HETEROSTRUCTURE TRANSISTOR TECHNOLOGY FOR MICROWAVE MONOLITHIC INTEGRATED CIRCUIT APPLICATIONS.

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ABSTRACT

In this article we demonstrate that the HEMT technology can be applied to MESFET based microwave monolithic integrated circuits to yield improved performance margins. Typical performance for the low-noise (LNA) and wideband (TWA) amplifiers studied are: for the HEMT-LNA ≃ 2.2 dB noise figure and ≃ 26 dB gain at 12 GHz in comparison with ≃ 2.8 dB noise figure and ≃ 20 dB gain for the MESFET-LNA; for the HEMT-TWA ≃ 8 dB gain in the frequency range 0.2 to 18 GHz as composed to ≃ 6 dB gain for the MESFET-TWA.

INTRODUCTION

In recent years heterostructure materials technology has advanced very rapidly in both digital and analog circuit applications as a result of the excellent room temperature performance of high electron mobility transistors (HEMT's) (1-3). In particular the large adaptability margins of these devices in analog matching networks has made heterostructure microwave monolithic circuits (MMIC's) increasingly interesting for many high yield/performance applications (4-6). In this article this latter concept is extended further by demonstrating that the HEMT device, with its relatively large dynamic range in input capacitance for a given minimum transconductance, can be easily substituted in MESFET monolithic circuits to yield much improved performances. In particular by means of appropriate demonstrators (i.e. moderate bandwidth low-noise LNA and wide-band travelling wave TWA ampliers) we confirm that the performance margin of a given circuit topology can be appreciably improved in going from a MESFET to a HEMT technology.

ACTIVE DEVICE CONSIDERATIONS

For both MESFET and HEMT technologies conventional 0.5x300 μm devices with double gate interconnects (i.e. 75 μm unit cell) are used. The active layer for the MESFET devices is formed by ion-implantation of $^{29}Si^+$ (dose of $1x10^{13}$ at 40 keV plus $5x10^{12}$ at 120 keV) in semi-insulating (S.I.) GaAs substrates, whereas for the HEMT devices the active layers are grown by molecular beam epitaxy (MBE). For these devices the heterostructure comprises: a buffer layer (8000 Å thick) of undoped GaAs, followed by Si doped layers of n^+- $Ga_{.78}Al_{.22}As$ (350 Å thick at $1.5x10^{18}/cm^3$), n^- GaAs (2000 Å thick at $3x10^{17}/cm^3$ and n^+ GaAs (1000 Å thick at $2.5x10^{18}/cm^3$) as the capped layer.

The transconductance and input capacitance characteristics as a function of the source-gate voltage for both MESFET and

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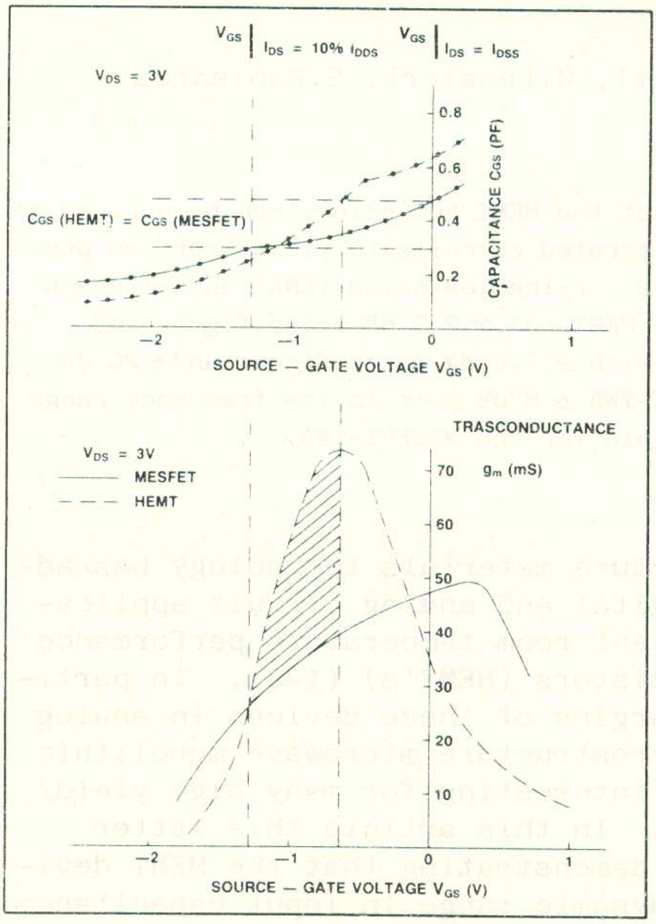

FIG.1 - Typical input capacitance and transconductance characteristics of the 0.5x300 μm HEMT and MESFET devices.

