60 GHZ LOW NOISE HEMT MMIC AMPLIFIERS

AND THEIR CHARACTERIZATION

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ABSTRACT

Recent advances achieved in both the high frequency characteristics of microwave probes and the precision and stability of the hardware of the vector network analyzer have extended the present working domain to the millimeter wave length range. These performant measurements have been carried out. They have allowed the realization of a monolithic V-band low noise amplifier. It consists of two stages using 0.25 µm HEMTs, and it exhibits more than 12 dB gain with 5 ± 0.5 dB noise over 10% frequency range at 57 GHz. The chip size (including matching and biasing circuits) is 1.0 x 1.5 mm².

Keywords : Millimeter-wave, MMIC, Characterization, HEMT.

INTRODUCTION

MMIC design uses extensively the TCM microwave database which provides constant information concerning the foundry's process in terms of performance, stability and uniformity. For the millimeter wave domain, data come mainly from S parameter measurements achieved with on-wafer probing systems. This technique is straightforward since quick and accurate characterization of complete wafers (i.e. hundreds of devices) are achieved. These methods, becoming now avalaible, are absolutely necessary to propose reliable monolithic products, in front of the constantly increasing attraction of the millimeter wave frequencies for civil applications.

Thanks to these new methods of measurements, a monolithic low-noise amplifier has been realized, showing high performances at 60 GHz. This paper describes the design, fabrication and measurements of the amplifiers.

CIRCUIT REALIZATION

Figure 1 shows the block diagram of the two-stage amplifier. For the circuit design, the losses and discontinuities of microstrip lines were modelized [1] [2] [3]. Measurements in test jigs were taken into account by modelling the associated bonding wires. A special effort was made to improve the stabilization of the circuit at low frequencies, using RC circuits and the biasing bonding wire. The active element of a two stages is a GaAIAs/GaAs HEMT with a 0.25 μm triangular gate.

The circuits were processed in the THOMSON COMPOSANTS MICROONDES foundry (Figure 2). They are composed of 0.25 μm gate length HEMTs, Si_3N_4 overlay capacitors and via holes through a 100 μm thick wafer. Figure 3 shows the HEMT epitaxial growth structure.

FULL S PARAMETER CHARACTERIZATION UP TO 60 GHZ

Our set up, working up to 60 GHz, consists of a Wiltron 360 vector network analyzer and 65 GHz Cascate Microtech probes mounted on an automatic probing system Electroglass 1034. Accurate calibration is achieved with the Line Reflect Match (LRM) and Thru Reflect Line (TRL) techniques which do not require precisely known high reflect standards. For coplanar circuit measurements, the LRM is particularly interesting due to its broadband ability, reproducibility and consistency. Figure 4 shows the results of the measurement of the line standard immediately after calibration. The reproducibility in directivity is better than 45 dB, and phase stability for the transmission factor S_{21} better than 0.5 degree. Measurements of the reflect coefficient S_{11} with probe moved upward display a deviation of the modulus from unity less than 0.2 dB.

For microstrip MMIC design, it is however useful to include the effect of the In/Out cells inside the error model. The TRL technique is then prefered due to difficulties to process a perfectly load-matched microstrip standard. Three lines of different lengths are then required to cover the full band 1-60 GHz. For this purpose a complete TRL calibration kit was designed and processed at the TCM foundry. First results give a precision of 40 mU in the standing wave ratio of a 1 mm line, limited by the uniformity and reproductibility of the In/Out cells.

Full S parameter characterization of complete wafers of HEMT transistors and MMIC have been made in the full band 1-60 GHz. The different gains $|H21|^2$, MSG/MAG and stability factor k can therefore be determined and are presented Figure 5. A cut off extrinsic frequency of 60 GHz is deduced and equivalent circuit extraction provides F_t = 86 GHz, F_{max} = 120 GHz, allowing MMIC application in the bandwidth 40-60 GHz.

