Modelling and Realization of a Monolithic 27 GHz HEMT Amplifier in Coplanar Waveguide Technology

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ABSTRACT

A monolithic integrated amplifier in HFET-Technology for the 27 GHz band is presented, fitted for the use in digital radio link front ends with dedicated in- and out-of-band specifications. The amplifier consists of two stages of 0.5 μm HFETs and some passive circuitry for matching, biasing and gain stabilizing. Coplanar waveguides and lumped elements like thinfilm resistors, MIM-capacitors and spiral inductors were used. All passiv and active components were measured separately and the derived circuit models were placed into a CAD-library.

INTRODUCTION

Monolithic microwave integrated circuits (MMIC) in coplanar waveguide technology offer some advantages over conventional microstripdesign especially in the mm-wave range. Coplanar waveguides [1] interface conveniently to the HEMT-cells with low field distortion and with low source inductance. They allow easy integration of lumped elements such as thin film resistors and capacitors either shunted or in series. Air bridges are used for spiral inductors and for interconnections between sections of the ground plane on top of the GaAs substrate, eliminating the need for via holes. Substrate thinning is not required. This eases MMIC chip handling.

Up till now little data on CPW were available [2,3] and implemented in CAD systems. To overcome this problem a set of CPW lines and discontinuities as well as active elements were designed and fabricated on GaAs wafers. These circuits were measured on wafer to a high degree of precision using a hp 8510 vector network analyzer operating from 45 MHz to 60 GHz.

Circuit models were created and adjusted to correspond to the measured data. These wideband models are valid from DC to 40 GHz, some even to 60 GHz, and were used to design the 27 GHz amplifier.

The amplifier will be used in radio link equipment. The input terminal will be connected to rectangular waveguide via a low loss WG to CPW launcher. This structure is highly reflective below cutoff-frequency of the waveguide. Therefore on chip loads provide out of band stability. The matching network

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forms a bandpass filter, which lowers the sensitivity to unwanted input signals and reduces local oscillator feedthrough.

PASSIVE CIRCUITS

A variety of circuits was fabricated using the standard process. The layout includes simple CPW lines of various width, bends, tapers and air brigdes, as well as thinfilm resistors and capacitors both in series and shunt configuration (Fig. 1). The elements were measured exactly with Cascade Microtech on wafer test equipment. Key elements were characterized from DC to 40 GHz. Straight sections of CPW transmissionlines showed nearly no dispersion in the whole frequency range (Fig.3). Air bridged lines (Fig. 2) showed little differences to lines without bridges. These effects were corrected by a short section of a low impedance line. The line parameters match closely with predicted values from theory [4]. Thin film capacitors and resistors can be modelled almost perfectly by lumped elements due to their small geometry ($l_{max} < \lambda /20$). An example is given in Fig. 4.

HEMTS

Active devices were also modelled from measured S-parameters. The external elements were derived by the so-called "cold-modelling", when the FET is measured at 0 volt drain-to-source voltage. An improved method was used to determine the broad band small-signal equivalent circuit of the intrinsic device [5]. This method is based on an analytic solution of the equations for the y-parameters of the intrinsic FET. The parameters are evaluated straight forward for every measured frequency point. This procedure is very fast, because no iteration is necessary. Measured and simulated data of a HEMT device (Fig. 5) match very cosely up to 40 GHz (Fig. 6). The model can be applied even slightly beyond the measured frequency range. All modelled elements were placed into a CAD-library. Based on this library the amplifier circuit had been simulated.

AMPLIFIER DESIGN

The amplifier was designed as gain block for use in radio link equipment. All biasing, matching and stabilizing circuitry was built on chip for easy interfacing with other chips. The amplifier layout is shown in Fig. 7.

The design of the monolithic amplifier utilized the previously derived circuit models. The basic FET-cell is matched to 50 Ohm at operating frequency by sections of high impedance CPW-line, spiral inductors and capacitors at gate and drain acting as band pass filters. DC bias circuits ensure safe operation and protection of the FETs. (Schematic circuit diagram see Fig. 8)

Each stage of the amplifier is terminated by an ohmic load connected to the drain line via a low pass filter, which gives unconditionally stable operation in the entire frequency range. The loading network forms a compromise between stability requirements and maximum gain. The realized simple filter structure slightly reduces pass-band amplification, but a more complex filter would consume more chip space and become less predictable due to unwanted coupling effects.

