Ka-BAND POWER PHEMT ON-WAFER CHARACTERIZATION USING PREMATCHED STRUCTURES

A. K. Sharma, G. S. Dow, M. Aust, J. Canyon,
B. Allen, S. Pak, D. Yang, Y. Hwang, K. Tan

TRW / Space and Electronics Group
Electronics Technology Division,
One Space Park,
Redondo Beach, CA 90278.

ABSTRACT

High power Ka-band power amplifiers have been developed using monolithic prematched structures utilizing power InGaAs pseudomorphic HEMT (PHEMT) devices. On-wafer load-pull impedance data on the structures containing $0.15\ \mu m \times 400\ \mu m$, $0.15\ \mu m \times 800\ \mu m$ and $0.15\ \mu m \times 1600\ \mu m$ devices were obained. Based on the above information, a two stage MIC amplifier consisting of a single 1600 µm monolithic prematched structure driving four 1600 µm monolithic prematched structures was realized. The amplifier achieved an output power of 1.6 watts (32.2 dBm) with 8.1 dB gain at 35 GHz.

INTRODUCTION

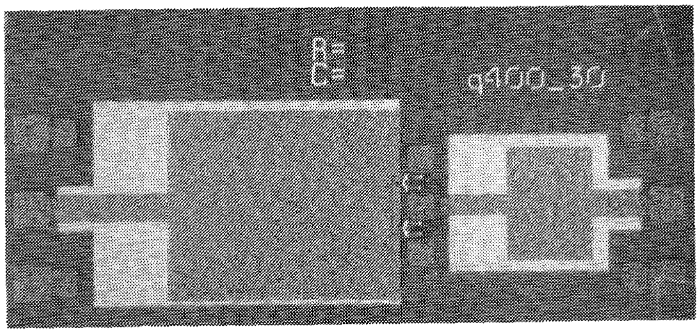
Millimeter-wave power amplifiers have potential of being extensively used in future military and space communication systems. Potential candidates for technology insertions are missile seekers, smart munitions, electronic warfare and doppler radars. They generally require high output power with high efficiency, smaller size and lower cost. The monolithic power amplifiers, such as those presented by Aust *et al* [1], provide excellent performance. The monolithic approach eliminates intensive assembly, tune and test normally associated with hybrid microwave integrated circuits resulting in lower costs. The amplifier attains an output power greater that 30 dBm with an associated gain greater than 10 dB and power added efficiency greater than 20%. This performance is comparable to the hybrid amplifier reported earlier by Dow *et al* [2]. These results are significantly better than those reported earlier by Arai *et al* [3] which attained 2 watts with 3.3 dB gain and 11% power added efficiency utilizing low power chip level combining.

This paper presents an alternative approach based on monolithic prematched structures. They provide an easy and accurate realization of hybrid amplifier circuits with lower design risk, as well as lower assembly and test costs. Furthermore, this approach provides an ability to tune the load of the output stage, if required, to achieve higher output power or power added efficiency. In this paper we shall report the measured load pull data on the monolithic prematched structures with 400 µm, 800 µm and 1600 µm device peripheries using 0.15 µm, T-gate InGaAs/GaAs pseudomorphic HEMT device technology. Using the measured load pull data on the 1600 µm prematched structure, a 2-stage MIC amplifier was developed which produced an output power of 32.2 dBm (1.6 watts) with an associated gain of 8.1 dB at 35 GHz. The linear gain is 10.9 dB.

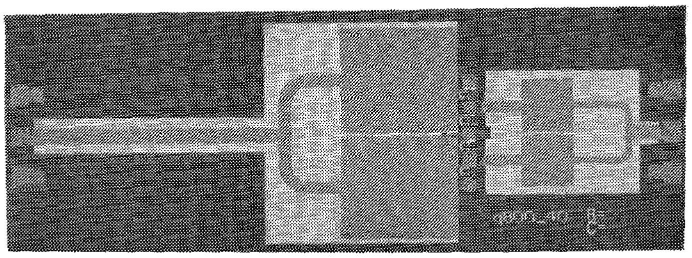
MONOLITHIC PREMATCH STRUCTURE DESIGN

The pseudomorphic HEMT process at TRW has been optimized for higher breakdown voltage and higher current densities as well as higher gain and efficiencies at millimeter wave frequencies [4]. In our present work we have utilized $0.15\mu m \times 400\mu m$ device as a basic cell for prematched structures. The device layout consists

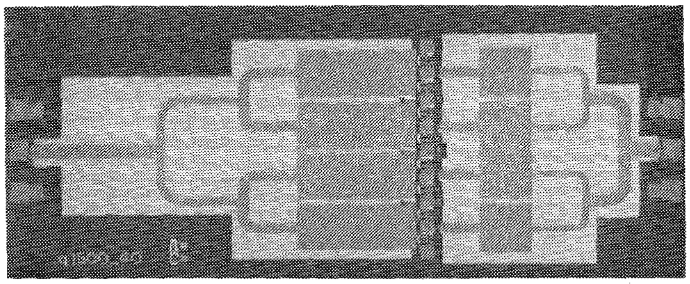
This work is supported by MIMIC Phase 2 Program (Contract No. DAAL01-91-C-0156) from DARPA and Army Research Laboratory.



