A MINIATURE, MMIC ONE WATT W-BAND SOLID-STATE TRANSMITTER

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ABSTRACT

The design features and performance summary for a fully coherent, miniature (1.3 in^3), lightweight (2.4 oz.), all MMIC 1-watt W-Band transmitter is presented. The design utilizes 16 channels each delivering 90 mW at W-Band consisting of a cascaded Ka-Band phase shifter, Ka-Band amplifier, Ka to W-band tripler and a W-Band amplifier. The outputs are efficiently combined with only 1.2 dB loss using two planar radial combiners and an integrated waveguide magic tee.

SUMMARY

Introduction

In the past, hardware implementation at W-Band was primarily in waveguide that is large, heavy, and unsuitable for modern miniature, lightweight, low cost systems. Previous transmitters have been implemented using output power frequency multipliers, which require high power driver stages [1,2]. With the advent of MMIC devices that produce direct power at W-Band, [3,4] higher efficiency solid-state transmitters are feasible [5]. Planar implementation techniques for multifunction W-Band MMIC modules [6-7] have addressed packaging, chip interconnection, and assembly techniques, however, lower loss millimeter wave combining techniques with reduced size and weight are required. This paper presents the electrical, mechanical, and thermal design and performance for the 1-watt W-band transmitter that weighs only 2.4 oz. in a volume of 1.3 in^3. This is the smallest and lightest 1-watt W-Band transmitter yet reported.

Electrical Design and Performance

The 1-watt high duty cycle solid-state transmitter presented utilizes state-of-the-art MMIC device technology along with unique planar low loss integration techniques. The block diagram for the all MMIC solid-state transmitter is shown in Figure 1. An input signal at Ku-Band is doubled to Ka-Band,

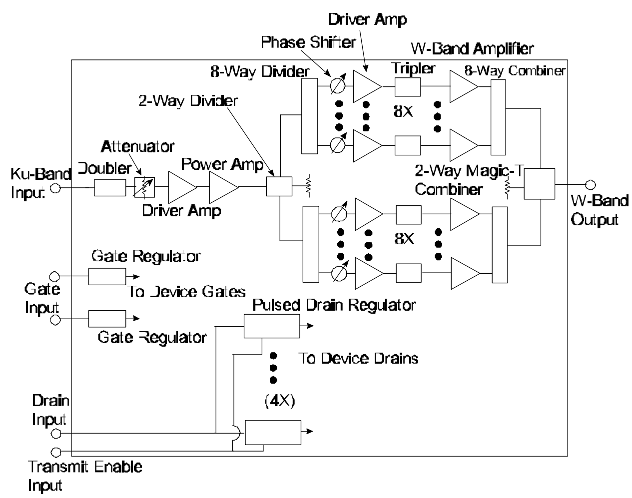

Figure 1. W-Band Transmitter Block Diagram

and then amplified. This signal is then split through a 2-way divider and two 8-way dividers that feed the 16 Ka to W-Band power channels. The 2-way and 8-way divider circuits are implemented on an alumina substrate. The measured performance for 4 of the 8 outputs is shown in Figure 2. The 8-way divider exhibits nominally 0.6 dB of insertion loss for each channel at the desired Ka-Band frequency.

0-7803-4603-6/97/$5.00 (c) IEEE

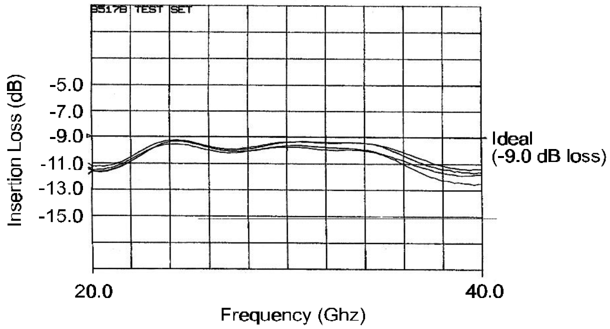

Figure 2. 8-Way Divider Insertion Loss Versus Frequency (4 Channels Shown)