In the first run of the amplifier fabrication the two stages are separated from each other. They are measured individually. Then they are tied together with quasi coplanar-on-chip bond wires to form a two stage amplifier. The simulated gain of both versions is shown in Fig. 9. Fine tuning in the redesign phase leads to the final two stage monolithic amplifier.

RESULTS

The amplifiers were processed on 2"-GaAs wafers. The active layers were deposited with MBE.

Measurements were carried out on wafer, and compared to simulated results.

CONCLUSION

A monolithic GaAs HEMT-amplifier in coplanar waveguide technology is presented. Active and passive parts were characterized previously by on wafer measurement. The elements are placed in a CAD-database for easy and quick design. A close agreement between simulated and measured results is obtained.

ACKNOWLEDGEMENT

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REFERENCES

/1/ M. Muraguchi; T. Hirota; A. Minakawa; Y. Imai:
Uniplanar MMICs and Their Applications
Review of the Electrical Communications Laboratories
Vol. 36, No. 6 (1988)

/2/ I.Wolff; K. Heime:
Entwicklung von monolithisch integrierten rauscharmen
Breitbandverstärkern im Frequenzbereich von 12 GHz bis 40 GHz,
Arbeits- und Ergebnisbericht, SFB 254 (1989), University of
Duisburg

/3/ G. Ghione; C. Naldi:
Analytical Formulas for Coplanar Lines in Hybrid and Monolithic
MICs. Electronics Letters Vol. 20, Nr.4, Feb.(1984) pp.179

/4/ R.K. Hoffmann:
Integrierte Mikrowellenschaltungen, Springer Verlag (1983).

/5/ M.Berroth; R. Bosch:
Broad Band Determination of the FET Small-Signal
Equivalent Circuit. To published in IEEE-MTT.

