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A W-BAND MONOLITHIC AMPLIFIER

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ABSTRACT

Monolithic amplifiers at 90 GHz have been fabricated using 75um GaAs MESFET and Pseudomorphic HEMT (PHEMT) devices. The sub .2um gate length PHEMT devices have demonstrated an F_t of 100GHz and an F_{max} of 200GHz. Monolithic MESFET and PHEMT single stage amplifiers have achieved 3.5 dB and 7 dB gain respectively at 90 GHz.

INTRODUCTION

Recent advances in GaAs materials and electron-beam lithography have made it possible to build amplifiers that operate at the higher millimeter-wave frequencies beyond W-band [1]. This paper reports the results for the first published monolithic W-band amplifier using MESFET or PHEMT GaAs materials. The results published to date show monolithic PHEMT data up to 60 GHz [2]. Other hybrid results using PHEMT or InP based HEMTs have been published at W-band [1,3]. This paper describes a single stage monolithic amplifier chip that operates from 85 to 95 GHz. This monolithic amplifier has been processed using state of the art sub .2um MESFET or PHEMT devices. Typical performance for the W-band amplifier is 3.5dB of gain for the MESFET and 7dB gain for the PHEMT at 90 GHz. The monolithic chip size is 0.75 x 0.35 mm.

DEVICE AND FABRICATION

The devices used in this monolithic design were made using MBE material. A schematic diagram showing the cross section of the PHEMT structure used on this MMIC is shown in Figure 1.

The gates were defined using electron-beam lithography resulting in gate lengths ranging from .12 to .17um. The gate cross sectional area was also increased by making it in the shape of a mushroom in order to reduce gate parasitic resistance. Figure 2 shows a SEM micrograph of the typical cross section of the mushroom gates.

The device layout used in this design consisted of an interdigitated 75 um structure made up of a single gate feed which branches into two parallel gate fingers of 37.5 um length.

From measured s-parameters, the MESFETs have an F_t of 60 GHz and an F_{max} of 120 GHz while the PHEMTs have an F_t of 100 GHz and an F_{max} of 200 GHz. Figure 3 shows the maximum stable gain and the current gain for the 75um device measured with an on-wafer probe S-parameter system up to 26.5 GHz. From this data, one can

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observe that the K-factor is less than 1 at 26.5 GHz. This is due to the reduced parasitics in the device design thus conserving all the available gain and power produced by the active area of the device.

The typical dc characteristics of the PHEMT devices are an I_{dss} of 15 mA (.2A/mm) with a pinch-off voltage of -0.6 V and a transconductance of 40 mS (.53S/mm). The I_{max} for the PHEMT devices is typically 30 mA (.4A/mm) which occurs at a gate bias of +0.6 V and a dc gate to drain breakdown of 6 V. The typical dc characteristics of the MESFET devices are an I_{dss} of 25 mA (.33A/mm) with a pinch-off voltage of -1 V and a transconductance of 30 mS (.4S/mm). The I_{max} for the MESFET devices is typically 45 mA (.6A/mm) which occurs at a gate bias of +0.8 V and a dc gate to drain breakdown of 10 V.

The monolithic design made use of via-holes for source grounding, air-bridges for interconnect, and MIM capacitors using silicon nitride for RF grounding and dc blocking. In order to increase the yield and avoid reliability problems, the MIM capacitors were not placed on top of via-holes in this design.

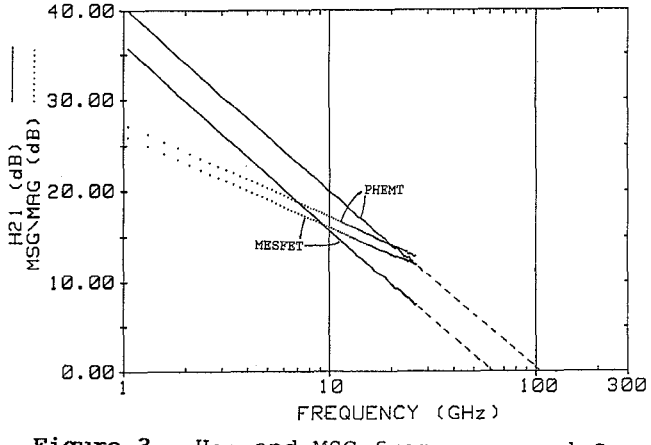


Figure 3. H_{21} and MSG from measured S-parameters for 75x.15 um devices. This shows an F_t of 60 GHz with an F_{max} of 120 GHz for the MESFET and an F_t of 100 GHz with an F_{max} of 200 GHz for the PHEMT.