Gain performance obtained with two stages MMIC amplifier using 0.25 micron triangular gate HEMT are above 12 dB at 60 GHz. It is presented Figure 6, for several amplifiers. This figure demonstrates the high yield of the circuits. Moreover the amplifiers are well stabilized at low frequencies.

LIMITATIONS FOR HIGH FREQUENCY

The presented results demonstrate how efficient are the on-wafer probing techniques for MMIC design. However, some difficulties and limitations related to the high frequencies should be stressed.

First, the transmission of the microwave signal from the testset to the probe tips becomes a real problem if the full band from 1 to 60 GHz or more has to be covered. Indeed the loss between the testset and the end of the probe tips will enhance the directivity error of the couplers inside the analyzer. We addressed this problem by optimizing the configuration of the experiment in order to reduce the distance between the testset and the probes and by using dedicated semirigid coaxial cables.

Second, some care has to be taken if one does not want to be confused by isolation and cross talk problems which are expected to become predominent as the working frequency is increased. In order to evaluate their importance, we made cross talk measurements as function of the distance between the probe tips (Figure 7) for probes directly landing on a 100 µm thick gallium arsenide wafer. The isolation problem inside the testset had been previously measured and is taken into account down to -45 dB by a full 12-term error model as one checked with probes moved upward and 4 mm apart from each other. Results show first that the cross talk effect considerably grows with frequency and second that it remains less than -40 dB for a frequency lower than 60 GHz and a spacing between the probes greater than 250 microns. For higher frequencies or closer spacing a 16 term error-model [4] should be used.

NOISE CHARACTERIZATION

The amplifier was also measured in test fixtures, using V connectors (Figure 8). The losses in that jig are less than 2 x 0.5 dB. The amplifier was measured adding 2 wave-guide coaxial transitions. VSWR and losses of these transitions were measured. They exhibit less than 0.5 dB each, with more than 20 dB of reflection losses (Figures 9, 10).

The noise characterization set-up consists essentially of the HP 8970B noise figure meter and a Hughes noise source. A maximum noise figure of 5.5 dB was measured.

CONCLUSION

The presented results demonstrate how efficient are the on-wafer probing techniques for MMIC design and development even in the millimeter wave range.

These methods have allowed the realization of V-band monolithic amplifiers, which show high performance and high yield. Nevertheless, these techniques are still limited to allow characterization in higher frequencies. These difficulties are by no means fundamental, and solutions are expected to emerge shortly.

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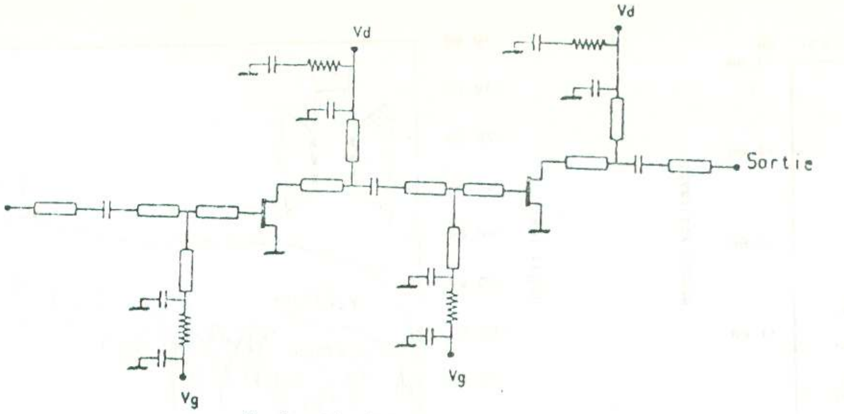


Fig 1 : Block diagramm of the 2-stage amplifier

GaAs:Si	n = 4.0 : 0.3 cm^{-3} e = 500 : 15 Å
AlGaAs:Si	n = 2.0 ± 0.2 cm^{-3} e = 500 ± 15 Å X_{AlAs} = 0.21 ± 0.02
AlGaAs	e = 22.6 ± 5.65 Å X_{AlAs} = 0.21 ± 0.02
C GaAs	e = 300 ± 30 Å
B(Ga/AlGa)As	e = 10x(20+80) Å X_{AlAs} = 0.21 ± 0.02
B GaAs	e = 5000 ± 150 Å
Substrat GaAs S.I.	

