EIGHT WATT KU-BAND MODULE

M. Gat, D. S. Day and J. R. Basset

Microwave Power Products
Avantek Inc.,
3175 Bowers Ave., Santa Clara, CA 95054

ABSTRACT

A Ku-band MBE monolithic power amplifier is reported. In the design, two pairs of MMICs combined in parallel are balanced between Lange couplers and driven by a fifth identical MMIC. Each MMIC is a two-stage power amplifier which incorporates a full interstage matching network and a partial input matching network. Individually, the MMICs deliver more than 3 watts of power, 11 dB gain and more than 20% power-added efficiency (PAE) from 15 to 18 GHz. To our knowledge, these are the best published results for a power MMIC operating at 18 GHz. The full power module has 8 watts of P_{out}, 20 dB gain and 14% PAE at 18 GHz. The module could be tuned for a 1 GHz instantaneous bandwidth anywhere in the 15-18 GHz band.

INTRODUCTION

Drop-in power modules have been gaining in popularity in recent years. The clear trend towards higher P_{out}, gain and power added efficiency makes power modules increasingly more attractive and useful to the end user. Power modules have evolved from a two-stage discrete MIC realization [1], to a three-stage half-MIC-half-MMIC module [2]. This paper presents a four-stage full-MMIC power module.

The building block used for this module is a newly-developed two-stage MMIC which delivers more than 3 watts of power and 20% PAE from 15 to 18 GHz. A 3-W building block seems optimal for Ku-band power modules. A 3-W module is small, the power density is still high and at least two such modules could easily be combined directly in parallel with low combining loss. This MMIC was designed using Avantek's power MMIC approach which favors partial input and output matching networks over a fully-matched MMIC. The partially-matched MMIC provides improved performance at a lower module cost [3,4,5].

The high-power, high-frequency requirements combined with the high die count in the module compelled us to break the amplifier into sub-modules. Pairs of MMICs were first combined in parallel, producing a device we call a *dual*. Each dual was tuned and tested individually. To achieve the 8-watt level a pair of duals, matched for P_{out} and small-signal insertion phase, were combined with Lange couplers and integrated with a driver sub-carrier into the main carrier.

CIRCUIT DESIGN

The MMIC consists of a 4.22-mm FET driving an 8.45-mm output-stage FET. The latter device combines 16 cells, each cell with eight gate fingers and each finger being 66 µm wide. The driver FET is split into four equal parts, each with two of these identical cells. The number of cells in both transistors is a binary (2^N) number, which helps simplify the networks for power combining and splitting. Detailed information on the FET structure and MMIC fabrication have been published previously [3,4,5]. The layout and a simplified schematic of the MMIC are shown in Figures 1 and 2, respectively.

