A HIGH POWER AND HIGH EFFICIENCY MONOLITHIC POWER AMPLIFIER FOR LOCAL MULTIPOINT DISTRIBUTION SERVICE

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ABSTRACT

A high power and high efficiency monolithic power amplifier operating from 27.5 to 29.5 GHz is presented for local multipoint distribution service (LMDS). Using 0.15 μm InGaAs/AlGaAs/GaAs pseudomorphic HEMT (PHEMT) devices, the two stage power amplifier on 4 mil GaAs substrate demonstrated greater than 16 dB small signal gain, 32 dBm (1.6 watts) power with 35% power-added-efficiency. The amplifier attained peak output power of 33.9 dBm (2.4 watts) and peak power-added efficiency of 37%. At the peak power level, the amplifier exhibited power densities in excess of 640 mw/mm which is the highest output power density attained by Ka-band monolithic power amplifiers.

INTRODUCTION

With the emergence of local multipoint communication service (LMDS), there is now considerable activity in Ka-band. In order to provide communication services such as television, video-on-demand, distance learning, internet access, interactive games as well as a host of other services to homes, various system architectures are being implemented.

In a typical analog FM system operating in 27.5 to 29.5 GHz, 20 MHz wide FM channels are used to broadcast video. A local multipoint distribution service (LMDS) system in a cellular network consisting of low power transmitters operating in 1 GHz bandwidth, provide transmission to the subscribers, as shown in Fig. 1 [1]. Newer digital QPSK systems use typically 40 MHz channels to provide high capacity data transfer.

This tremendous need has created considerable interest in the development of Ka-band high power and high efficiency amplifiers. Transmit power of 1 watt is required for various system implementations.

Solid state discrete devices in a MIC amplifier can be used to achieve the desired power level. The large periphery devices used in high power amplifiers present very low impedance levels. The variations in assembly fabrication process invariably require extensive assembly, test and tune operations which result in modules with high cost. The power MMICs, on the other hand, offer small size, reproducible performance, and high reliability. They are also highly cost effective due to minimum or no tuning requirements in module fabrication process.

For LMDS applications, Siddiqui and Sharma *et al* [2] presented a hybrid power amplifier which produced 8.75 dB small signal gain, 39.6% power-added-efficiency, and 37 dBm (5.0 W) from 27.5 to 29.5 GHz. At this power level, amplifier power density was 780 mW/mm. This is the best power density achieved using HEMTs on a 1.2 mil GaAs substrate.

Recently, Yarborough, Saunier and Tserng [3] presented performance comparison of 1 watt Ka-band MMIC amplifiers realized using pseudomorphic HEMTs and ion-implanted MESFETs. The power amplifier using pseudomorphic HEMTs achieved greater than 20 dB gain, 35% power-aided-efficiency from 26.5 to 28 GHz. It utilized four 600 μm cells, to achieve 1 watt power level and exhibited power density of 417 mW/mm. The power amplifier using 0.2 μm MESFET also achieved 1 watt power with 18 dB gain and 24% power-aided efficiency.

Ingram *et al* [4] also presented a 6 watts power amplifier utilizing monolithic amplifiers on 2 mil GaAs substrate producing 35.4 dBm (3.47 watts) output power with 11.5 dB gain and 28% power-aided efficiency. The power density of the output devices was 516 mW/mm.