Fig 3 : HEMT epitaxial growth structure

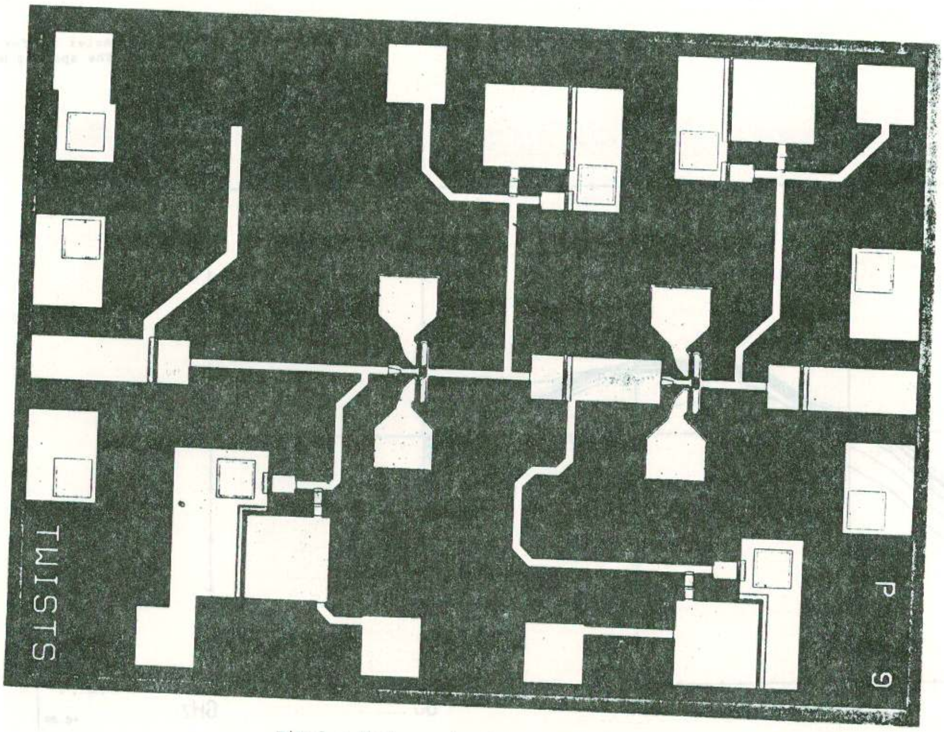


Fig 2 : Photograph of the amplifier

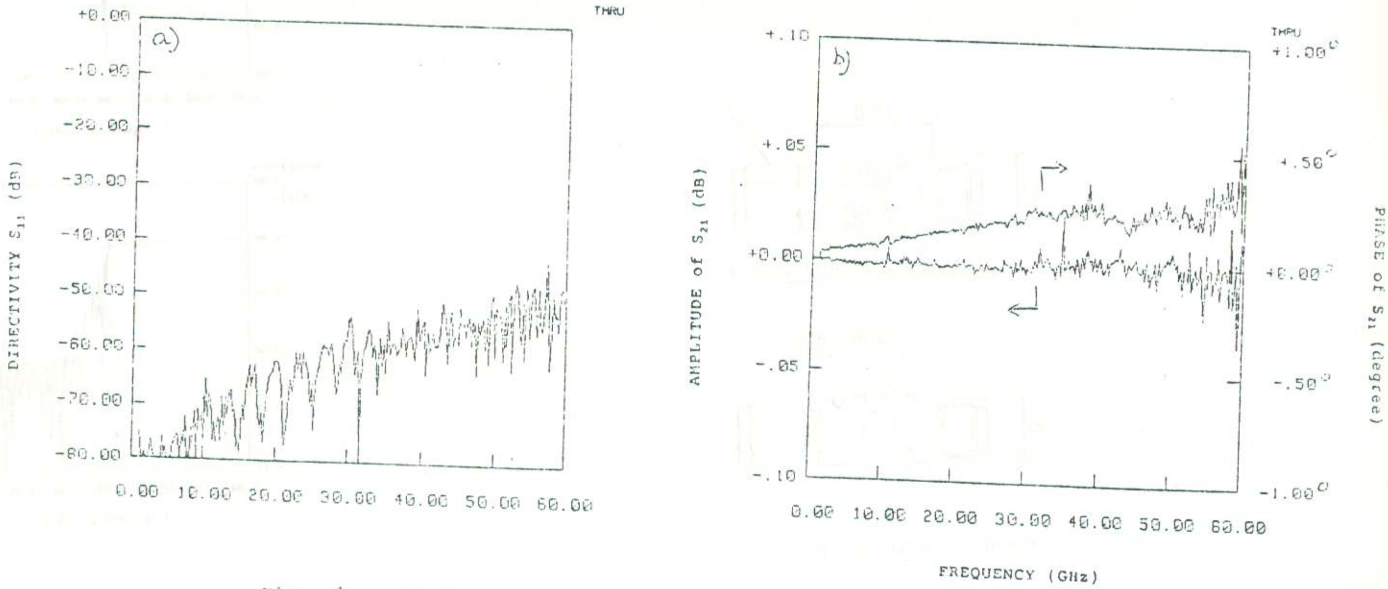


Fig. 4 : Reproductibility in: (a) directivity factor S_{11}, (b) transmission factor S_{21} of the THRU standard after LRM calibration.

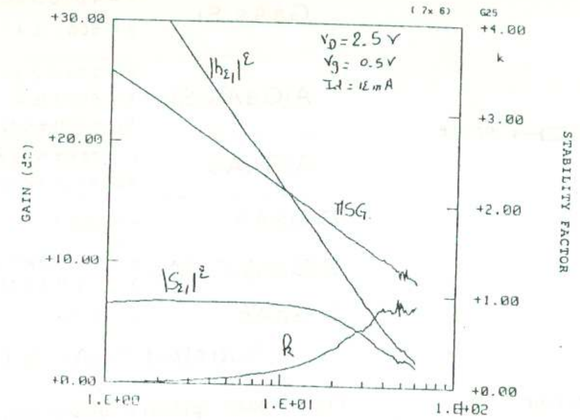