HEMT devices are shown in fig.1. These devices have a typical I_{dss} of 200 mA/mm with maximum gain bias g_m of 240 mS/mm for the HEMT and 160 ms/mm for the MESFET device. As illustrated in fig.1, by choosing appropriate bias conditions (within I_{dss} and 10% I_{dss}), the input capacitance of the HEMT device can be adjusted to be similar to that of a MESFET with the added advantage that the HEMT device has much higher gain. The minimum noise figure (NF_{min}) for the HEMT device is typically 1.2 dB with 10 dB associated gain (G_{ass}) at 12 GHz and for the MESFET NF_{min} = 1.8 dB with G_{ass} 7 dB at the same frequency.

MONOLITHIC CIRCUIT DESIGN AND FABRICATION

The moderate bandwidth low-noise amplifier (LNA) and wideband travelling wave amplifier (TWA) were designed with MESFET equivalent circuit parameters by using linear microwave CAD such as Touchstone and Supercompact. Lay-out discontinuities and coupling effects were simulated by electromagnetic analysis using Linmic Plus. The low-noise amplifier was designed for 20 dB gain and better than 3.5 dB noise figure at 12 ± 0.5 GHz with input/output return loss better than 10 dB. The travelling wave amplifier was designed for a 6 dB gain in the frequency range 0.2 to 18 GHz input/output return loss better than 10 dB.