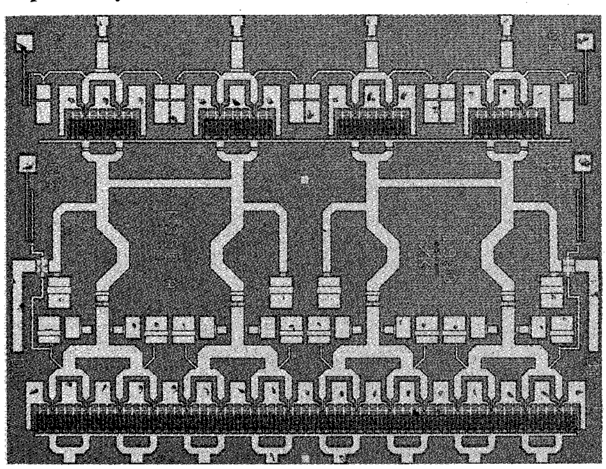

Figure 1. Micrograph of Ku-Band MMIC

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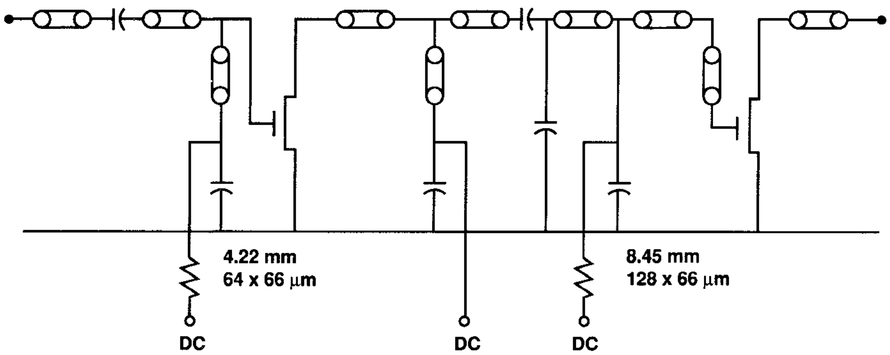
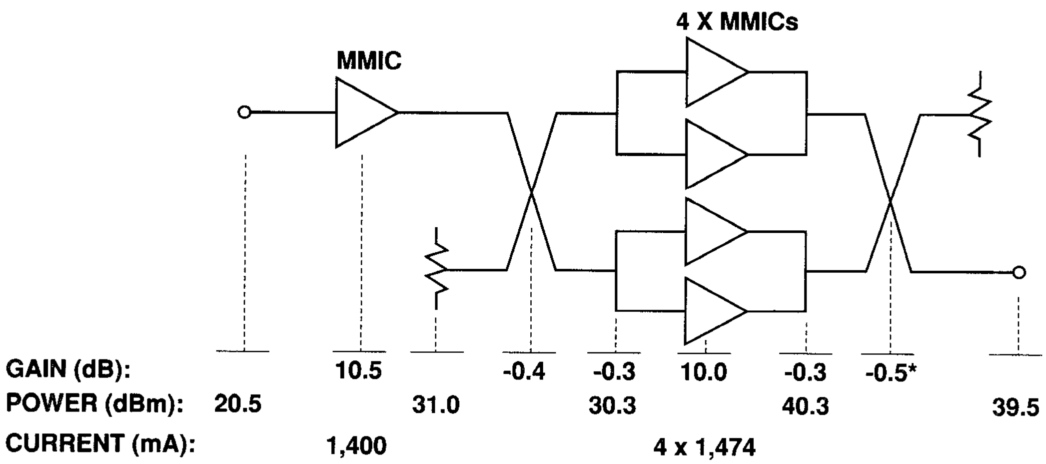


Figure 2. Simplified Circuit Schematic of the MMIC

The MMIC is clustered into four segments with identical RF characteristics. Clustering eases the realization of the matching network and keeps the electrical length of the combining network to a minimum. The gate and the drain buses of the four driving FETs are connected to avoid odd-mode oscillations [6]. Series resistors on the gate DC lines of both the driver and the output FETs are realized on-chip to prevent low-frequency oscillations and to obtain better protection of the gates from transients. The gates of both driver and output stages can be biased from either side of the chip. Under normal biasing conditions, both FETs are biased to the same V_{gs}. The interstage matching network is purely reactive to maximize efficiency. The input DC block and a shunt L-C pre-match network are realized on chip. The output of the MMIC has eight bonding pads and the MMIC die size is 0.081 x 0.104 x 0.003 in. A detailed description of the MMIC is also being presented at this Symposium.

The module's block diagram and layout are shown in Figures 3 and 4, respectively. The Ku-band power module operates using +9 V & -5 V bias supplies. There are three individual +9 V lines, one for each of the duals and one for the driver. This permits monitoring the bias consumption of each sub-carrier, which helps in troubleshooting. All the circuits are realized on alumina substrates and all carriers are made of gold-plated copper-molybdenum. The use of *Cu-Mo* carrier system minimizes mechanical stress during assembly and temperature cycling. Soldering the sub-carriers to the main carrier ensures good thermal conduction and good RF ground continuity. Assembly is performed with soldering temperatures in a sequence from highest-to-lowest temperature, to ensures a subsequent step does not interfere with the integrity of previously-made solder joints. The module size is 0.963" x 0.710" x 0.075".



