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GaAs Monolithic Components Development for Q-Band Phased Array Application*

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ABSTRACT

Major components for monolithic Q-band phased array applications have been developed using 0.2 μm doped channel pseudomorphic InGaAs/GaAs high electron mobility transistor technology. The components include a high gain, high efficiency monolithic amplifier and a three-bit switched line, monolithic phase shifter. At 44 GHz, measurement results of the amplifier demonstrates a small signal gain of 19.5 dB, and a power added efficiency of 20% at 3-dB compression point with an output power of 9 mW. The phase shifter has a measured insertion loss of 7.5 dB and a phase error smaller than 7^o from 43 to 45 GHz for all phase states. These components are suitable for monolithic integrated phased array transmitter applications.

INTRODUCTION

Monolithic millimeter-wave integrated circuit approach is an inevitable trend for the applications which require light weight, high reliability, low cost and mass producibility. A typical transmitting phased array antenna design will require critical elements such as high gain and high efficiency amplifiers and phase shifters. The objective of this work is to develop these components for a 44 GHz monolithic integrated phased array antennas.

Excellent gain and efficiency performance have been achieved by discrete devices [1-3] using pseudomorphic (PM) InGaAs/GaAs high electron mobility transistors (HEMTs) at millimeter-wave frequencies. Both monolithic low noise amplifiers (LNA) and power amplifiers have also been fabricated with good results using HEMT technology at Q-band [4-8]. For a monolithic integrated transmitting phased array system, high gain, high efficiency, low power amplifiers and low loss phase shifters are needed because of thermal consideration. This paper will present the design of a fully monolithic high gain, high efficiency Q-band amplifier and a three-bit phase shifter using PM InGaAs/GaAs HEMT technology. The measured results demonstrated a small signal gain of 19.5 dB, and a power added efficiency (PAE) of 20% at 3-dB compression point with an output power of 9 mW at 44 GHz. To our knowledge, this is the first reported monolithic high gain, high efficiency, low power amplifier at this frequency. The phase shifter has an average insertion loss of 7.5 dB for all phase states and a phase error smaller than 7^o from 43 to 45 GHz. The successful development of these components greatly enhance the viability of a monolithic phased array at 44 GHz.

DEVICE CHARACTERISTICS AND MODELS

A common HEMT structure was used for the high efficiency amplifier and the phase shifter for future monolithic integration of these two circuits. The device structure is a planar-doped channel PM InGaAs/GaAs HEMT whose cross section and gate geometry with a gate length of 0.2 μm are shown in Fig. 1. This is a derivative of the low noise PM InGaAs/GaAs HEMT design except an additional planar doping was introduced in the channel region to increase the device current capability. This also improves the transconductance linearity over a wider range of gate

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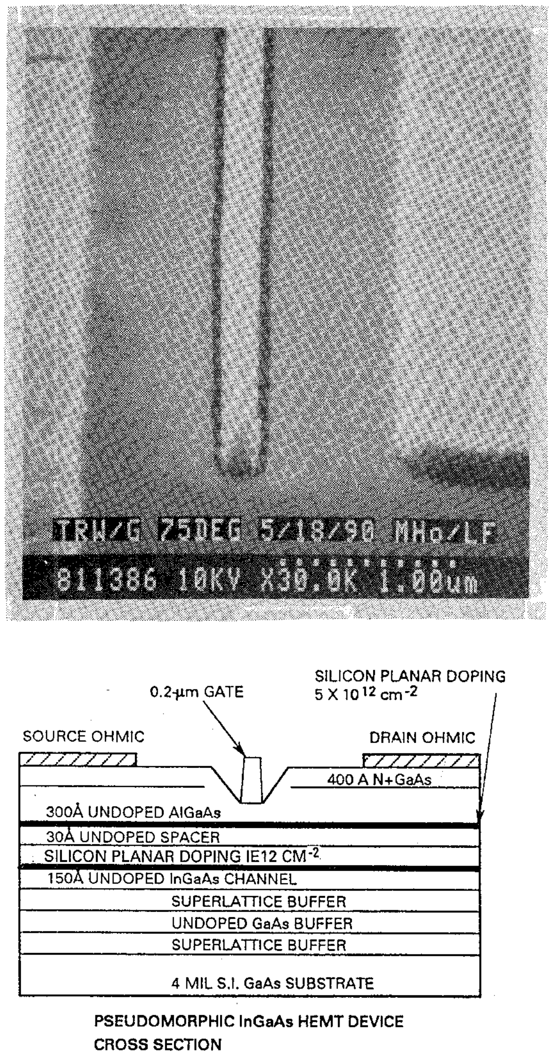


Fig. 1. (a) The cross section of the planar-doped channel PM InGaAs/GaAs HEMT. (b)The SEM photograph of the gate area.

voltage. By using the planar doping, high Schottky gate-drain breakdown of 9-12V are obtained.

