Wideband Transmit Modules Designed for Production

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ABSTRACT

This paper presents novel, multi-channel transmit modules designed for high-volume manufacturing, which operate over the multioctave EW bandwidth, and are intended for use in an active array. Use of multi-layer high temperature cofired ceramic (HTCC) as the base of the modules allows high-density routing of RF, bias and digital control lines, reducing the overall size of the modules. In a tightly-packed module, custom MMIC's are often called upon [1]. Lower cost can be achieved by selection of MMIC's used in popular wireless products. For each transmit channel, the phase and gain are independently controlled by digital commands sent to on-board application-specific integrated circuits (ASIC's). The design goals were achieved without unnecessary MMIC development by selecting commercial off-the-shelf (COTS) MMIC's designed for the wireless market

INTRODUCTION

In active-aperature phased arrays, antenna beam steering is performed by changing the RF gain and phase shift feeding each antenna element [2]. Each radiator is fed by an RF output from a transmit module; thus module size is limited by the element spacing. Grating lobe free operation at Ku frequencies requires tight element spacings, and therefore miniaturized packages[3]. To meet these mechanical and electrical requirements a novel packaging concept was utilized that involves using a High Temperature Cofired Ceramic(HTCC) as the base of the modules, so that RF, digital and power supply lines can be incorporated into the same substrate. This paper details novel transmit modules with a wide bandwidth (X to Ku band) that are designed for high-volume production.

DESIGN GOALS

These transmit modules are two of a three-module set designed for use in an active-aperture phased-array. Each of the three modules is indicated by the dashed boxes in Figure 1. The high-power module (HPM) acts as a power amplifier module feeding two radiating elements (Figure 2). Low-level RF is fed into each of two inputs from the low power module that controls the phase and amplitude of each signal (Figure 3). Circulators are used between the HPM outputs and the radiators to protect the power amplifier from signals that are incident upon the array antenna, and to provide a good match to the radiators.

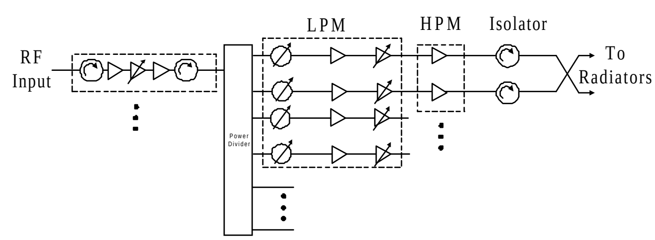

Figure 1: Block diagram showing location of LPM & HPM in relation to other components of the phased array.

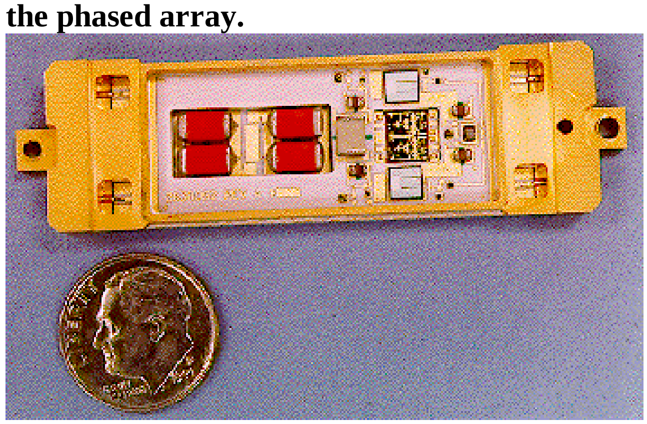

Figure 2: Photograph of the HPM transmit module. The power amplifier is placed in a cavity on the right side of the module.

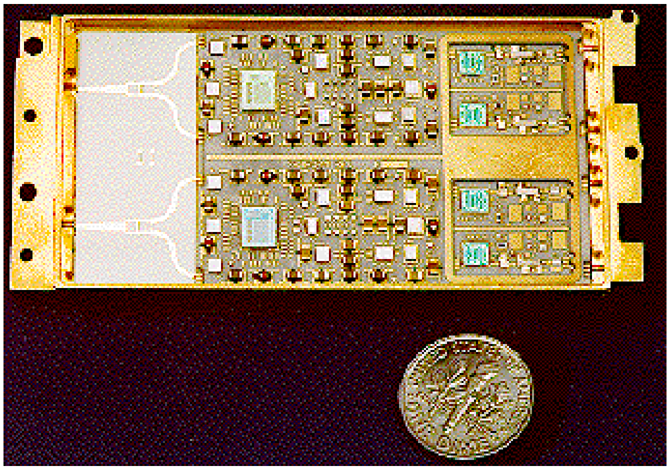

Figure 3: Photograph of the LPM transmit module. The power dividers are shown on the left-hand side. The large devices in the digital section are the ASIC's. Two subcavities on the right-hand side contain all RF circuitry

Each RF path contains a 360° six bit wideband MMIC phase shifter, the Northrop Grumman WPHS2583. Followed by a medium-power amplifier MMIC, the Hewlett-Packard HMMC-5618. In order to achieve 35dB of dynamic range, the Hewlett-Packard HMMC-5022 traveling wave MMIC with dual gates was selected as the second gain stage. Control for both the phase shifter and variable gain amplifier originate from a Northrop Grumman controller ASIC, the W4453, which is useful for a variety of T/R module applications [4].

