A 100GHz Medium Power MMIC Amplifier with 15dBm Output Power on a GaAs Substrate

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Abstract - *The design and measurement of a PHEMT MMIC medium power amplifier, designed on 2mil thick GaAs substrate for operation at 100GHz is described here. The unconditionally stable design has over 20dB gain, with saturated output powers in excess of 15dBm at 100GHz whilst using a 4V bias supply. The paper discusses the design methodology and the limits that GaAs MMIC designers are increasingly facing as higher frequency designs become more common and focuses on the trade-off between power and gain as the devices approach their operational limits.*

INTRODUCTION

Since 1976 when the first monolithic microwave integrated circuit, or MMIC, using a field effect transistor was reported by R. S. Pengelly [1], MMIC circuit complexity and operational frequency has continued to increase. In addition while the reliability of MMICs manufactured on Si and GaAs are well understood [2] and with many MMICs having been qualified for space-borne applications [3] - [6], as the frequency of operational communications increases, circuit designs that now appear trivial at lower frequencies become increasingly difficult. In security applications mmWave scanning is commonplace where whole body scanning type machines are often used at airports and where objects can be detected underneath a person's clothing. Since clothing becomes translucent or invisible at mmWave frequencies, there is an advantage in using scanners which operate at higher frequencies and specifically in W-band.

For future space technologies, W-Band solid-state amplifiers continue to garner interest in space instrumentation for earth observation and Van Heijningen has demonstrated good performance using both AlGaN/GaN materials and GaAs MHEMT technologies [7]. Xiaobin [8] has also demonstrated how AlGaN/GaN can be used to demonstrate high power levels at mmWave frequencies although the higher voltage requirement may prove restrictive to some applications. As a consequence, many recent MMIC developments have been at W-Band.

In this paper the design of a 100GHz medium power amplifier which uses a GaAs PHEMT technology is presented. As the usuable frequency of operation for the technology is approached, the maximum available gain of the devices are lowered and the chip designer has to make a trade-off between a device gain or power match and this balance is discussed.

BACKGROUND

The 100GHz power amplifier was manufactured on a 0.1µm single recess PHEMT process with an f_T of 130 GHz and a reported power density of 860 mW/mm at 4V drain bias when measured at 29GHz [9]. Work carried out by Bahl [10] has shown that as the frequency of operation increases, the use of microstrip structures on thicker substrates become impossible, Figure 1:-

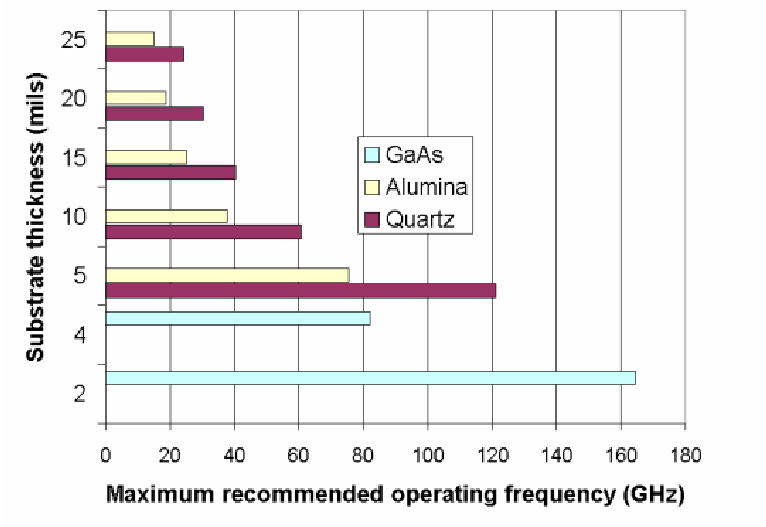


Figure 1:- Maximum Operating Frequency on different Substrate Thicknesses

Thus the circuit is designed on a 50um substrate thickness, using a process Design Kit on Keysight's Advanced Design System (ADS) simulator [11]. It is well known that the gain of a device drops as its operating frequency is increased and as f_T is approached its use in practical applications therefore becomes limited. The gain of the device is also inversely proportional to the gate width while the available power is directly proportional to the gate width. In addition whilst the matches to the device for maximum gain and power are different, Cripps has shown that the reduction in power when the conditions for maximum gain are presented to the device, is about 2dB [12].

