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W-band Waveguide Amplifier Module with InP-HEMT MMIC for Millimeter-wave Applications

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Abstract

A waveguide (WR-10) power amplifier module with an InP-HEMT MMIC developed for millimeter-wave applications has 9 to 22 dB of small signal gain from 75 to 110 GHz and 16.5- to 18.5-dBm output power from 80 to 100 GHz with 5-dBm constant input power. The saturated output power is more than 100 mW from 82 to 98 GHz.

Introduction

Broadband and high-output power waveguide amplifier modules operating in the W-band are required for many applications, such as millimeter-wave spectroscopic systems, active imaging systems, and even broadband wireless access systems. Recently developed W-band MMIC amplifier chips exhibit significant output power and bandwidth [1,2]. However an economic waveguide module having both sufficient output power and enough operation bandwidth has still not been achieved.

In this paper, we present a broadband waveguide amplifier module with an InP-HEMT MMIC. Saturated output power of the module exceeds 100 mW from 82 to 98 GHz.

Circuit Design and Experimental Results

The 0.1-μm-gate InAlAs/InGaAs HEMT [3,4] was used with a MIM capacitor and double-layer interconnection process. The device typically has a unity current gain frequency f_t of 170-GHz and a maximum oscillation frequency f_{max} of 350-GHz. Maximum transconductance is 1.2 S/mm at DC. The HEMT small signal equivalent circuit parameters with 20-μm gate width were obtained from a careful fit of the measured small signal S-parameters to 110 GHz [5]. Pad parasitics were de-embedded and intrinsic parameters for FET were extracted for circuit design. The MMIC amplifier consists of four medium power amplifiers (MAMPs) and on-chip power splitters/combiners as shown in Figs 1 and 2. Each MAMP is a four stage source-common design with 1, 2, 4, and 8 identical transistor cells in the 1st, 2nd, 3rd, and 4th stages, respectfully. All transistor cells have four FETs with 20-μm gate width, resulting in a 640-μm total periphery for the final stage of MAMP and a 2560-μm total output periphery for the chip. The gain of the first stage of MAMPs can be controlled by applying negative gate bias voltage externally. The other stages have an internal gate bias circuit to simplify assembly. Some applications require low input return loss during gain control. Therefore, we added a 3-dB attenuator at the input port of the amplifier to suppress the variation of S11 induced by gain control. Coplanar lines with 2.5-μm metallization thickness were used for all matching networks, together with MIM capacitors and WSiN resistors. Instead of an air-bridge, double-layer interconnection was used to short grounds at all discontinuities of coplanar lines to prevent the odd-mode from propagating. The use of miniaturized coplanar lines and lumped MIM capacitors in RF circuits allows us to reduce electromagnetic simulation time and dramatically reduce chip size and still maintain sufficient simulation accuracy. For broadband operation, low-pass-filter matching networks were employed for input, output, and the interstages for the MAMPs. High impedance coplanar lines and shunt MIM capacitor were used to design an equivalent low-pass π network and its combination in a narrow space. The MMIC amplifier is mounted in metal package, which incorporats WR10 (75-110 GHz) waveguides for signal input and output. Figure 3 shows a photograph of the W-band module. The amplifier MMIC was connected to input and output waveguides via conventional *E*-plane probe-type waveguide-to-microstrip transitions fabricated on metalized 150-μm-thick quartz substrates. Figures 4 and 5 show measured S-parameters of the waveguide module at various bias voltages. S-parameters were measured with a vector network analyzer (HP8510FX). Figure 4 indicates the drain bias voltage (VD) for high-gain operation should be from 1.3 to 1.5 V. This amplifier module has 9 to 22 dB of small signal gain from 75 to 110 GHz at VD=1.5 V. At VD of less than 1.5 V, the gain flatness is improved, though the bandwidth becomes narrow. The control range of the small signal gain is 15 dB from 75 to 105 GHz at VD=1.5 V with input return loss kept at less than -8.3 dB (VSWR 2.3) as shown in Fig. 5. This gain control function with stable input return loss eliminates the need for a variable attenuator module in some millimeter-wave applications.

Figures 6 and 7 show the input and output properties of the amplifier module. The measurement was performed with an isolator (MRI FRW-110) at the input and output port of the amplifier module. The saturated output power is more than 100 mW from 82 to 98 GHz. The amplifier module has 16.5- to 18.5-dBm output power from 80 to 100 GHz with 5-dBm constant input power.

References

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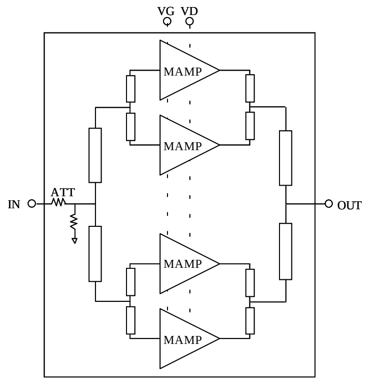

Fig. 1. Configuration of the amplifier MMIC.