GLOBAL PERFORMANCE AT T_F = 25°C	
CURRENT: 7,296 mA TYP.	E_{add}: 13.4%, 11.4% MIN.
GAIN: 19.0 dB TYP., 18.5 MIN.	P_{out}: 39.5 dBm TYP., 39.0 dBm MIN.

*Coupler Loss + Loss Due to Imbalance

Figure 3. Block Diagram & System Budget of the 8 Watt Module

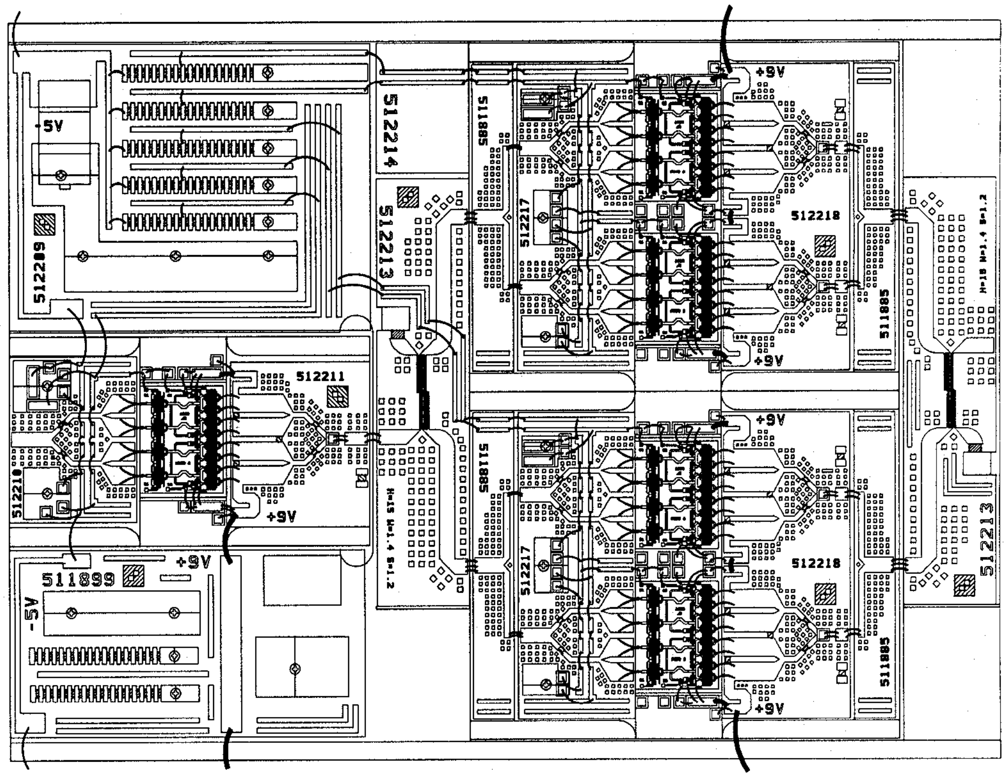


Figure 4. Layout of the 8 Watt Module

PERFORMANCE

The MMICs were tested individually using input and output matching circuits printed on 5-mil alumina substrates. Figure 5 shows typical test results at 2 dB gain compression for class AB operation. These results were obtained from a good wafer with the best revision chosen out of several on the mask. Figure 7 shows the performance of the best MMIC, which produces +37 dBm of power, 10 dB of gain and 29% PAE at 18 GHz. The purpose of this project was to optimize performance at 18 GHz, however the MMIC is useful with even better performance all the way down to 14 GHz. Figure 6 shows test results of a typical module. Some data points show more than 10 watts of power, thus leaving a comfortable margin for variation in the production of these modules. All test results are at CW, and launcher losses were not de-embedded. For short pulse operation (<50 μs), 0.5 to 1.0 dB more power is expected.

