A Q-BAND MONOLITHIC THREE-STAGE AMPLIFIER

J. Yonaki, M. Aust, K. Nakano, G. Dow, L.C.T Liu,
E. Hsieh, R. Dia and H.C. Yen

TRW
One Space Park
Redondo Beach, CA 90278

ABSTRACT

A Q-band High Electron Mobility Transistor (HEMT) amplifier has been designed and fabricated. This three stage circuit utilizes 0.2 x 60 micron HEMT devices. The amplifier has a measured gain of over 10 dB from 42 to 47.5 Ghz and a peak gain of 16 dB at 44.5 Ghz. This result represents the state-of-the-art monolithic HEMT amplifier performance.

INTRODUCTION

Millimeter-wave (MMW) systems offer high information bandwidth, resolution and jamming resistance. HEMTs have demonstrated superior performance over conventional MESFETs, at these frequencies [1]. Millimeter wave amplifiers, both hybrid and monolithic, have been described [2], [3]. This paper presents the effort in developing a three stage Q-band HEMT amplifier with advanced performance. This monolithic amplifier is a key component in the satellite communication application.

DESIGN CONSIDERATIONS

The design of millimeter-wave monolithic integrated circuits is a technical challange at the present time. Accurate models of circuit elements are well documented for microwave frequencies, but their accuracy above 26 GHz are generally unknown.

To tackle this problem, we have fabricated monolithic components and test patterns on GaAs substrates. These structures enabled accurate models of several basic circuit elements critical to our designs to be developed. Ring resonator structures were used to determine microstrip transmission line properties, metal insulator metal (MIM) capacitor models, junction effects, steps and bends at millimeter-wave. [4]

To design an amplifier, three types of HEMTs are available, ie, depletion, enhancement, and a device that is centered in between known as depletion enhancement mode. The gm peak for each of these types is shown in figure 1. For each type, a different equivalent circuit can be represented. Best performance was achieved with the centered depletion-enhancement mode device where gm peak corresponds to a Vgs peak close to 0.0 volts. The model and design is based on this type of device.

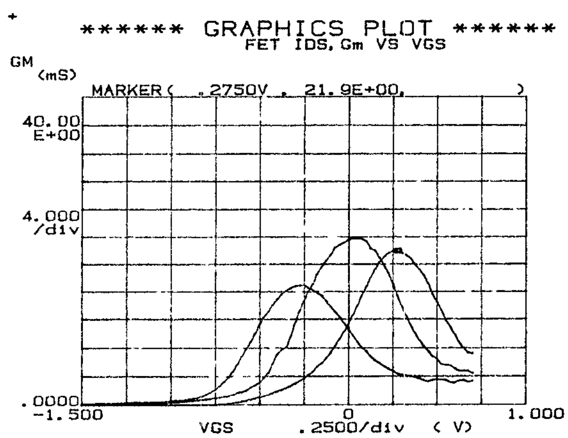


Figure 1.

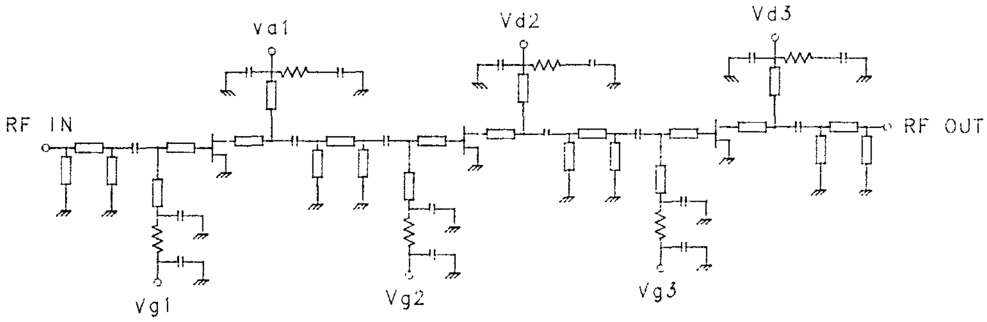
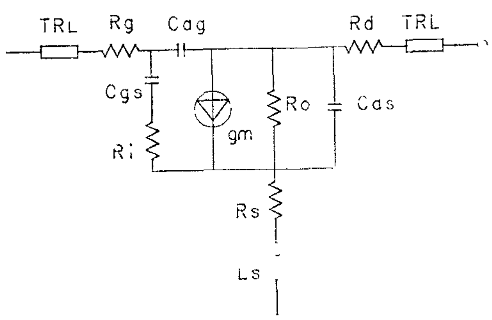


Figure 2. Circuit Schematic

The circuit design was kept as simple as possible to facilitate the diagnosis of the amplifier. Matching circuits for input, output and interstage (Figure 2) utilize tee and pi section structures consisting of transmission lines and shorted stubs. MIM capacitors were used for RF bypass and DC blocking applications while thin film resistors were used for low frequency stability. All grounding was achieved through via holes.