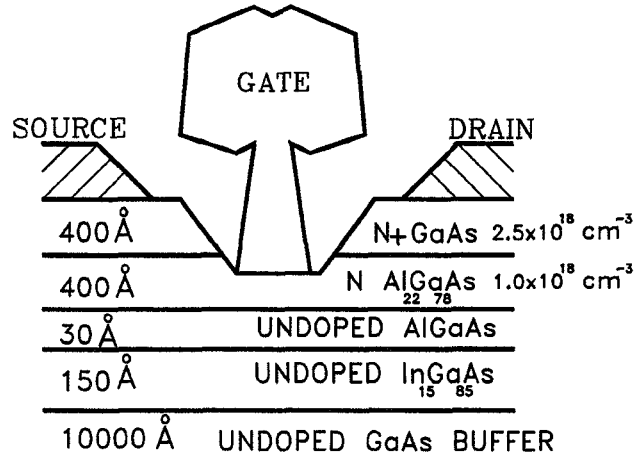


Figure 1. Schematic diagram for the vertical structure of the PHEMT.

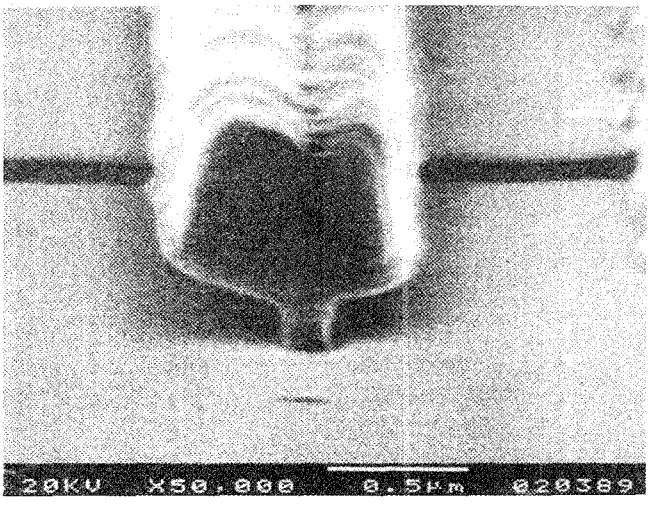


Figure 2. Cross sectional SEM micrograph of the sub .2um mushroom gate.

MONOLITHIC W-BAND AMPLIFIER DESIGN

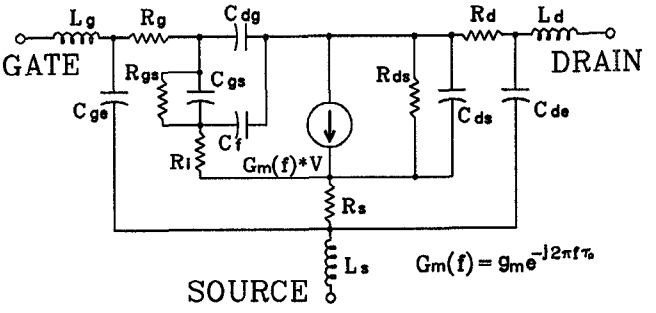
The W-band monolithic design relied on accurate device modeling in order to achieve reasonable correlation between measured and simulated data. The model was derived from s-parameter data taken up to 26.5 GHz. With the aid of on-wafer probing, accurate s-parameter data was available which made it easy to construct an accurate small signal model. The element values of the 75um MESFET and PHEMT device used in this monolithic design are shown in Figure 4.

Small signal analysis was then used to establish the design. The W-band design makes use of a 75 um interdigitated FETs. The equivalent circuit for this design is shown in Figure 5. Both input and output matching circuits consisted of a series transmission line, an inductor to ground (also used for biasing), another series transmission line, and shunt capacitive stub. The monolithic design made use of via-holes for source grounding, air-bridges for interconnect, and MIM capacitors for RF grounding and dc blocking. At W-band, the inductors to ground on both the input and output matching networks consist of an air-bridge to an MIM capacitor as shown in the CAD layout of Figure 6. In this layout, one can observe the redundancy of transmission lines and air-bridges put in place to facilitate tuning on the MMIC if required. The data given in this paper is for the untuned MMIC. A picture of the monolithic amplifier is shown in Figure 7. The chip size for this monolithic amplifier is 0.75 x 0.35 mm.

The gain for a MESFET and a PHEMT amplifier is shown in Figure 8. The measured versus simulated frequency response has about 5% frequency shift. Considering that the device data was extrapolated from 26.5 GHz S-parameter data and the inaccuracies of the planar circuit simulation at W-band, the simulated and measured data are close. This monolithic chip has demonstrated 7 dB gain with PHEMT devices and 3.5 dB gain with MESFET devices. The PHEMT MMIC operates at a slightly higher frequency than the MESFET one. This occurs since the input capacitance of the MESFET is slightly higher than that of the PHEMT device.