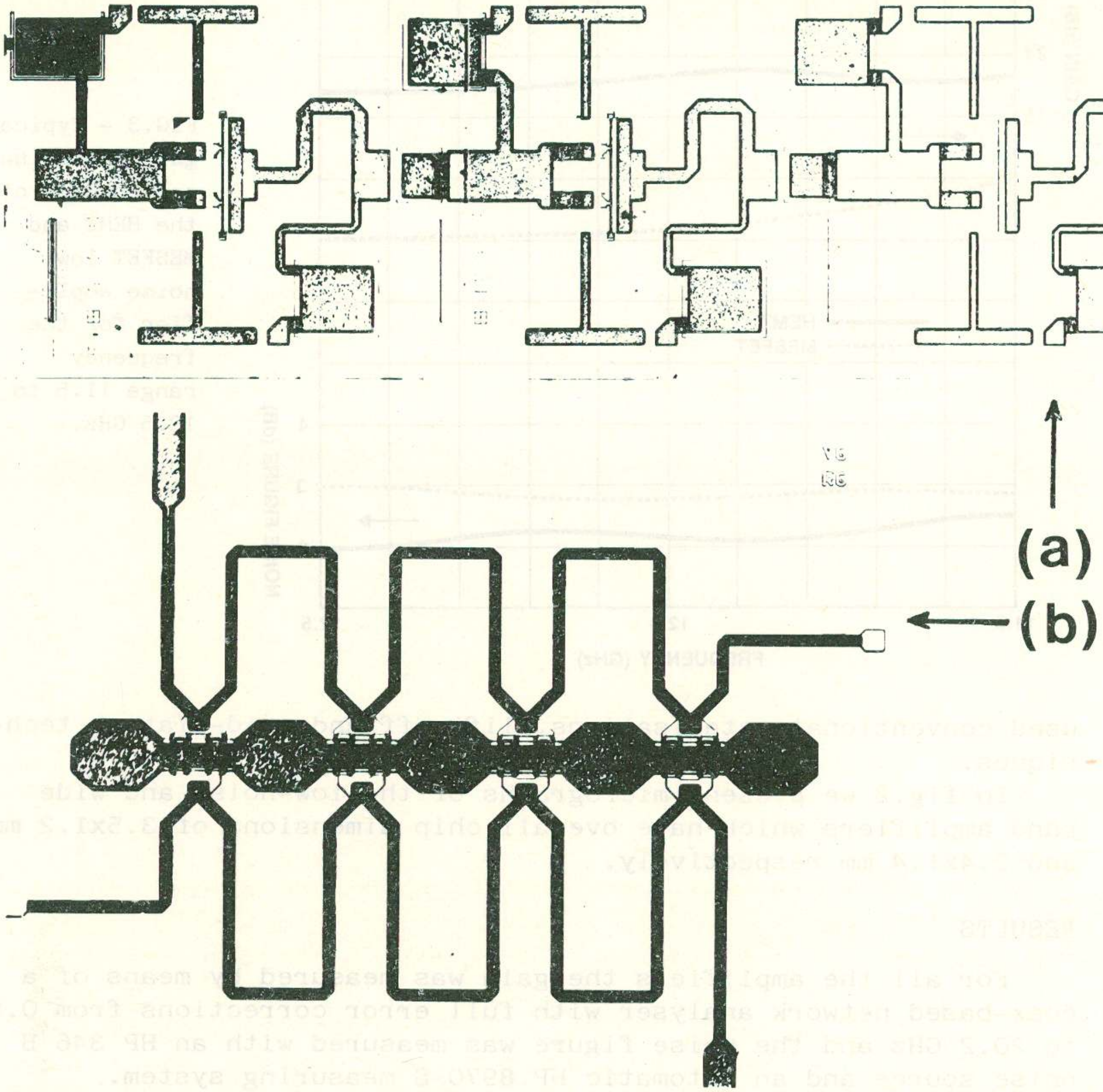

FIG.2 - Photographs of the low-noise (a) and wide band (b) amplifiers fabricated with HEMT and MESFET technology.

Standard processing techniques were used for both MESFET and HEMT amplifier. For the former, isolation was achieved by selective ion-implantation of the donor species whereas for the latter isolation was achieved by proton implantation. The 0.5 μm gate length was realised by conventional hard contact optical lithography using positive photoresist. A reactively sputter deposited Si_3N_4 layer (approximately 3000 Å thick) was used as the capacitor dielectric film.

In order to achieve good r.f. grounding, in the TWA 60 μm diameter by 120 μm long via-holes were incorporated using reactive ion-etching and gold-electro-plating. All other process steps

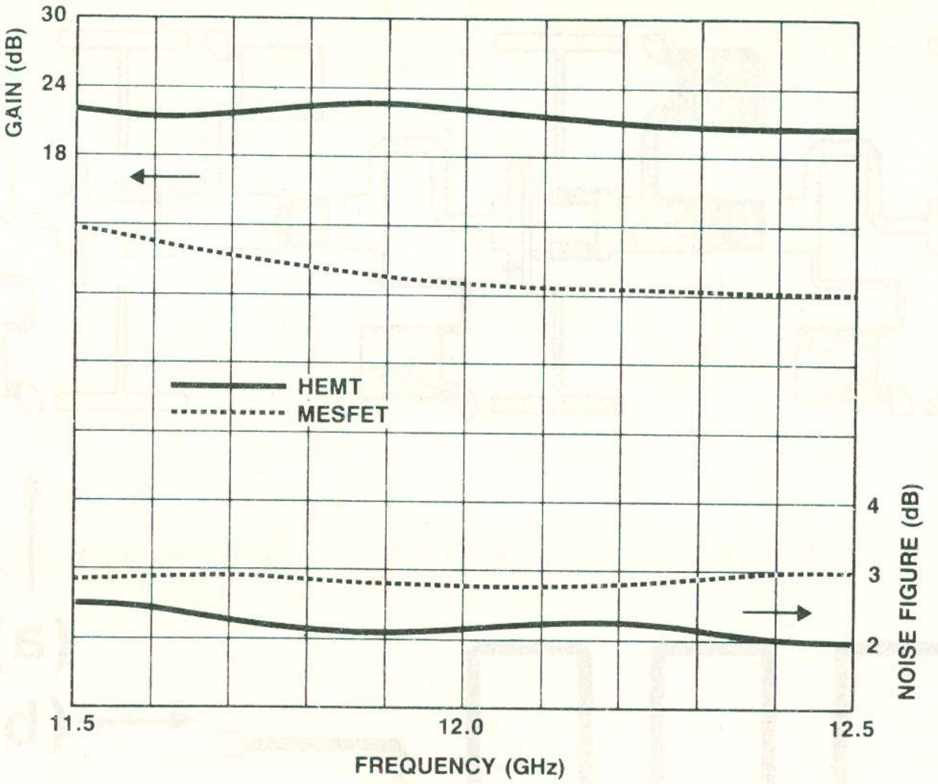

FIG.3 - Typical gain and noise performance of the HEMT and MESFET low noise amplifier for the frequency range 11.5 to 12.5 GHz.

used conventional metalisations, lift-off and gold-plating techniques.