The design was based on a HEMT model derived from discrete device measurements. The initial element values were determined through DC characterization and on wafer S-parameter measurements (2 - 26 GHz) utilizing a Cascade Microtech Wafer Probe System. Wafer probing allows a more accurate model to be derived due to the absence of test fixture parasitics. The initial element values were then optimized using CAD tools. The resulting HEMT model (Figure 3) was then extended to Q-band to provide necessary S-parameters. From this, generation of equivalent input and output models were derived and used with filter synthesis procedures to arrive with the required matching circuits.

Input and output matching networks were synthesized to provide for best match to 50 ohms. Interstage matching was accomplished by synthesis for the best gain match between the output of the HEMT model to the input of the model.



ELEMENT	60um HEMT WAFER 30_2A
TRLg	0.25um x 20um
Rg	10 ohms
Cgs	0.045pf
Ri	2.3 ohms
Cag	0.0067pf
Ls	0.01nh
Rs	1.23 ohms
Gm	17.2ms
Tau	1.3ps
Rg	1280 ohms
Cas	0.11pf
Rd	8 ohms
TRLa	8um x 15um

Figure 3. HEMT Model

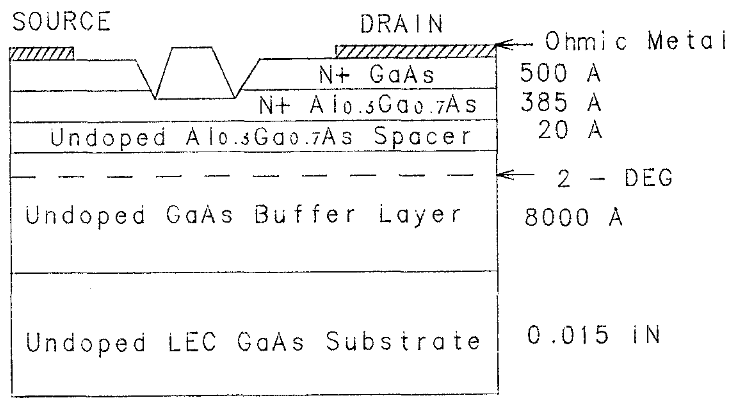


Figure 4. HEMT Cross Section

WAFER FABRICATION

The circuit was fabricated on an AlGaAs/GaAs heterostructure HEMT wafer grown on MBE. The device structure (figure 4) utilizes a TRW base line planar HEMT process.

The process begins with oxygen ion implantation to obtain device isolation and a planar process which is critical for uniform EBL gate processing. Gold-germanium metallization is used for ohmic contact metal to achieve contact resistance of less than 0.08 ohm/mm by using rapid thermal alloying. Thin film resistors (nichrome) are deposited for the biasing networks. First level metal (Ti-Au) is then deposited to form the matching network and bottom capacitor electrode. Electron beam lithography is used to define 0.2 - 0.25 um gate length resist patterns with Phillip Beamwriter system. Gate recess etching is performed followed by deposition. MIM capacitors, using a silicon dioxide insulator, are used to provide DC blocks and RF bypassing. Airbridges are used to reduce capacitor parasitics and to eliminate capacitor edge breakdown problems. Lift off technique is used for both dielectric deposition and air bridge metal deposition. The substrate is then thinned down to 0.1 mm thickness and via holes are etched. Finally, the backside is metalized and the wafer is scribed. A completed amplifier chip is illustrated in figure 5. This chip measures 1.4 x 2.7 mm.