Both active and passive PM HEMT linear models are obtained by curve fitting of the measured device small signal S-parameters using on-wafer probing technique up to 60 GHz. Thus the uncertainty from the frequency extrapolation is eliminated. The Curtice-Ettenberg FET asymmetric model was used to describe the device nonlinear behavior. The nonlinear transconductance coefficients are then obtained from fitting the DC I–V measurement of the devices.

HIGH EFFICIENCY MONOLITHIC AMPLIFIER DESIGN

The monolithic Q-band amplifier is a single-ended three-stage design. This approach offers the advantages of simple topology, small size and fewer transistors required over some other common high efficiency configurations such as push-pull design. The first two stages use HEMTs with 50 μm gate width and operate as class A amplifiers for gain consideration, while the third stage employs a 80 μm devices for power and efficiency requirements and operates at class AB.

A photograph of the monolithic amplifier is shown in Fig. 2 with the chip dimensions of 2.8 $\times$ 1.4 mm^2. The circuit was fabricated on a 100 μm thick GaAs substrate. The matching structures utilized series and shunt microstrip lines and open stubs. Metal-insulator-metal (MIM) capacitors were used for DC block and RF ground. Thin film resistors (TFRs) were added to each bias network to ensure unconditional stability. Each devices has two via holes for source grounding. The output stage matching network was designed for high efficiency, while the interstage and input matching networks were designed for gain and return loss. The harmonic balanced technique was used to perform circuit nonlinear simulation. An output power of 10 dBm with 22% PAE and a linear gain of 19 dB was predicted at 44 GHz.

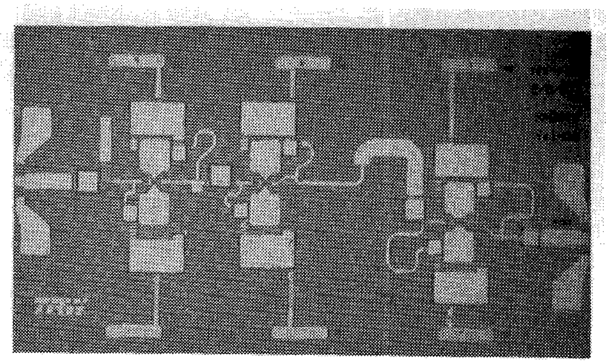


Fig. 2. The photograph of the monolithic Q-band three-stage high gain and high efficiency amplifier.

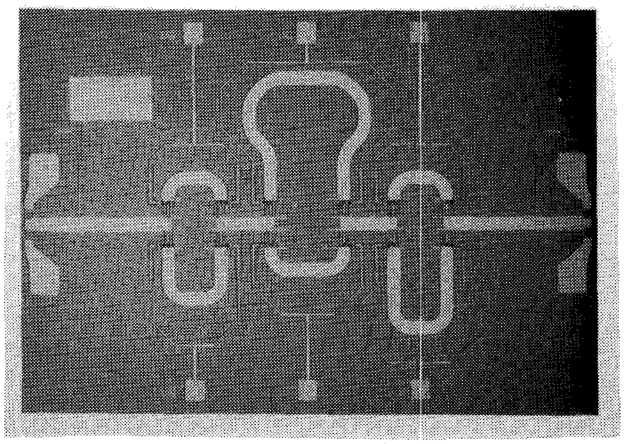


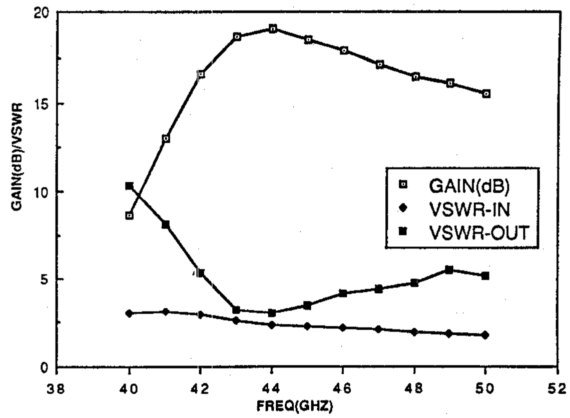
Fig. 3. The photograph of the monolithic Q-band phase shifter.

MONOLITHIC PHASE SHIFTER DESIGN

Fig. 3 shows a photograph of the monolithic phase shifter. The chip dimension is 2.8 × 2.0 mm^2. The phase shifter is a three-bit switched line design, similar to a K-band one reported earlier [9]. A single pole, double throw (SPDT) HEMT switch configuration is used for phase control. The phase shifts of 45, 90 and 180 degrees are achieved by three different microstrip time delay lines. Six control lines are used to switch six pairs of HEMT switches for desired phase shifts. Only a control voltage of 0 or 2 V is required to switch the HEMT between on and off states. Since the gates draw virtually no current, no DC power is consumed. A short section of transmission line was added in shunt with the device to resonate with the off-state HEMT capacitance at 44 GHz to enhance the isolation.