In fig.2 we present micrographs of the low-noise and wide band amplifiers which have overall chip dimensions of 3.5x1.2 mm and 2.4x1.4 mm respectively.

RESULTS

For all the amplifiers the gain was measured by means of a coax-based network analyser with full error corrections from 0.2 to 20.2 GHz and the noise figure was measured with an HP 346 B noise source and an automatic HP 8970 S measuring system.

In fig. 3 we present typical gain and noise performance of the MESFET and HEMT low-noise amplifiers in the frequency range 11.5 to 12.5 GHz. As shown for the MESFET amplifier the gain is always better than 18 dB, with corresponding input/output return loss of approximately 10 dB, and noise figure always better than 3.0 dB. Similarly for the HEMT amplifier the gain is always better than 25 dB, input/output return loss 10 dB, and noise figure better than 2.5 dB.

Even thougth not shown in fig.2, the measured gain and input/output return loss for the MESFET-LNA are in good agreement with the simulated results whereas the performance of the HEMT-LNA is found to be in good agreement with active device performance, i.e. large improvement in gain with moderate improvement in noise figure.

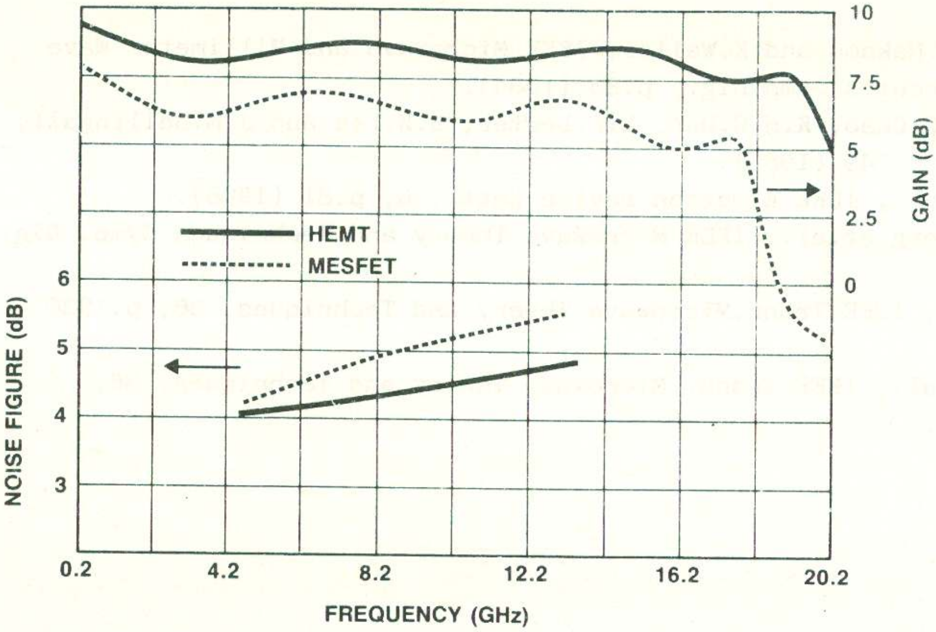

FIG.4 - Typical gain and noise performance of the HEMT and MESFET wide-band amplifiers in the frequency range 0.2 to 18 GHz.

In fig.4 we present typical gain and noise performance of the MESFET and HEMT wide band TWA in the frequency range 0.2 to 18 GHz. To verify the theoretical behaviour of this type of amplifier, the bias circuit which limits low frequency cut-off, and the termination matching circuit, which reduces flat-band ripple, have been omitted (see fig.2). As shown in fig.4 the MESFET TWA has a flat-band gain which lies between 6 and 7 dB for the entire bandwidth, whereas the gain of the HEMT-TWA is better than 8 dB in the same frequency range. For both amplifiers the input/output return loss is always better than 10dB. Because of present equipment characteristics the noise figure was only measured between 4 and 13 GHz. As shown at the higher frequency the HEMT amplifier has approximately 0.7 dB improvement in noise figure whereas at the lower frequency the noise figure is approximately 4 dB for both amplifiers.

CONCLUSIONS

In this article we have demonstrated that the HEMT device can be easily substituted in MESFET monolithic circuits to yield improved performance. In particular by means of appropriate demonstrators, such as a moderate bandwidth low-noise amplifier and wide-band travelling wave amplifier we have shown that for a given circuit topology appreciable performance margins can be achieved in going from MESFET to HEMT technology.

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