Fig. 5 Current gain $|h_{21}|^2$,maximum stable gain MSG, transducer power gain in 50 ohm system $|S_{21}|^2$ and stability factor of a 0.25 um gate length HEMT.

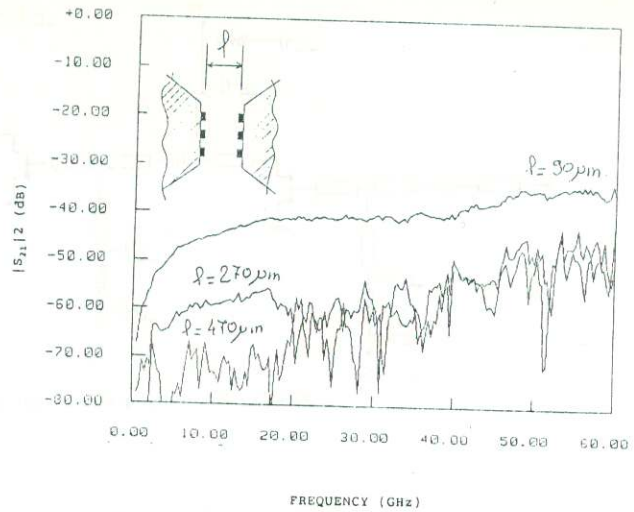


Fig. 7 : Cross talk parameter S_{21} for probes directly landing on a 100 microns GaAs wafer. The spacing between the probe tips is: 90, 270 and 470 microns.

