WHITE PAPER

120 W Ka Band Power Amplifier Utilizing GaN MMICs and Coaxial Waveguide Spatial Power Combining

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Abstract

The availability of increasingly higher power commercial microwave monolithic integrated circuit (MMIC) amplifiers enables the construction of solid state amplifiers achieving output powers and performance previously achievable only from traveling wave tube amplifiers (TWTAs). A high efficiency power amplifier incorporating an antipodal finline antenna array within a coaxial waveguide is investigated at Ka Band. The coaxial waveguide combiner structure is used to demonstrate a 120 Watt power amplifier from 27 to 31 GHz by combining quantity (16), 10 Watt GaN MMIC devices; achieving typical PAE of 25% for the overall power amplifier assembly.

Index Terms: Antipodal finline, MMIC, power amplifiers, spatial power combining, Ka Band.

I. Introduction

CAP Wireless Inc. was originally granted a patent for a broadband power combining structure utilizing an antipodal finline antenna array in a coaxial waveguide in 2007. This embodiment has since been trademarked, Spatium® amplifier. The original platform developed was a 16 element combiner structure utilizing commercially available GaAs MMIC amplifiers to produce a 2 to 20 GHz 10 W power amplifier[1]-[2]. This combiner platform has since been used to create the following power amplifiers; at various frequencies and power levels utilizing various GaN and GaAs commercially available MMICs from Qorvo.

- 6 to 18 GHz, 35 W
- 2 to 6 GHz, 300 W
- 2 to 18 GHz, 40 W
- 2 to 18 GHz, 100 W

Figure 1. 16 Way Spatium Power Amplifiers.

The original platform was the first of five broadband power combiner platforms that have been demonstrated utilizing Spatium® technology; the other four are listed below.

- 4.5 to 20 GHz, 16 Elements
- 4.5 to 20 GHz, 10 Elements
- 7.5 to 15 GHz, 16 Elements
- 10 to 40 GHz, 16 Elements

These platforms allow for the combination of a large number of MMIC amplifiers covering up to multi octave bandwidths from 2 to 40 GHz with high combining efficiency. The 10 to 40 GHz platform is suitable for use in power amplifiers for satellite communication and electronic warfare applications at Ka Band. The high efficiency combining methodology coupled with the advancements in GaN MMIC technology enable solid state amplifiers to achieve output power levels at Ka Band previously only obtainable by traveling wave tube amplifiers. Figure 1 shows the 2 to 20 GHz, 4.5 to 20 GHz, and the 10 to 40 GHz sixteen element platforms side-by-side.

II. Coaxial Waveguide Spatial Power Combining Structure

The five Spatium® amplifier platforms developed to date are all based on the same scalable architecture shown in Figure 2. The input transition and the output transition along with the input antenna array and the output antenna array are longitudinally mirrored structures in all embodiments of the combiner. This does not have to be true, but has been due to ease of design in utilizing identical splitters and combiners in a given power amplifier assembly.

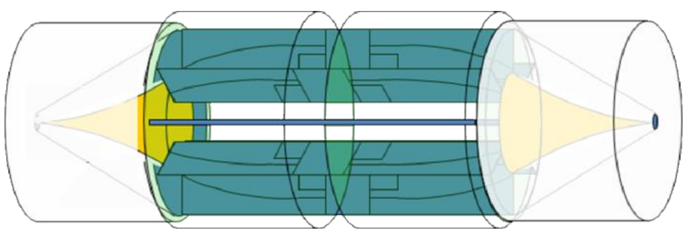

Figure 2. Coaxial Waveguide Spatial Power Combining Structure.