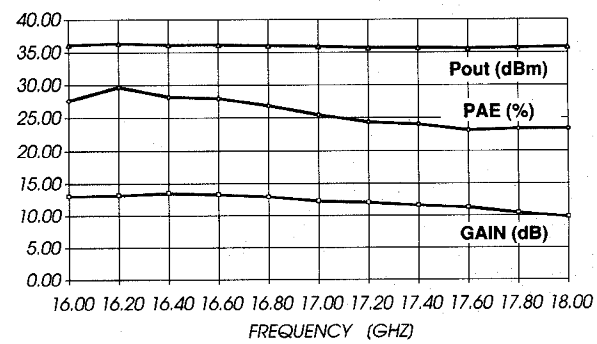


Figure 5. Typical MMIC Response at 2 dB Gain Compression

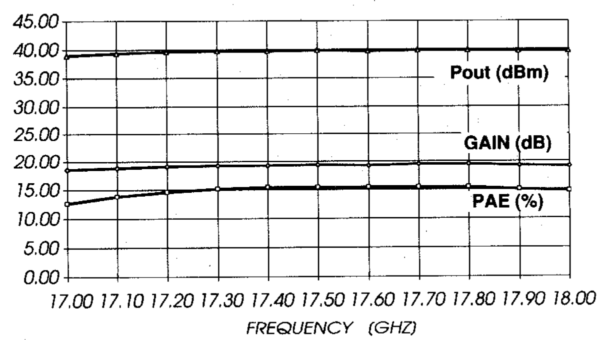


Figure 6. Typical 8 Watt Module Response at Pn=20.5 dBm

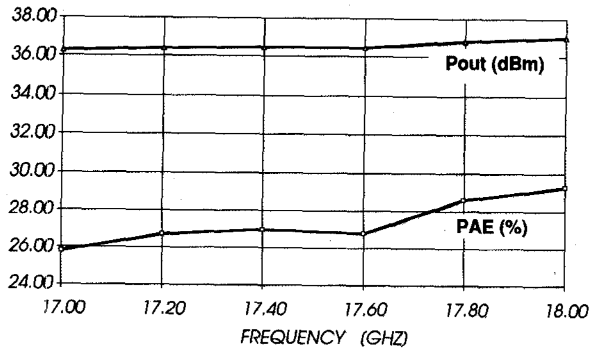


Figure 7. Best MMIC Response at 2 dB Gain Compression

CONCLUSION

The concept of a full-MMIC power module composed of an individually tested sub-carrier on top of a main carrier is here to stay. The resulting power module with its higher gain and higher P_{out} makes the module an attractive building block for system designers. The module described in this paper demonstrated 10 watts P_{out}, 20 dB gain and 14% PAE at 18 GHz. To the best of our knowledge, these are the best published results for a module of that size at 18 GHz. Coupled with Avantek's partially-matched MMIC approach, it is expected that modules of this type will become a standard building block of future systems.

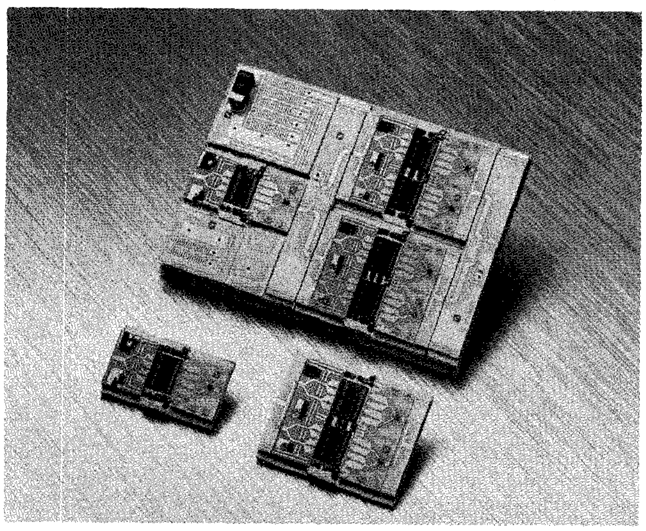


Figure 8. Micrograph of Ku-Band Driver, Dual, Modual

ACKNOWLEDGEMENT

The authors wish to thank Drs Simon S. Chan, Chang Hua, Chian S. Chang and John S. Wei for wafer fabrication and Walter F. Blanset for tuning and testing of the modules.

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