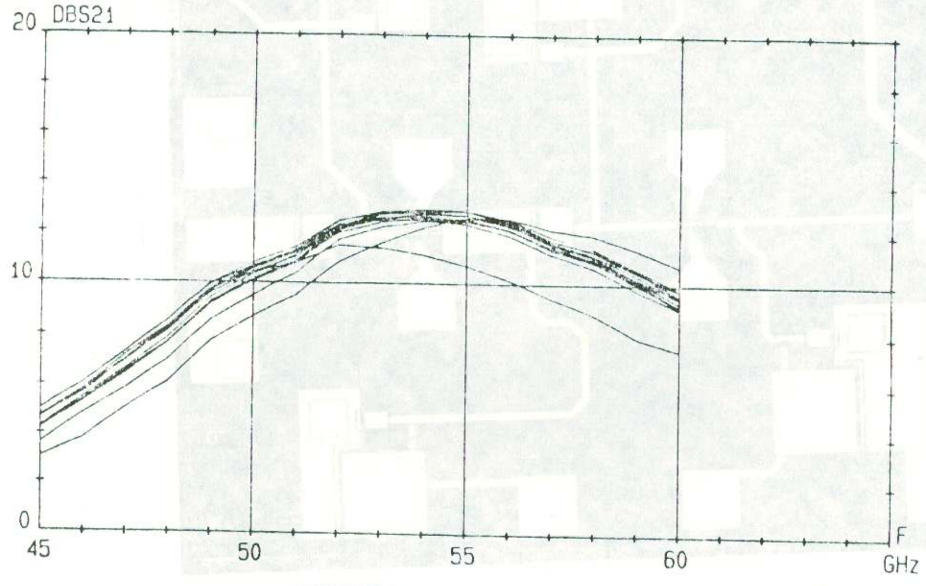


Fig 6 : On-wafer measurements of the V band amplifiers

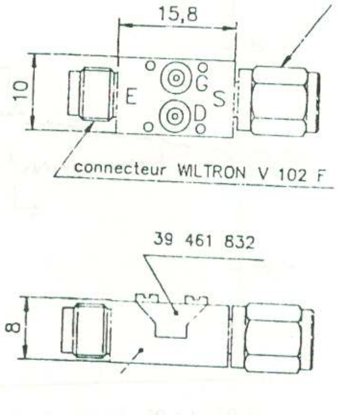
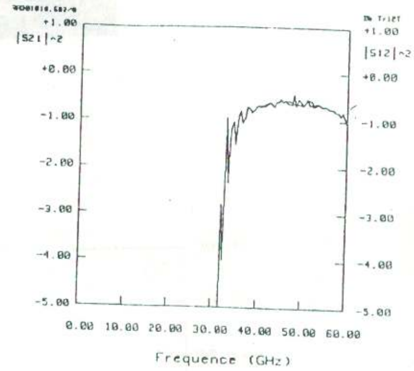


Fig 8 : V-band test fixture



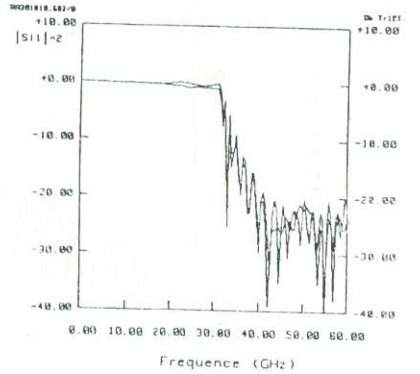


Fig 9,10 : Measurements of 2 transisitions coaxe/guide