In order to reduce the unfocused noise generated by the array when not transmitting, the drain power supply to each channel of the power amplifier can be switched electronically [5].

Table 1: Transmit Module Design Goals

Frequency Range	EW bandwidth
Output Power	6 W (3W per Output)
Small Signal Gain	20 dB mean; 30 dB dynamic range
Power Consumption	16W/channel (8V @ 1.9A; -8V @ 45mA)
Size Constraints	height 0.190", width 0.746"

ELECTRICAL PERFORMANCE

The maximum output power of the module when compressed is shown in Figure 4; 3W (34.7dBm) per channel was the design goal. At the low end of the band and at midband we meet this goal. At the high end of the band and near 8 GHz , however, the output power drops below this goal. The small signal gain is also plotted in Figure 4, showing the dynamic range achieved.

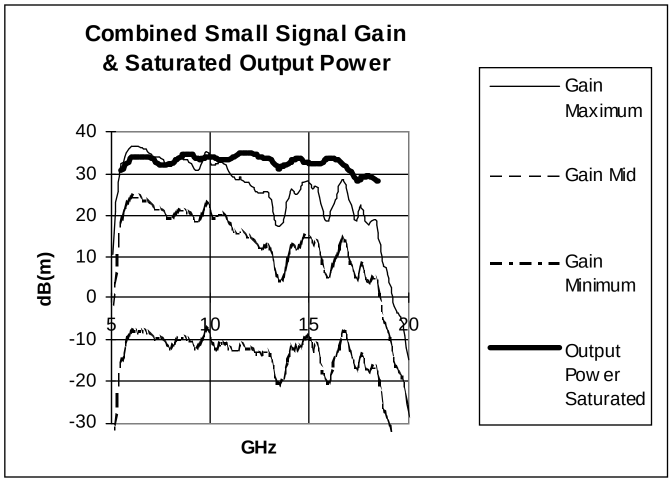

Figure 4: A dynamic range of 30dB is achieved, with a saturated output powers of over 2 watts.

The losses associated with the RF transmission lines in the HTCC are >7dB. These losses are dominated by the conductor loss in the transmission lines, since the resistance of the tungsten metalization is approximately 10mW /square [5] A design with minimum VSWR was simulated using Hewlett-Packard's High-Frequency Structure Simulator (HFSS). Otherwise little tuning was done on the module.

When the power amplifier is driven into compression its drain current can rise from a quiescent bias point of 0.9A per channel to 1.6A per channel. Because of the inductance inherent to the power distribution buses in the array, it is necessary to include energy storage capacitors in the module to handle pulsed RF signals. In order to damp the drain bus 1600mF of capacitance is required per module; 400mF is placed inside the module, and the rest is placed on the bus near the power supply.

As with most T/R module designs, the MMIC cost was the primary driver of the total module cost. Cost reduction was possible by designing in standard MMIC's used in the wireless industry. Contributors to this were the Hewlett-Packard MMIC's, available at a significant price reduction due to growing communications markets in the microwave and millimeter wave ranges. In addition, an off the shelf power amplifier, built by Triquint, was used rather than developing a new MMIC.

MECHANICAL CONSIDERATIONS

One of the dominant factors that limited the design of this module was the size limitation. Since this module is to be used in an active array transmit antenna it is desirable to keep the width of the module close to the radiator spacing. Module height was also constrained by the radiator spacing. A maximum module height of 0.200" allowed enough space for material thickness in the highly pressurized cooling manifolds in the slats to which the modules were mounted, as well as enough clearance between slats to assemble the array.

Another consideration affecting module packaging was the desire to connectorize all electrical interconnections to the array, to avoid RF problems with open launches, such as coplanar waveguide flex circuits. However, the use of connectors increased the need for tight tolerancing in the module package.