A comparison of various Ka-band power

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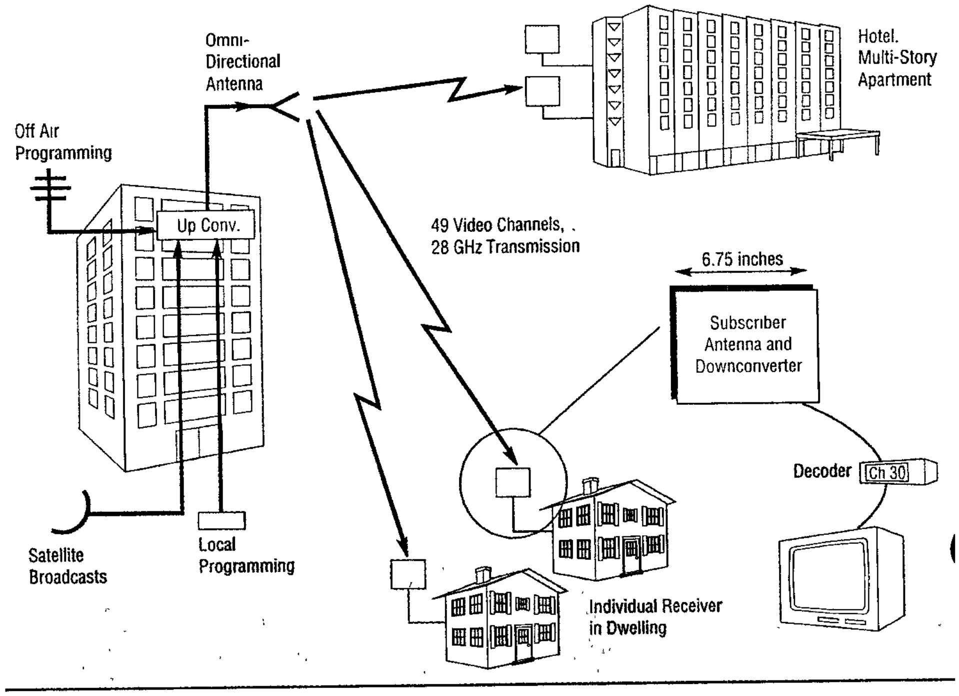

Fig. 1 Local multipoint distribution Service (LMDS) System.

amplifiers in terms of output power density is provided in Table I. It is clearly seen that the power density of 780 mW/mm, presented in [2], is still the best power density achieved by a hybrid MIC amplifier.

In general, it is possible to attain high efficiency and high power density with smaller periphery devices. However, the power amplifier design challenge is to achieve high efficiency at high output power levels. An additional challenge in the design of monolithic power amplifier is to achieve power densities somewhat closer to that achieved by MIC power amplifiers which are usually tuned to get the best performance from devices.

With that objective in mind, we designed a power amplifier operating in 27.5 to 29 GHz band. This power amplifier demonstrated greater than 16 dB small signal gain, 32 dBm power with 35% power-added-efficiency. The amplifier attained peak output power of 33.9 dBm (2.4 watts) and peak power-added efficiency of 37%. At peak power level, the amplifier exhibited power densities in excess of 640 mW/mm which is closer to the earlier results of 780 mW/mm [2]. This paper will present details of design approach, process and measured performance of this monolithic power amplifier.

Table I Comparison of Ka-band Power Amplifiers

Frequency Range (GHz)	Output Power dBm (Watts)	Power density (mW/mm)	Reference
18-19	37.2 (5.248)	540	5
27-30	37.0 (5.000)	783	2
27-30	30.0 (1.000)	417	3
27-30	33.9 (2.454)	640	This Paper
34-36	30.0 (1.000)	312	6
34-36	35.4 (3.467)	516	4
34-36	37.8 (6.025)	448	4

DEVICE AND PROCESS TECHNOLOGY

The pseudomorphic InGaAs/AlGaAs/GaAs HEMT devices have been engineered to provide high breakdown voltage and high current densities. They also provide high gain and power-added efficiency at millimeter wave frequencies. To improve the breakdown voltage, the AlGaAs layer is left undoped and the Schottky gate is recessed to this undoped region. Furthermore, to increase the current density, an additional planar doping is employed to increase