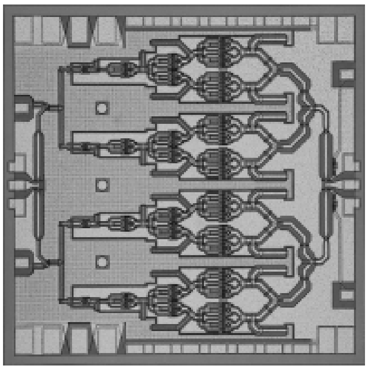

Fig. 2. Photograph of the MMIC amplifier chip (chip size:2.0 x 2.0 mm).

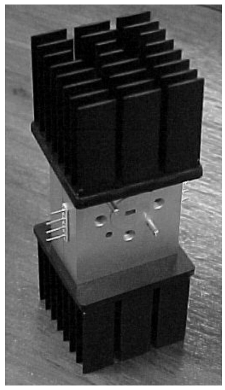

Fig. 3. Photograph of the amplifier module with heat sink.

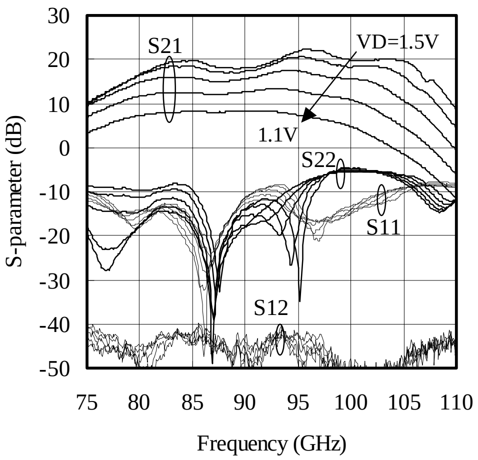

Fig. 4. Measured S-parameters with various VD (VG=0 V, VD=1.1, 1.2, 1.3, 1.4, and 1.5 V).

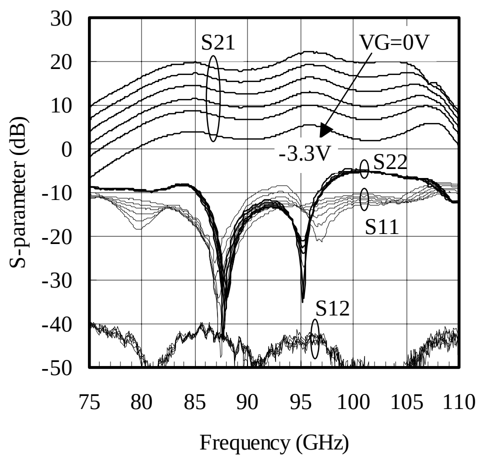

Fig. 5. Measured S-parameters with various VG (VD=1.5 V, VG=0, -2.0, -2.5, -2.8, -3.0, and -3.3 V).

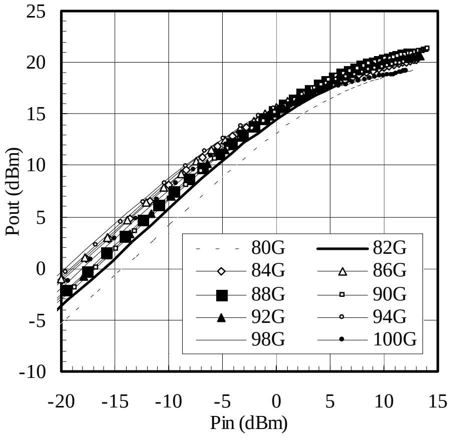

Fig. 6. Input and output properties of the amplifier module at VD=1.5 V and VG=0 V.

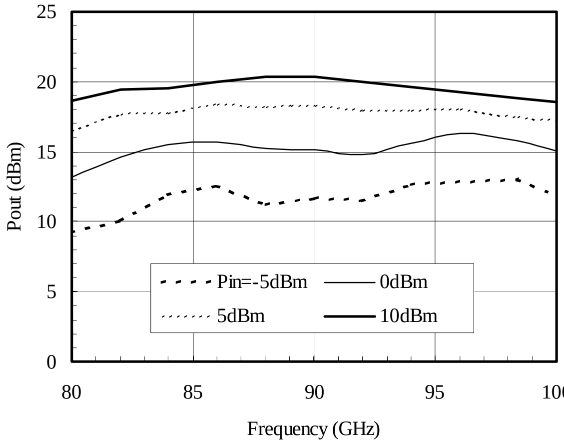

Fig. 7. Input and output properties of the amplifier module at VD=1.5 V and VG=0 V.