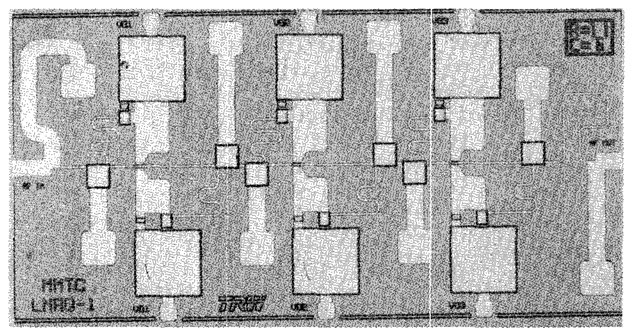


Figure 5. Amplifier Chip

AMPLIFIER CHARACTERIZATION

The amplifier chip was mounted into a Q-band test fixture utilizing finline transitions. The finlines (figure 6) were etched on polished 5 mil thick quartz. Insertion loss of two finlines back to back demonstrated 1 dB over a frequency range of 42 - 47 GHz. Return loss was generally better than 15 dB, worst case 11 dB at band edges (figure 7).

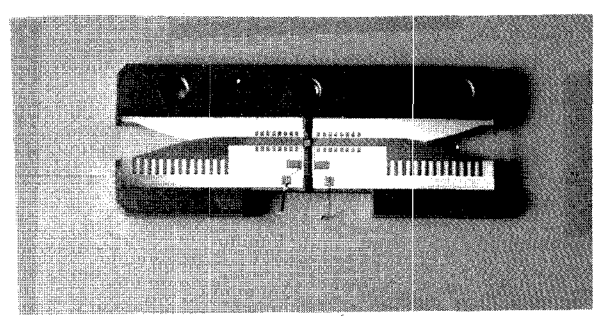


Figure 6. Finline Transition

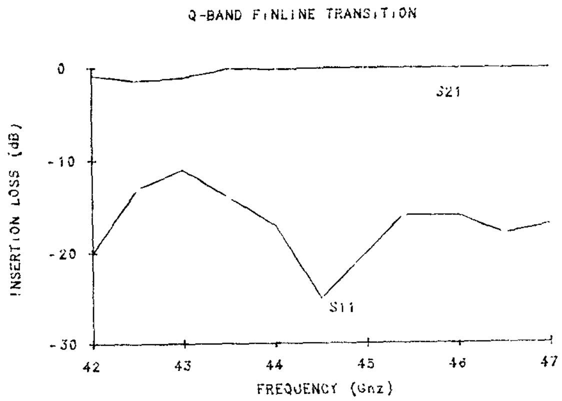


Figure 7. Measured Finline Transition Results

The amplifier gain and return loss were measured using an HP 8510B automated vector network analyzer and Q752D extension kit. Each stage was biased at 4.0 volts drain to source. Gate bias for each device was optimized to provide maximum gain which corresponds to gm peak for each HEMT device.

Measurements reflect actual performance of the Q-band MMIC amplifier chip with no external tuning to the chip or finline transition structures. Measured results (figure 8) show a peak gain of 16 dB at 44.5 Ghz with over 10 dB gain from 42 to 47.5 Ghz.

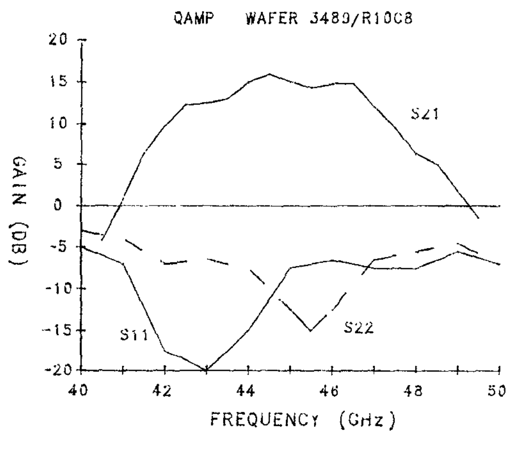


Figure 8. Measured Amplifier Results

CONCLUSION

A Q-band HEMT amplifier has been successfully developed to demonstrate the feasibility of HEMT monolithic technology at millimeter-wave frequencies. This work is a key step in advancing this technology into V and W band for future systems applications at MMW frequencies.

Futhur improvements of these monolithic circuits can be realized by recent technology advances in both design and processing. On wafer 50 GHz probes will enhance modeling accuracy for circuit design at higher frequencies. Also, with new developments in error-correcting, automated test equipment, new developments are within our grasp at millimeter-wave.

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