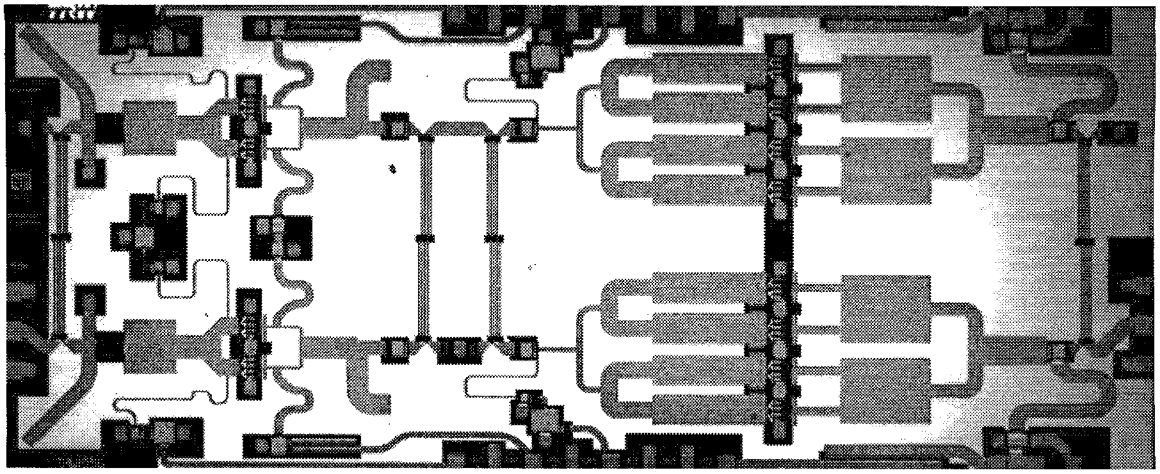

Fig. 2 Photograph of 28 GHz monolithic power amplifier.

the amount of charge in the 2-dimensional electron gas. The device optimization was performed to ensure high aspect ratio which is defined as the ratio of gate length to the gate to channel separation. This enables the device to provide high gain, high efficiency as well as high cut-off frequency for millimeter wave operation. Typically, for a 0.15 µm gate length devices, gate to drain voltage of greater than 12 volts (measured at 0.1 ma/mm), maximum channel current of 500 ma/mm, transconductance of 550 mS/mm, and f_t greater than 75 GHz is obtained. TRW's power HEMT process is capable of providing better than 800 mW/mm, as documented in [2].

POWER AMPLIFIER DESIGN

The amplifier uses 0.15 µm x 320 µm and 0.15 µm x 480 µm devices as a basic cell for use in in-phase multi-cell matching. The first stage uses 1.28 mm periphery devices to drive 3.84 mm output stage devices. The amplifier is developed on 4 mil GaAs substrate. The design employed simple transmission line elements to transform the device optimum load to moderate impedance level. We used a Curtice nonlinear model to design this amplifier [7]. Figure 2 shows the photograph of the amplifier. The amplifier provides unconditional stability under all load conditions.

POWER AMPLIFIER PERFORMANCE

The amplifiers were initially tested for output power as a function of frequency at a given input power using an on-wafer pulse power test set. The test data show consistent 1 watt performance with RF functional yield greater than 70%. Several amplifiers were then assembled in a test fixture and they also achieved consistent performance.

The performance of the amplifier is shown in Fig. 3. It shows output power, gain and power-added efficiency performances of the amplifier at 27.5 GHz biased for high efficiency operation.

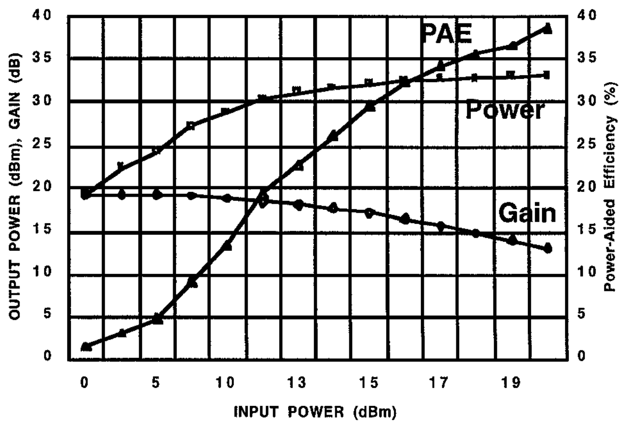

Fig. 3 Measured performance of the amplifier at 27.5 GHz for high efficiency operation.