As a figure of merit the output stage of a power amplifier is chosen to have a minimum gain of 6dB (to account for the stage going into saturation and to allow a reduction of power out of the driver stage) and although these conditions require that the driver stage gate periphery should not be reduced, the design constraints can be approximately defined.

In reality however, the largest device possible is matched for maximum gain at 100GHz with the resulting power defined by the number of these devices that can be added in parallel.

DESIGN AND MEASURED RESULTS

The 100GHz amplifier, which incorporates a 4-stage design using a basic 4x25um unit transistor cell, is shown in Figure 2:-

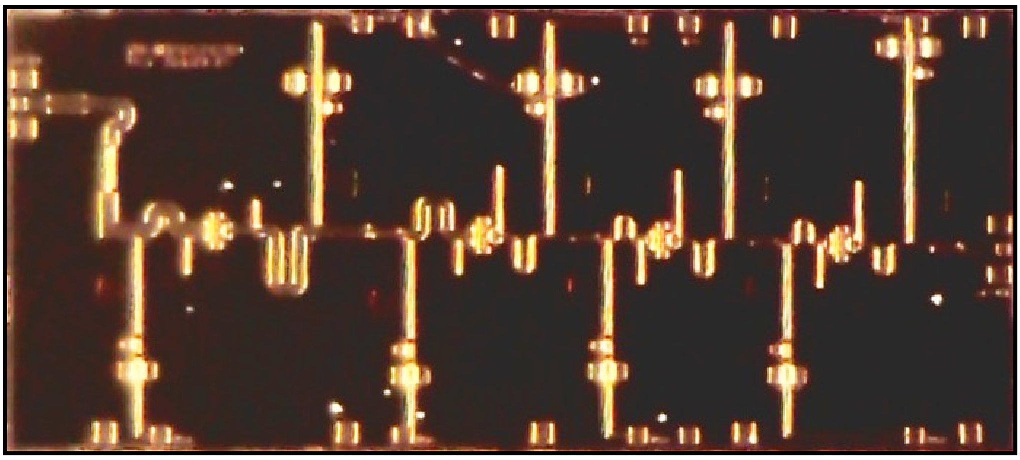


Figure 2:- 100GHz Medium Power Amplifier

As described in the previous section, it was known from the beginning that the gain / power balance was going to present a challenge and so ultimately the unit cell matching circuitry was chosen to allow the maximum gain per stage (i.e. a conjugate match). As gain is increased with a smaller gate periphery, the size of the unit cell was also varied to assess the available output power when presented with a conjugate gain match until, ultimately, the unit cell size of 4x25um was chosen. This device size showed about 6.5dB of gain with a calculated output power of 19dBm. As the power calculation was based on power density measurements taken at 29GHz [9], it was assumed (and indeed simulated) that this could be up to 5dB lower at W-Band, and so the amplifier was designed with a simulated gain of 24dB and simulated saturated output power of 15dBm. Whilst the power matching conditions require that the driver stage must remain at the same gate width periphery as the output stage, smaller unit cells could be used for stages 1 and 2 although the decision was taken to keep these at the same size.

The resulting measured gain is shown as a function of current per stage in

Figure ***3***, with the input and output return losses for the same conditions shown in Figure 4. In all cases the drain voltages were kept constant at 4V as this is the condition for maximum power when the device breakdown voltage is considered [12].