The coaxial waveguide spatial power combining structure consists of as many wedge shaped blades, as shown in Figure 3, as elements to be combined arranged in a radial pattern to create the antipodal finline array within

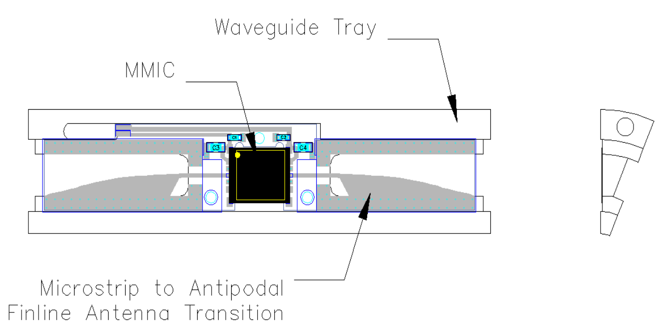

Figure 3. Assembled Blade.

the coaxial waveguide. Each assembled blade consists of a wedge or pie shaped aluminum or copper carrier. The blades are put together in a cylindrical configuration creating the coaxial structure to confine the electromagnetic field. Mounted on each blade is a microwave laminate PCB that has the antipodal finline to microstrip transition shown in Figure 4. The transition rotates the radially directed, TEM, electric field from the coaxial waveguide structure at point (a) in Figure 4 by 90 degrees to be compatible with the microstrip by the time it reaches point (c) in Figure 4. Once the transition is made to microstrip the mid-section of the blade assembly can be populated with any amplifier assembly that is compatible with 50 Ω microstrip.

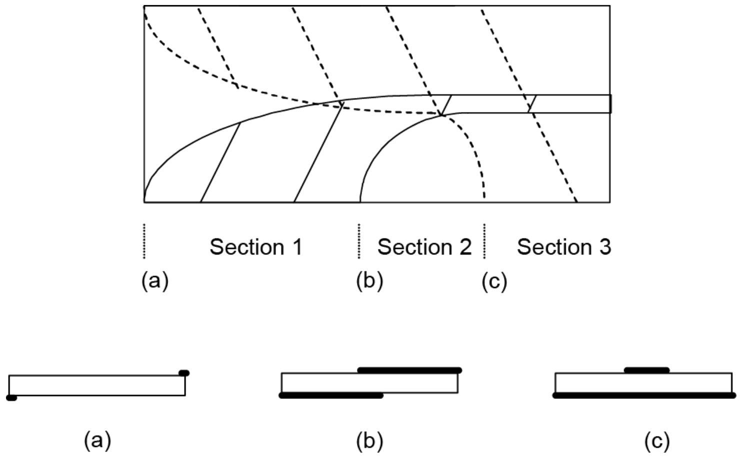

Figure 4. Antipodal Finline to Microstrip Transition.

A threaded center post slides down the center of the cylinder created by the assembled blades. A tapered cone is then attached to both ends of the center post; the taper transitions from the inner diameter of the oversized coaxial waveguide and narrows 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, outer cone, is then fixed in place over the tapered inner cone as the outer conductor for

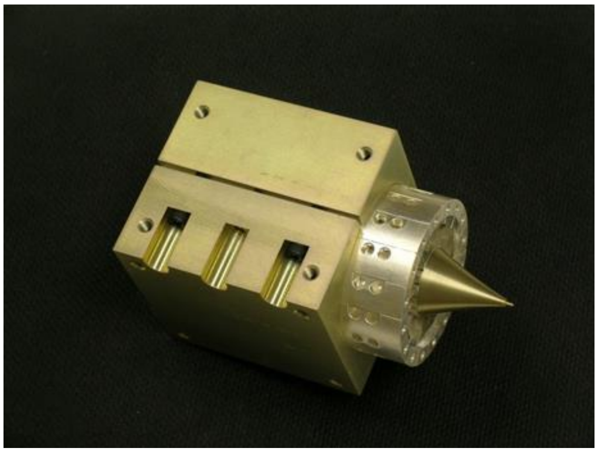

Figure 5. Assembled Spatium with Outer Cone Removed.

the coaxial structure. The cylindrical structure is then clamped to ensure good electrical contact between adjacent blades, and also to provide a surface from which heat can be removed to cool the amplifier. Figure 5 shows the 4.5 to 20 GHz Spatium® amplifier with the outer cone and connectors removed to illustrate the inner cone and clamps assembled with a set of blades.