Figure 4 shows the same performance parameters at 29 GHz for high power operation. A typical power-aided-efficiency and output power as a function of frequency is shown in Fig. 5. Figure 6 shows maximum output power as a function of frequency. The output power density of the devices ranges from 570 mW/mm at bandedges to 700 mW/mm at 29.5 GHz.

To our knowledge this is the first time that the performance of monolithic power amplifier in terms of power density is close to that achieved by hybrid MIC amplifiers and is approaching that of HEMT devices. The results are consistent since our 2 mil and 4 mil

GaAs MMICs, and 1.2 mil GaAs discrete devices use the same process and device structure.

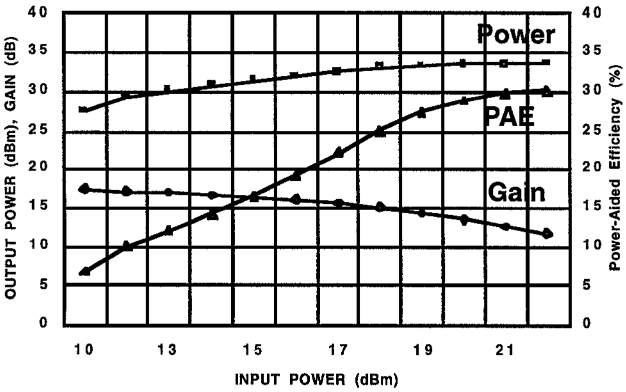

Fig. 4 Measured performance of the amplifier at 29 GHz for high power operation.

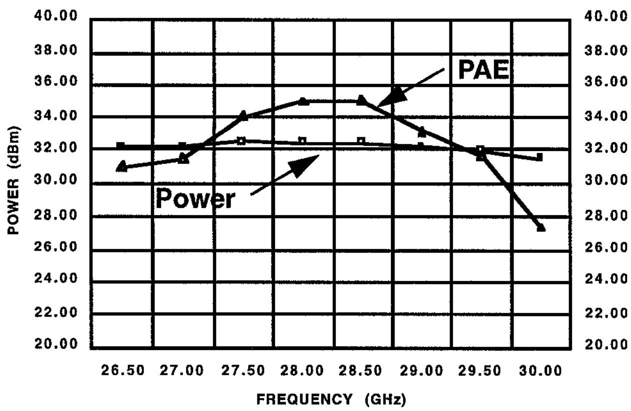

Fig. 5 Measured output power and power-aided-efficiency of the amplifier as a function of frequency. Input power =21 dBm.

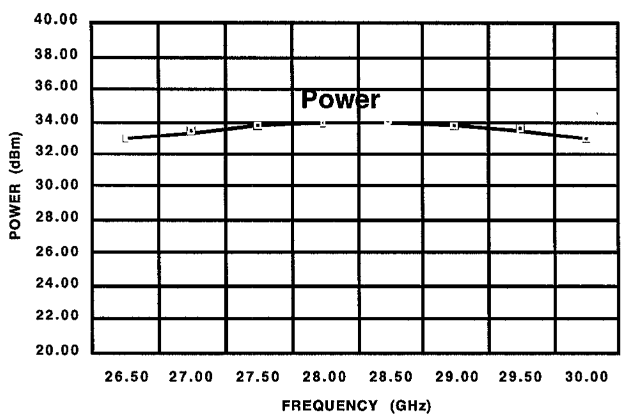

Fig. 6 Measured output power as a function of frequency. Input power =22 dBm.

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