(a)



(b)



(c)

Fig. 1 Ka band prematched monolithic structures using (a) 0.15 $\mu m \times 400\ \mu m$ device, (b) 0.15 $\mu m \times 800\ \mu m$ and (c) 0.15 $\mu m \times 1600\ \mu m$.

of a 4 finger, 200 μm cell juxtaposed between two ground via pads. This device size provide appropriate level of gain and resonable impedance levels. This also provides better heat sinking thus allowing the device to operate at a lower junction temperature for reliable operation.

The 400 μm prematched design (q400) is a single-cell matching, while the 800 μm (q800) and 1600 μm (q1600) designs use in-phase multicell matching. These designs employ simple series transmission line elements to transform the device optimum load to a moderate impedance level. Figure 1 shows the photographs of the three structures fabricated on a 100 μm thick GaAs substrate.

PREMATCH STRUCTURE CHARACTERIZATION

At millimeter wave frequencies, the commercially available mechanical tuner load pull systems now have excellent impedance coverage ($\Gamma > 0.9$). To obain accurate load pull data, on-wafer characterization is preferred compared to fixture characterization. However, the impedance range that can be measured is severely reduced in the on-wafer characterization procedure due to high losses associated with RF probes and transitions. This limits the ability of the load pull system to characterize power devices with gate large peripheries. Our approach to overcome this limitation was to transform the device impedance to a level that can be measured. The prematched structures presented in this paper have been designed using simple transmission line structures. These transforming networks are easy to de-embedded from the on-wafer measurements to obtain the device load pull impedance information.

The on-wafer load pull test utilizes computer controlled mechanical tuners (CCMT) from Focus Microwaves. The loss between tuner to probe tip is about 1.8 dB. Load pull measurements were performed using this test set and Wiltron 360 vector network analyzer. The Ka-band low loss bias tees were also developed for biasing prematched structures with large gate peripheries. Figure 2 shows the load pull contour at 35 GHz for the 400 μm, 800 μm and 1600 μm prematched structure with input power levels of 15.9, 19.8 and 23.8 dBm, respectively. The measured maximum output power was observed to be 20.1, 23.8 and 26.2 dBm, respectively.

POWER AMPLIFIER DESIGN AND TEST RESULTS

The two stage power amplifier design uses a single 1600 μm prematched structure to drive four 1600 μm prematched structures. The interstage networks perform both in-phase power division as well as impedance matching. The four output prematched structures are placed contiguous and are combined with an in-phase combiner. All the networks use only transmission line elements on a 5 mil thick Alumina (Al_2O_3) substrate. Figure 3 is a photograph of the MIC amplifier. Figure 4 shows the output power, gain and power-added efficiency performances of the amplifier. The amplifier achieved an output power of 32.2 dBm (1.6 watts) with associated gain of 8.1 dB and power-added efficiency of 15.4% at 35 GHz. The linear gain is 10.9 dB. The amplifier is biased at 5 volts and draws a total current of 1.8 ampere. To our knowledge this is the first time that these level of performances have been achieved from a single amplifier.