CONCLUSIONS

A monolithic W-band amplifier using either MESFET or PHEMT technology has been demonstrated. This monolithic chip has demonstrated 3.5 dB gain with MESFETs and 7 dB gain with PHEMT devices at 90 GHz. These are state of the art results for monolithic millimeter-wave amplifier technologies.



	MESFET	PHEMT
	75 μm	75 μm
g_m (mS)	30	40
τ_o (ps)	0.5	0.5
R_{gs} (Ω)	20000	17000
R_i (Ω)	1.2	1.4
R_{ds} (Ω)	475	400
C_{gs} (pF)	.076	.068
C_{dg} (pF)	.01	.011
C_f (pF)	.018	.020
C_{ds} (pF)	.005	.005
R_g (Ω)	0.8	0.8
R_d (Ω)	1.5	1.5
R_s (Ω)	2.2	2.2
L_g (nH)	.01	.01
L_d (nH)	.01	.01
L_s (nH)	.025	.025
C_{ge} (pF)	.01	.01
C_{de} (pF)	.002	.002

Figure 4. Small signal model for a 75x.15 um low noise MESFET and PHEMT.

All dimensions in um.

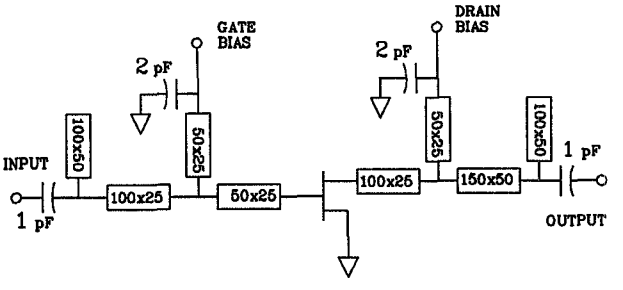


Figure 5. Equivalent circuit and element values for the W-band amplifier.

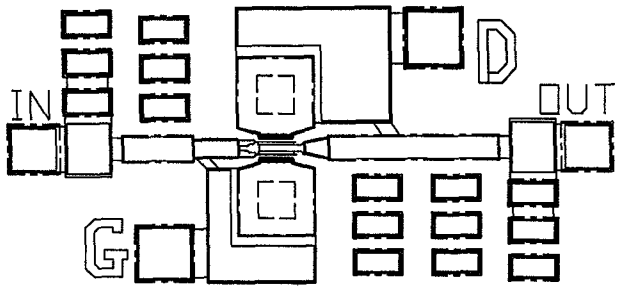


Figure 6. CAD layout for the single stage monolithic W-band amplifier.

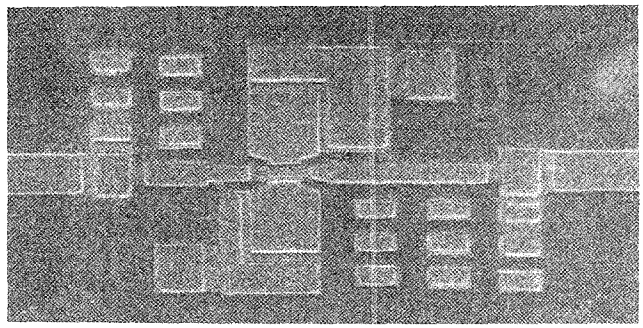


Figure 7. Picture for the single stage monolithic W-band amplifier.

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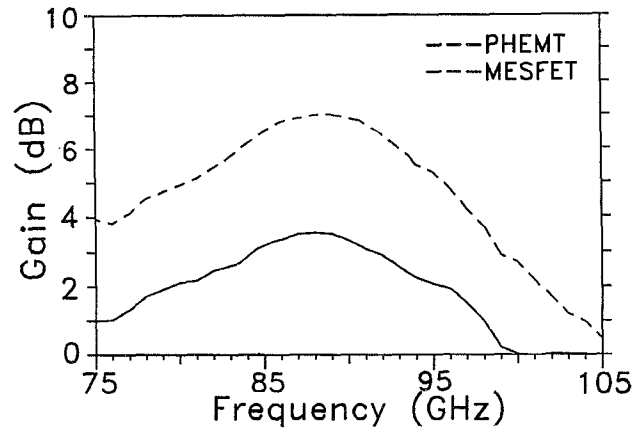

Figure 8. Measured gain for the monolithic single stage W-band amplifier using 75 um MESFET or PHEMT devices.