The 16 power channels each consist of a 4-bit digital phase shifter, followed by a Ka-Band amplifier, Ka to W-Band tripler, and a final W-Band amplifier. The phase shifter allows efficient coherent alignment of all the channels for maximum RF output power (the alignment can be done automatically under processor control). This MMIC phase shifter used 2 high-pass/low- pass sections for the 30 and 60 degree bits and two switched capacitance sections for the 7.5 and 15 degree bits. The overall loss was 6.5 dB with 15 dB return loss for the 112.5 degree phase shifter at Ka-Band. At W-Band the phase shift covers the full 360 degrees with a LSB of 22.5 degrees. This corresponds to a loss of power of 0.3 dB nominally. The phase shifter MMIC was fabricated at the Northrop Grumman foundry using a 0.25 micron gate length device. The Northrop Grumman 0.5 watt Ka-Band MMIC driver amplifier is a three-stage 22 dB gain unit with a power added efficiency of 25%, that also uses 0.25 micron gate PHEMT technology. The Ka-Band amplifier generates the required drive level for the MMIC tripler which produces W-Band. The
W-Band amplifier, after the tripler, generates 90 mW nominally at the output of each of the 16 channels. The output power versus frequency, for 11 power channels, is shown in Figure 3. The output power is nominally 90mW at the desired W-Band frequency.

The 16 power channel outputs are then combined in two 8-way radial combiners using a quartz substrate. The signals coherently converging at the center of each radial combiner, transitions into the TE-10 mode of rectangular waveguide. The signals in waveguide are then combined in a 2-way magic-T waveguide combiner, resulting in the final 1-watt W-

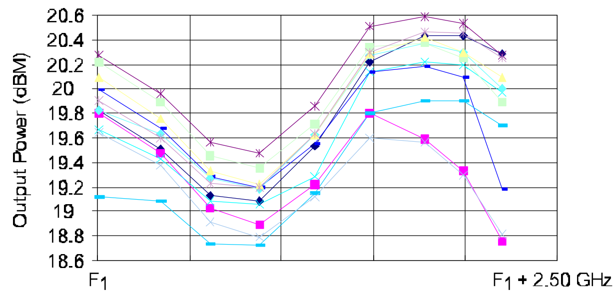

Figure 3. Combine Spoke W-Band Output Power Versus Frequency

Band output level. The performance of the overall 16 way combiner is shown in Figure 4. The combining loss exhibited is nominally 1.2 dB at the

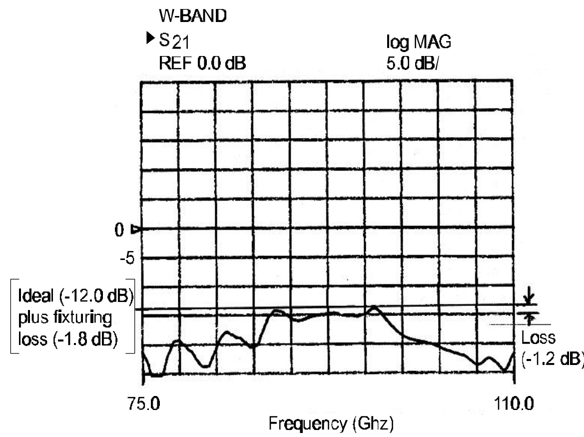

Figure 4. W-Band 16-Way Combiner Insertion Loss Versus Frequency

desired W-Band frequency after removing the loss due to the W-Band probe (1.4 dB) and the loss due to the interfacing waveguide (0.4 dB). The final measured power output of the solid state transmitter is displayed in Figure 5. The measured W- Band output power is greater than 1-watt peak over a 600 MHz band.

All the devices are gated for pulsed operation. A switchable Silicon voltage regulator, developed at Northrop Grumman ESSD (Electronic Sensors and Systems Division), is used for conditioning and setting the pulse width and duty cycle. Non-switchable voltage regulators are used to condition and set the gate bias for all the devices. The gate bias is applied continuously.

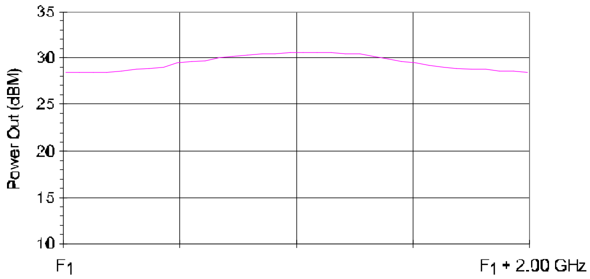

Figure 5. Transmitter W-Band Output Power Versus Frequency

Packaging

The outline of the miniature transmitter is shown in Figure 6. The interfaces consist of a coaxial Ku-Band input connector and a WR-10 waveguide output for the RF signals, input and output cooling ports, DC bias pins and a hermetic seal screw.