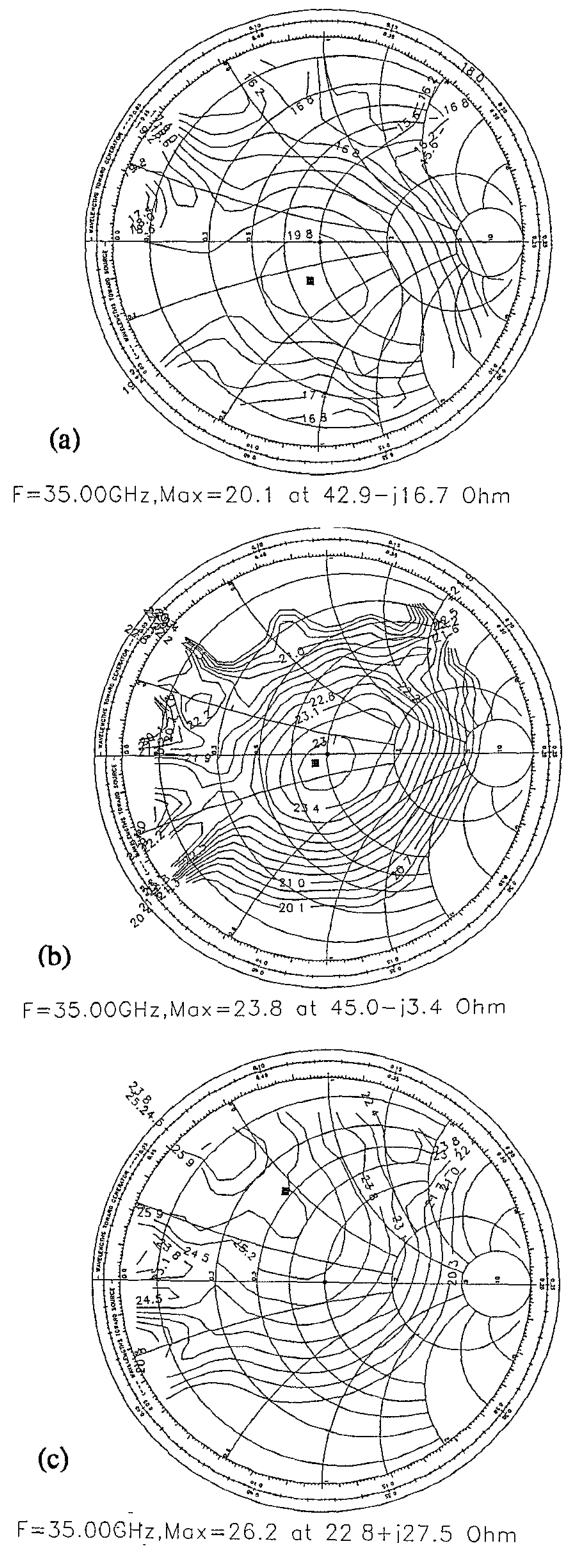


Fig. 2 Load-pull contour of (a) q400 with 15.9 dBm input power, (b) q800 with 19.8 dBm input power, and (c) q1600 with 21.5 dBm input power.

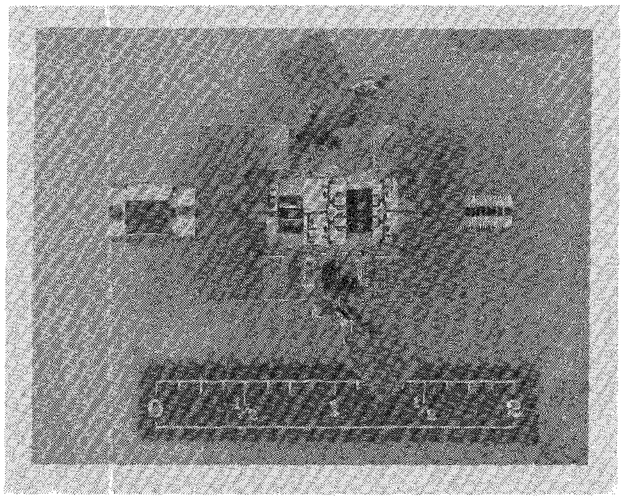


Fig. 3 Photograph of the 35 GHz MIC amplifier.

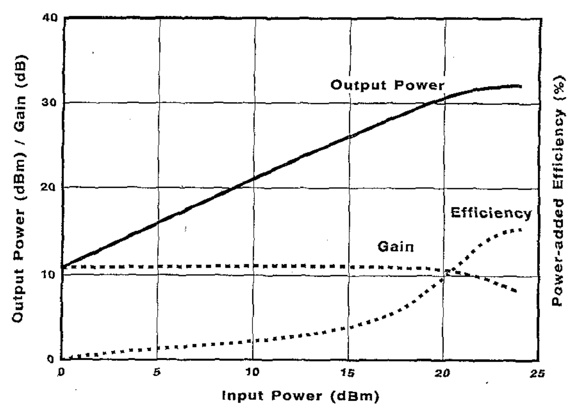


Fig. 4 Performance of the amplifier at 35 GHz.

CONCLUSION

In this paper we have reported the design and on-wafer test results of various Ka-band prematched structures, and a two stage power amplifier design using $0.15\mu m$ InGaAs pseudomorphic HEMT device technology. The amplifier used a 1600 µm prematched structure driving four 1600 µm prematched structures. It achieved an output power of 32.2 dBm (1.6 watts) with an associated gain of 8.1 dB and a power added efficiency of 15.4%. This approach allows quick realization of amplifier circuits using accurately characterized prematched structures.

ACKNOWLEDGEMENT

The authors would like to thank Dr. T.H. Chen for technical discussions and to E. Barnachea for his assembly work.

REFERENCES

[1] M.V. Aust, B. Allen, G.S. Dow, K. Tan et al, "Ka-band HEMT MMIC 1 Watt Power Amplifier," in IEEE MTT-S Int. Microwave Symp. Dig., June 1993.

[2] G.S. Dow, K. Tan, N. Ton et al, "Ka-band High Efficiency 1 Watt Power Amplifier," in IEEE MTT-S Int. Microwave Symp. Dig., June 1992, pp. 579-582.

[3] S. Arai, T. Yoshida, K. Kai, S. Takatsuka, Y. Ada and S. Yanagawa, "Ka-band 2 Watt Power GaAs MMIC," in IEEE MTT-S Int. Microwave Symp. Dig., June 1991, pp. 939-942.

[4] K. Tan et al, "High Power V-band Psedomorphic InGaAs HEMT," IEEE Electron Device Letters, vol 12, pp. 213-214, May 1991.