Following fabrication, the Ka Band 16 element Spatium® structure was tested with passive 50 ohm transmission lines in the MMIC mounting locations to assure the losses through the system were less than one dB. This measurement is a true indication of what the losses in the combining system are, and thus approximately how much power can be delivered to a load for a given MMIC power amplifier chosen for use in the structure. To facilitate measurement of the passive structure each blade was populated with a section of 50 Ω microstrip in place of each MMIC amplifier. The microstrip joined the input splitter network to the output combiner network on each element and was approximately 0.750” in length; fabricated on the same laminate PCB material as the antipodal finline to microstrip transition. The input and output connectors for the passive structure were both 2.92 mm female.

The passive Spatium® insertion loss across the targeted satellite communications band, 27 to 31 GHz, ranged from 1.4 dB to 2.4 dB from input connector to output connector. Subtracting out 0.4 dB of loss for the 0.750" piece of microstrip and the wire bond connections on and off the microstrip; then dividing in half, to identify the loss associated with only the recombining, results in a combining loss ranging from 0.5 dB to 1.0 dB. A plot of the variation versus frequency for the splitting/combining loss across the 27 to 31 GHz band is shown in Figure 6. Since these measured losses include the connectors, these are representative of true power loss between the MMIC power amplifier outputs and the load of the power amplifier assembly.

The low loss and predictable nature of the Spatium® combiner structure means that the power amplifier assembly small signal parameters will nearly mirror those of a single element and the output power will be the output power of a single element multiplied by 16, less the combining loss. Losses are known and can be readily measured, so projecting the full Spatium power amplifier performance can be done accurately once the single power amplifier element has been fully characterized for RF performance.

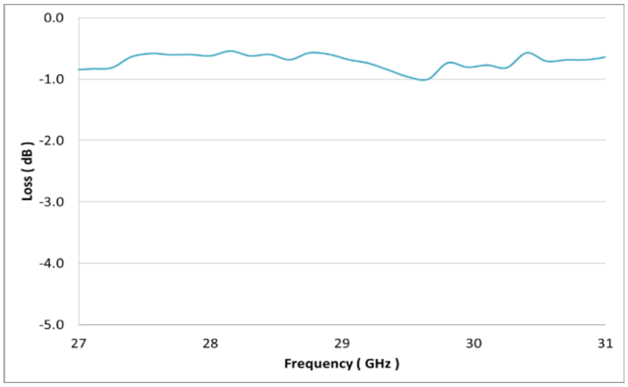

Figure 6. Combining Loss of Passive Spatium Structure.

III. GaN MMIC Performance

The Ka Band Spatium® platform has a usable bandwidth from 10 to 40 GHz, but is particularly useful in combining a large number of solid state devices for satellite communication applications in the 27 to 31 GHz band. Late in 2013 Qorvo introduced the TGA2595 GaN MMIC PA utilizing its 0.15 µm GaN process[7]. The MMIC is a three stage balanced topology that achieved approximately 10 W of output power across the full 27 to 31 GHz bandwidth, also achieving greater than 25% power added efficiency, shown in Figure 7.

A key parameter in satellite communication applications is linearity. One bench mark linearity specification for a power amplifier in a satellite communications application, known as the two tone IMD level, is the output power at which the third order intermodulation products are 25 dB down from the combined power of the two output carriers; this point is deemed the maximum linear output power for the amplifier. Typical GaAs based amplifiers reference their linear power capability in terms of backoff from the 1 dB gain compression (P1 dB) power level. GaAs devices typically have a very hard saturation curve so P1 dB and saturated output power are close together; less than 1 dB. GaAs devices can generally meet the two tone IMD requirement for satellite communication applications at a power level between 2 dB to 3 dB below the P1 dB point without any additional linearization.