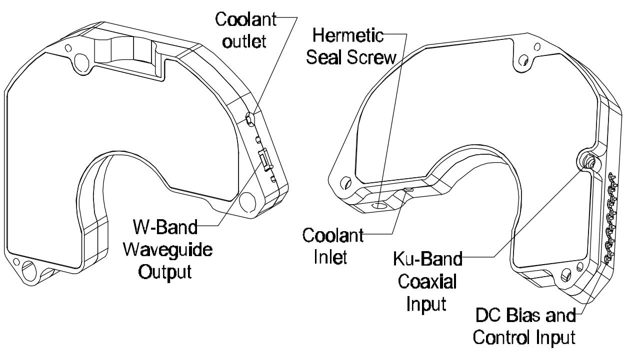

Figure 6. W-Band Transmitter Mechanical Form Factor

The layout of the two-sided transmitter assembly is illustrated in Figure 7 and 8. The power channels are arranged like spokes in a wheel, with part of each spoke on both sides of the assembly. Figure 7 shows the divider side which contains the mainline input carrier assembly, 2-way divider, dual 8-way dividers along with the cascaded Ka-Band phase shifter and Ka-Band amplifier chips in the spoke power channel. Figure 8 shows the combiner side which contains the cascaded Ka to W-Band tripler, W-Band power amplifier part of each spoke and the two 8-way radial combiners.

Mechanically, the transmitter consists of a two-sided aluminum chassis assembly with a center web that serves several functions. It acts as a liquid

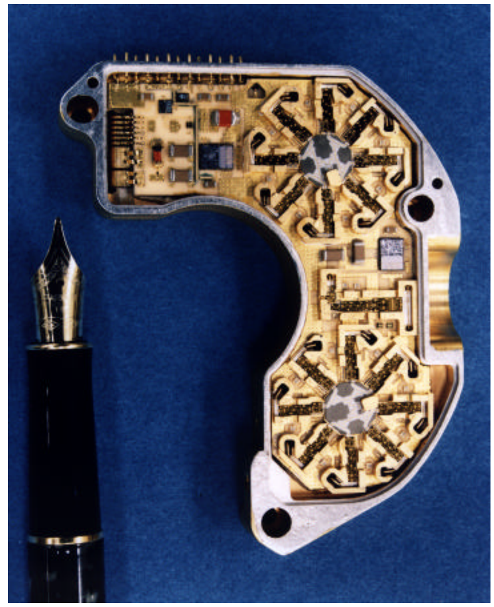

Figure 7. Divider Side View of W-Band Transmitter Assembly

Figure 8. Combiner Side View of W-Band Transmitter Assembly

coldplate that carries substrate assemblies on both sides, contains the internal waveguide including a magic-T combiner, and provides the path for the vertical transition between each divider/combiner spoke pair. The substrates are fabricated from a LTCC (Low-Temperature Cofired Ceramic) material, developed at Northrop Grumman ESSD, that exhibits exceptionally low-loss and voltage drop. Both substrates distribute DC power and signal to the various devices, and stripline RF transmission lines in the divider-side substrate carry the signal at Ku-Band and at Ka-Band.

The need for liquid coolant necessitated the use of brazed aluminum for the housing material. The MMIC chips are attached to carriers that are then integrated on top of the multilayer LTCC mother substrate, which is itself attached to the chassis floor on both sides. Hermetic sealing of the unit is accomplished by soldering the single RF glass seal input connector, a field of glass-to-metal seals for power and enabling, and a waveguide window for the W-Band output port into the housing. The seal is completed by laser welding aluminum covers to both sides of the housing.

Thermal Management

Continuous, reliable operation of the transmitter at high duty cycle necessitated the use of a liquid coolant to efficiently carry away power dissipated by the unit. The coolant, ethylene-glycol and water, enters the unit through a tube soldered into the housing's integral coldplate at 20° C and a flow rate of 0.1 gpm. The coolant travels through a serpentine channel in the center web of the housing and exits at 25° C through the outlet tube with a pressure drop of 100 psi across the unit.

The heat generated by the devices is conducted to the coldplate through the carrier substrate stack-up. A thermal analysis performed using Direct Numerical Simulation software, developed at Northrop Grumman ESSD, finds the maximum steady-state junction temperature to be 80° C.

CONCLUSION

A state-of-the-art 1-watt all MMIC W-band transmitter has been developed that is miniature, lightweight and uses innovative packaging and power combining techniques. The outputs from 16 W-band MMIC amplifiers are combined with only 1.2 dB loss in a miniature 2.4 oz, 1.3 in^3 assembly.

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