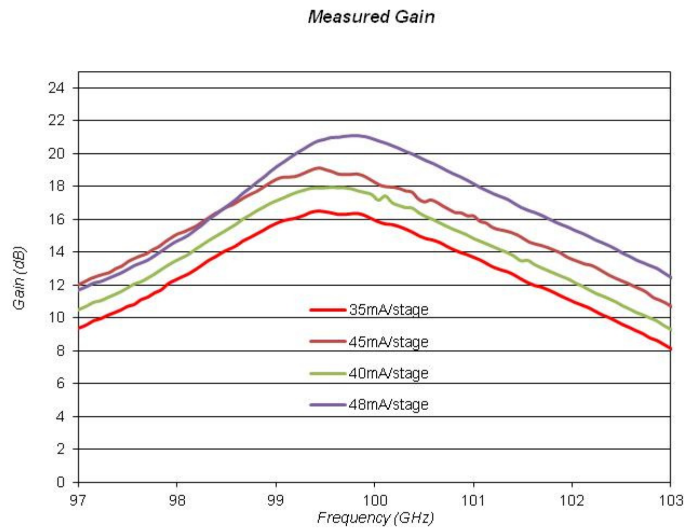


Figure 3:- Measured Gain as Drive Current is Increased for V_{DD}=4V

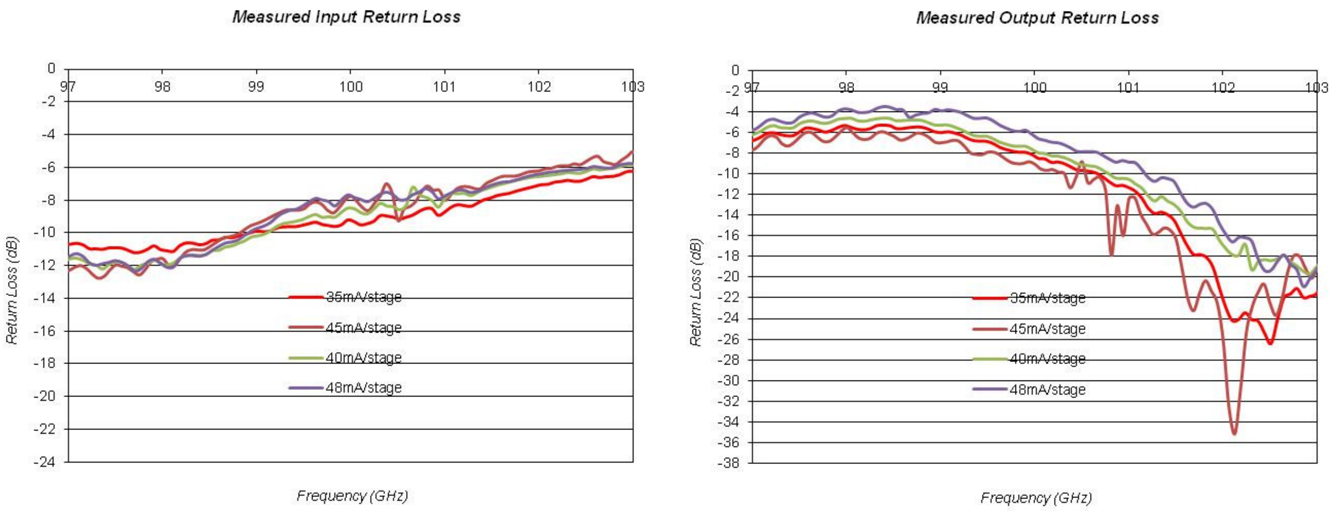


Figure 4:- Measured Return Loss as Drive Current is Increased for V_{DD}=4V

One of the main constraints of a usuable amplifier is to ensure that the amplifier is unconditionally stable. This is largely maintained by introducing out-of-band stability networks on the bias feedlines and by ensuring that the devices are unconditionally stable in-band. The resulting measured stability graph shows that the amplifier is unconditionally stable:-

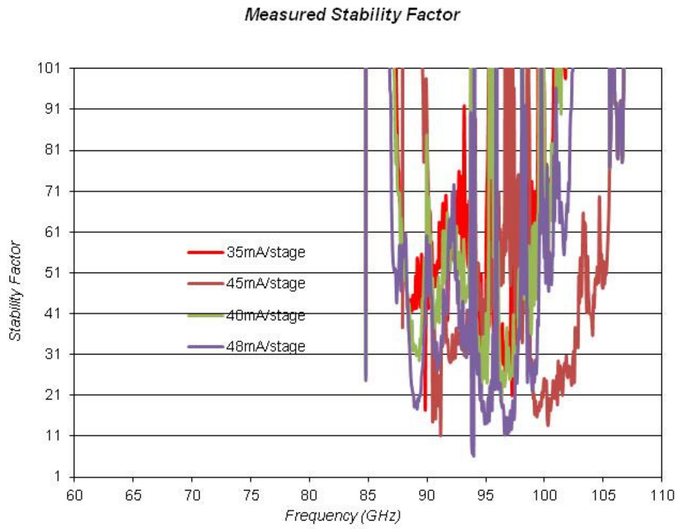


Figure 5:- Measured MPA Stability Factor

The power measurements were performed at chip level using the setup shown in Figure 6, with the results shown in Figure 7:-