GaN amplifiers typically have a softer saturation curve; the TGA2595 is no exception so P1 dB and saturated output power are nearly 5 dB apart for this device, 35 dBm versus 40 dBm respectively. The graph in Figure 7 for

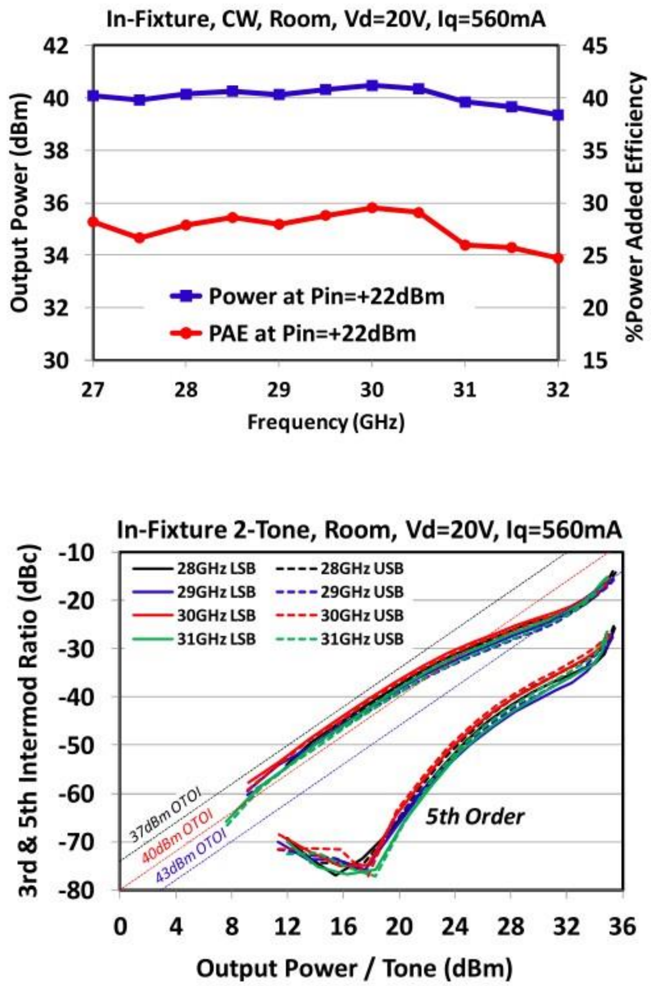

Figure 7. GaN MMIC Performance.

the two tone measurements for a single TGA2595 show that the device meets the satellite communications third order intermodulation distortion specification at 33 dBm per tone, 36 dBm of total output power. The GaN device actually meets the linearity requirement at an output power greater than the P1 dB point. The TGA2595 meets the linearity bench mark at 4 dB back off from saturated output power without additional linearization, approaching the same linear power as available GaAs devices in this frequency range, but with significantly better power added efficiency (PAE). Being able to meet the linearity requirement this close to the saturated output power point makes this part ideal to combine to create a high power and efficient amplifier for satellite communication applications.

IV. Spatium Power Amplifier Performance

The assembly of the Ka Band Spatium® used quantity (16) TGA2595 MMIC devices, one per blade. Each of the TGA2595 devices was mounted to a CuMoCu tab using AuSn solder, and then each tab assembly was attached to the blade using a high electrical and thermal conductivity epoxy. The connections, both DC and RF between the microstrip antenna PCB to the die on tab assembly were all wire bonds. The input connector on the assembly was a 2.92 mm female, as it was for the passive measurements. Since the targeted output power level of 120 W exceeds the rating for a standard off the shelf 2.92 mm connector, and most end users of the Spatium® will use this to feed a transmit antenna with a WR-28 waveguide feed, the output connector was changed to an inline WR-28 rectangular waveguide. The inline adapter is a custom made piece that mates directly to the coaxial output of the combiner structure and transitions the TEM mode output from the Spatium® to the TE10 fundamental mode of the rectangular waveguide.