CIRCUIT PERFORMANCE

The measured small signal gain and input/output VSWR vs. frequency using on-wafer probing technique of the Q-band monolithic high efficiency amplifier are shown in Fig. 4(a). It demonstrates a small signal gain of 19.5 dB at 44 GHz. The measured output power, associated gain, and efficiency at 44 GHz of the monolithic amplifier in a test fixture are presented in Fig. 4(b). The drain bias voltages for first, second and third stage are 1.0, 1.3 and 2 V, and the drain to source current are 4.9, 6.6 and 13.4 mA, respectively. The amplifier has over 19 dB gain at -12 dBm input power and 20% PAE at 3 dB



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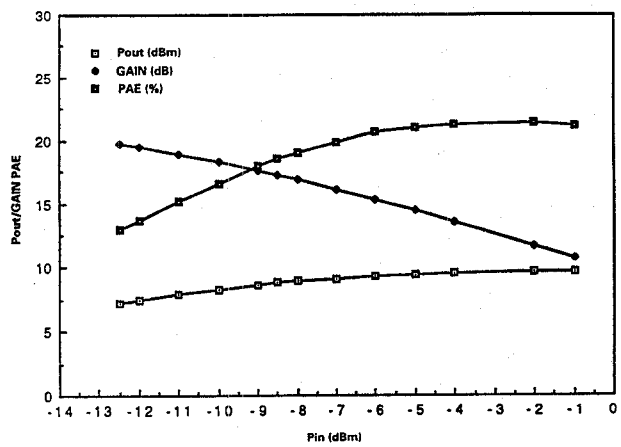
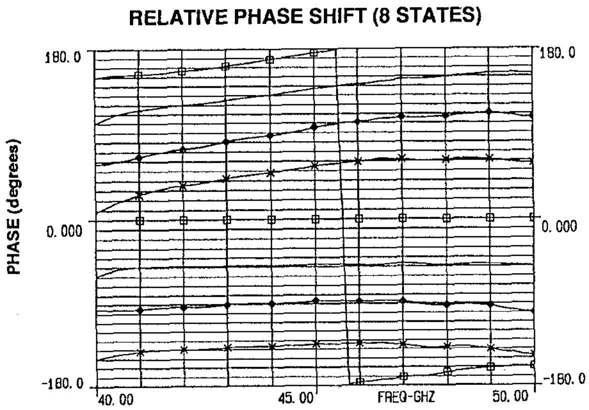


(b)

Fig. 4. (a) The measured small signal gain vs. frequency, and (b) measured gain, output power and efficiency as function of input power at 44 GHz for the monolithic Q-band three-stage high gain and high efficiency amplifier.

compression without any tuning on the matching structures. The RF yield of this amplifier on the best wafer is about 48%. The phase shifter has measured insertion loss of 7.5 dB and phase error smaller than 7^o from 43 to 45 GHz. Both input and output VSWR are better than 1.6:1. The frequency response of the phase shift and insertion loss for eight different state of the phase shifter are depicted in Fig. 5.



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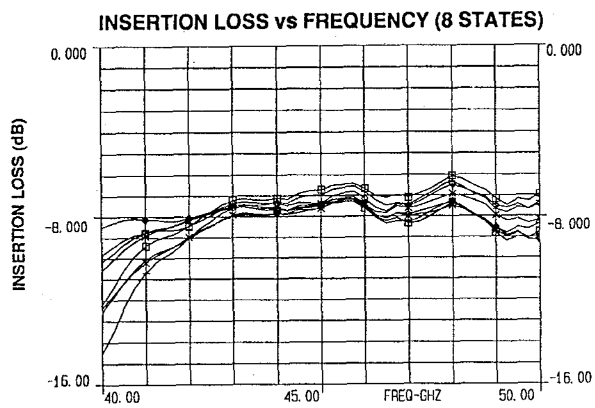

(b)

Fig. 5. (a) The measured phase shift and (b) insertion loss of 8 different states as function of frequency for the monolithic Q-band phase shifter.

SUMMARY

We have presented a Q-band monolithic high gain, high efficiency three-stage amplifier and a three-bit switched line, all pass monolithic Q-band phase shifter using 0.2 μm PM InGaAs/GaAs HEMT technology. The amplifier demonstrates state-of-the-art performance: 19.5 dB gain and 9 *mW* output power with 20% PAE at 44 GHz. The phase shifter has achieved insertion loss of 7.5 dB with phase error smaller than 7^o. These components are suitable for the monolithic integrated phased array antenna application.

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