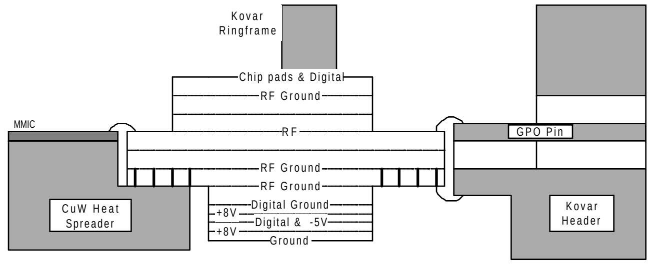

Figure 5: Cross Section of RF Transitions

Figure 5 shows a cross section of the HPM RF transitions and substrate. In the connector regions we transition from stripline to coplanar waveguide with a ground then to the coaxial connectors. Ribbons are used to connect the coplanar grounds on the HTCC to the ringframe. In the HPM, ribbons are also placed in cavities on the bottom side of the package between the ceramic and ringframe, to ensure an adequate ground transition between the connector and the substrate. Many vias are used to connect the parallel stripline ground planes throughout the module, so that any parallel plate waveguide modes will not propagate and cause oscillations or suckouts.

In populating the HPM, the power amplifier die is soldered to the slug using a AuSn preform. The two Hexfet switches also required soldering due to electrical current considerations. They were soldered to their own Cu/Mo/Cu tabs. These chip tab assemblies, along with all the other devices in the module, were bonded to the substrate using a conductive epoxy.

The modules are sealed with a seam-welded Kovar lid which has RF absorber material attached to the underside for better isolation[5] and to reduce the chance of oscillations.

Power Amp Spreader / Cooling Channel
Temperature Predictions

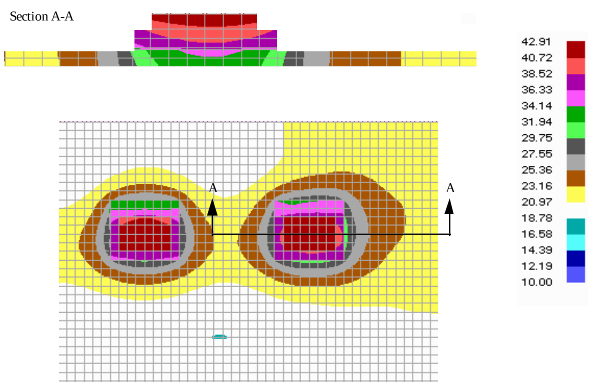

Figure 6: Temperature predictions of the power amplifier.

Thermally, chip junction temperatures had to be maintained below 125°C in order to provide long-term reliability [7]. With typical liquid cooled systems in the field a liquid temperature of 20°C could be reasonably expected. The temperature differential between the junction and the bottom of the chip on the power amplifier was found by measurement to be about 70°C. Adding a margin of 10°C for measurement and analysis uncertainty, this allowed only 25°C of temperature rise from the liquid coolant to the chip. This dictated a design having a direct thermal path from the chip to the cold plate. Thus the chip is soldered to a CuW thermal spreader, which penetrates the module housing and attaches directly to the cold plate using the high-conductivity Thermstrate material. By growing the footprint of the spreader to the maximum allowed by packaging constraints, the heat is spread sufficiently before reaching the liquid convection interface to meet the temperature requirement. A finite difference thermal analysis was run on this structure. Figure 6 shows the temperature profiles of the CuW spreader on the aluminum coldplate in cross-section and in top view.

CONCLUSIONS

The transmit modules described provides wideband power amplification with phase and gain control for an active transmit array. Since the module size is driven by the spacing of the array elements, at high Ku band frequencies this requires a very tight module spacing. Novel use of multi-layer HTCC produces a compact module with wide bandwidth performance. This led to several packaging challenges with the RF transitions, and cooling the power amplifier MMIC. The modules have been designed for manufacturing with automated chip placement and wirebonding tools, since hundreds of these modules are required for each array. Using commercial MMIC's available to the wireless industry significantly reduced the total cost of this module.

ACKNOWLEDGMENTS

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REFERENCES

[1] David N. McQuiddy et al., "Transmit/Receive Module Technology for X-band Active Array Radar," IEEE Proc., Vol. 79, No.3, pp.308-341, Mar. 1991.

[2] D. K. Barton et al., *Radar Evaluation Handbook*. Norwood, MA: Artech House. 1991.

[3] Eliot D. Cohen, "Trends in the Development of MMIC's and Packages for Active Electronically Scanned Arrays (AESA's)," 1996 IEEE Int'l Sym. On Phased Array Sys. And Tech., pp.1-4, Oct. 1996.

[4] Adrian Garrod, "Digital Modules for Phased Array Radar," 1996 IEEE Int'l Sym. On Phased Array Sys. And Tech., pp.81-86, Oct. 1996.

[5] Eric L. Holzman et al., "Active Phased Array Design for High Clutter Improvement Factor,"

1996 IEEE Int’l Sym. on Phased Array Sys and Tech., pp. 44-47, Oct. 1996.
[6] *Kyocera Multilayer Ceramics Design Guidelines*, Kyocera Corporation, 1990, Cat 2T9012THA 1241E.
[7] Paul W. Webb, “Thermal Modeling of Power Gallium Arsenide Microwave Integrated Circuits,” IEEE Trans. Elec. Dev., vol. 40, No. 5, pp. 867-877, May 1993.