromise the reliability of the amplifier. This problem is compounded when trying to simultaneously increase the output power level as well as the bandwidth, since the increase is bandwidth will generally drop the efficiency of the MMIC amplifier. The first and second generation Spatium amplifiers use aluminum trays; changing to a higher thermally conductive material, such as copper, will help to dissipate the heat produced by the MMIC amplifiers more efficiently.

VI. CONCLUSION

A second generation broadband coaxial waveguide power combiner is demonstrated. A high efficiency X band power amplifier is presented using the combining structure and 16 MMIC amplifiers. The combining structure is scalable for a wide array of applications, both broadband and narrowband. The structure itself has a usable bandwidth from 4.5 to 20 GHz. Across the full 8 to 12 GHz X-Band the combining loss ripple for combining 16 MMIC amplifiers in this structure is just +/- 0.25 dB. The particular power amplifier shown in this paper produced greater than 80 Watts of output power at around 30% efficiency over 40% of the X-Band.

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