The combination of the sixteen TGA2595 GaN MMIC devices using the Ka Band Spatium® structure yielded a power amplifier assembly with saturated output power between 120 W and 150 W across the 27 to 31 GHz frequency band. The associated PAE was a minimum of 23% across this same bandwidth. Figure 8 shows the graphs of both versus frequency. All of the measurements for saturated output power and PAE were taken under CW conditions. These output values correlate well with expectations based on the individual device data. One simple measure of the combining efficiency of the Spatium® is to compare the PAE of the device to the PAE of the power amplifier assembly. In this case the PAE of both are within one or two points of each other; showing the loss in the combining structure of the Spatium® is extremely low.

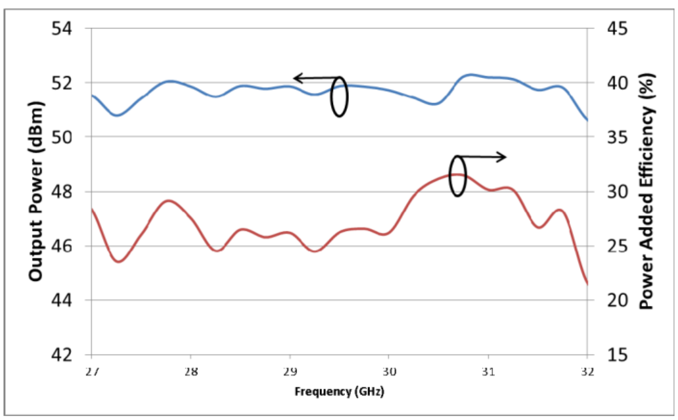

Figure 8. Saturated Output Power and PAE of the Spatium™.

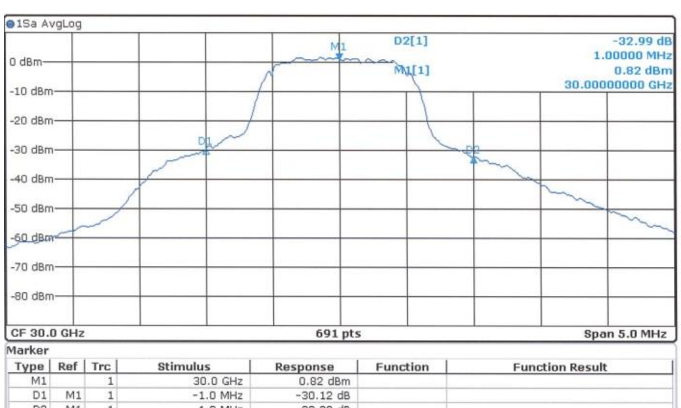

Figure 9. Linearity of Spatium Power Amplifier.

Linearity was also measured using another technique that is common for satellite communication applications for power amplifiers. The maximum linear output power is defined when an OQPSK modulated signal is applied to the input and the output signal spectral regrowth measured at one symbol rate offset is - 30 dBc. For purposes of this measurement, the modulation was applied at 1 MSPS (Megaymbol per second). The maximum linear output power was measured to be 48 dBm at 30 GHz, approximately a 4 dB back off from the saturated output power; the same back off needed to meet the two tone linearity specification at the MMIC level testing. The output spectrum at 30 GHz is shown in Figure 9.

V. Conclusion

A Ka Band power combining platform and a power amplifier assembly utilizing the platform and GaN MMIC amplifiers was demonstrated. The power combining platform demonstrated high combining efficiency, broadband operation, and high power capability. The power combining platform is one of five that has been developed using Spatium® technology demonstrating the flexibility and applicability of the technology to a wide array of applications. The TGA2595 utilized in the Spatium® power amplifier presented demonstrates the high efficiency and linearity that can be achieved utilizing the 0.15 µm GaN process developed by Qorvo for Ka Band power applications.

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