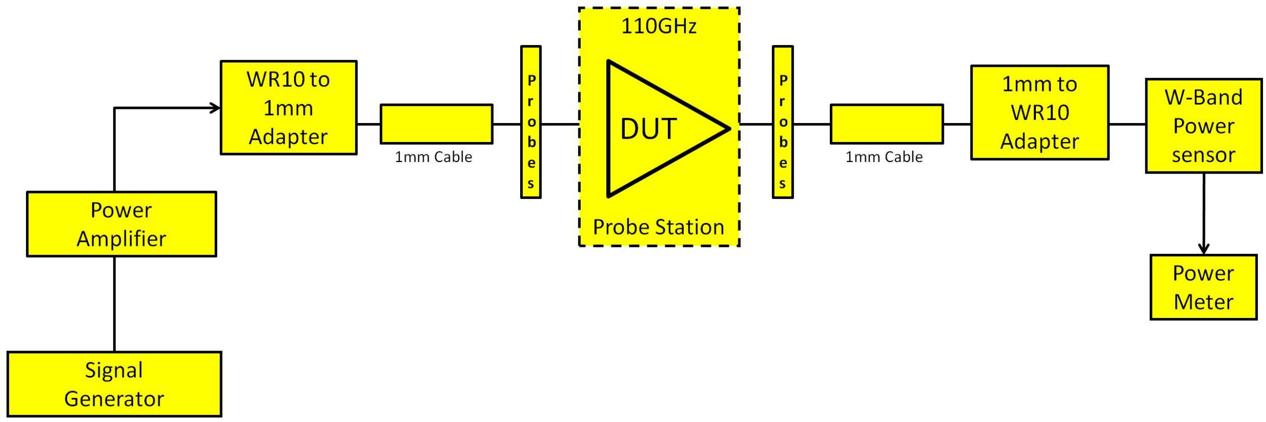
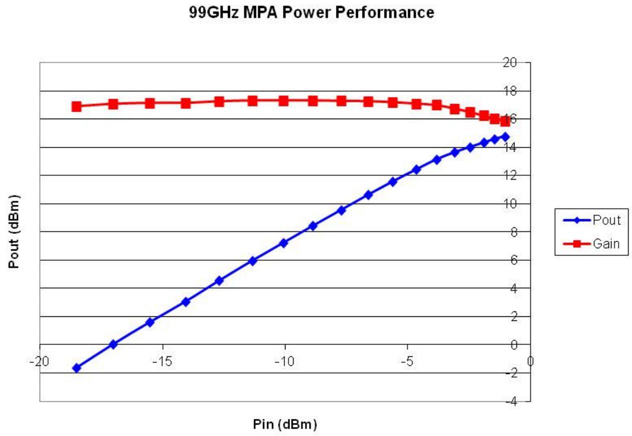


Figure 6:- Power Measurement System



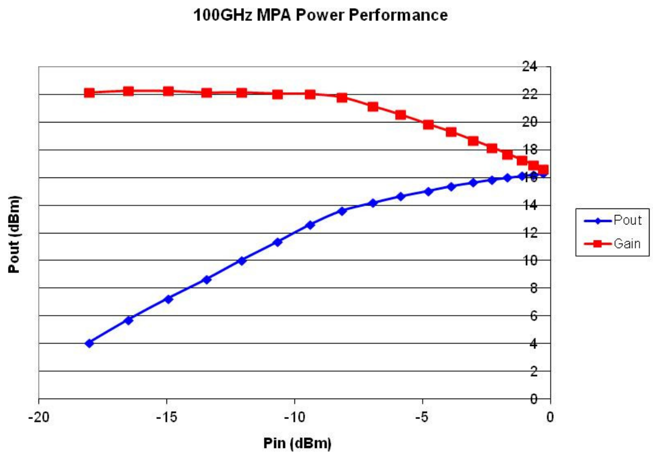


Figure 7:- MPA Power Measurements at 99GHz and 100GHz

Although the measured results show some deviation from the simulated models [11], particularly with regards to the overall gain, the amplifier achieved good gain and power performance at 100GHz.

CONCLUSIONS

The design of a 100GHz medium power amplifier has been presented using a 50um GaAs material and a 0.1um gate length PHEMT technology. The common-source amplifier yields over 16dBm output power with gains in excess of 20dB and although there are slight discrepancies between the transistor models and measurements in W-Band (particularly in gain), the device models have been shown to be accurate enough to allow circuit designs to be completed.

ACKNOWLEDGEMENTS

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