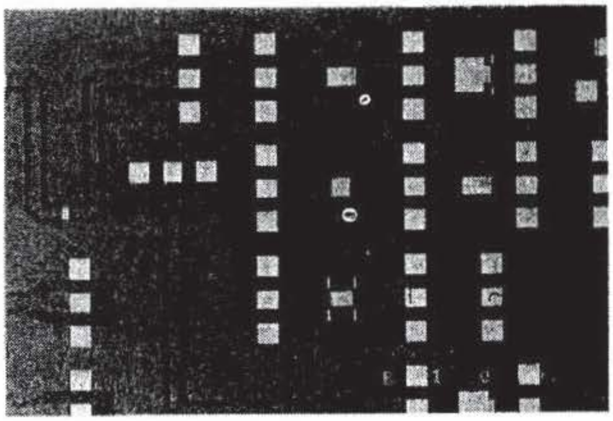


Fig. 1: Passive CPW structures for parameter extraction

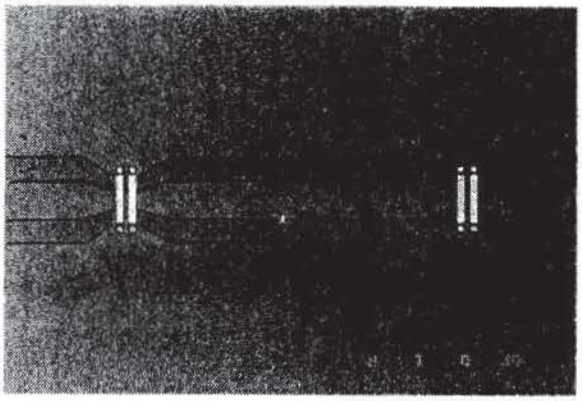


Fig. 2: CPW transmission line with air bridges

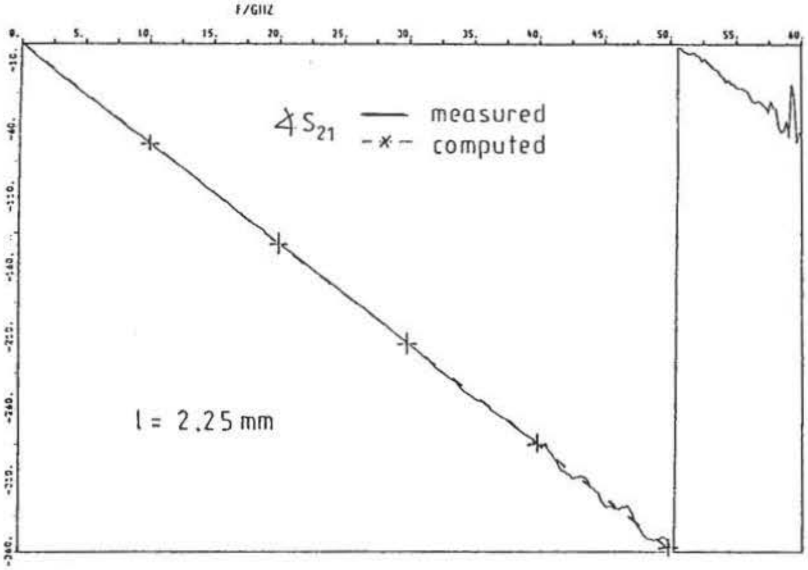


Fig. 3: Phase angle of CPW transmission line

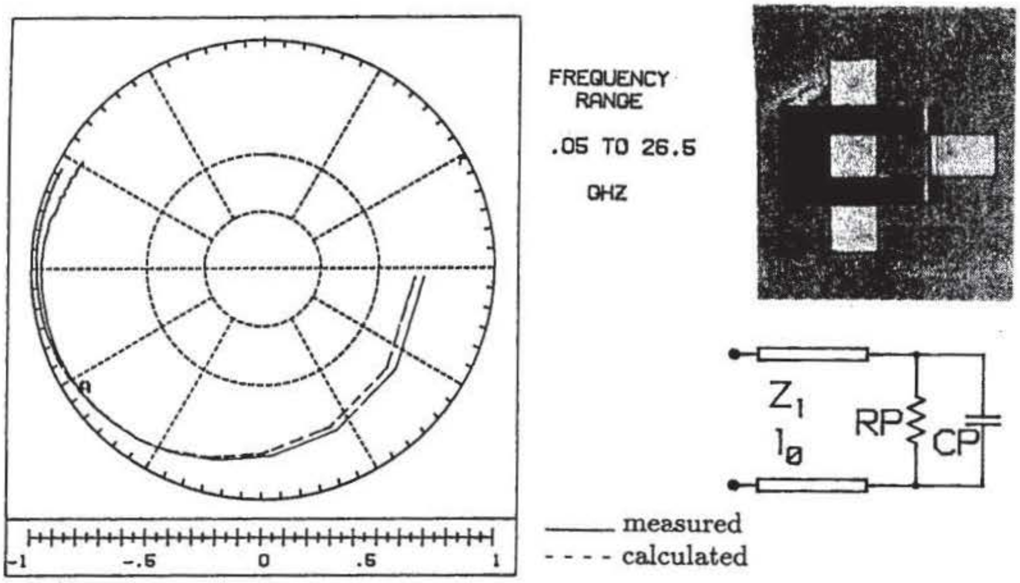


Fig. 4: Complex termination with transmission line, resistor and capacitor

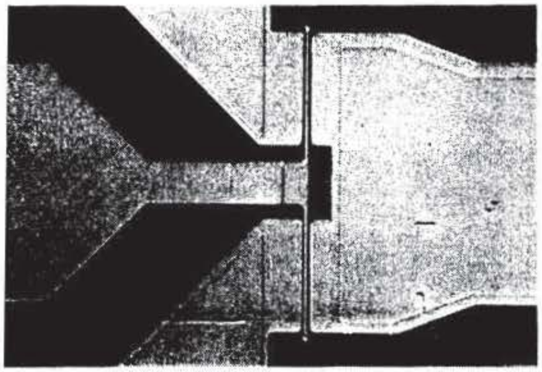


Fig. 5: Single HEMT-cell with CPW layout

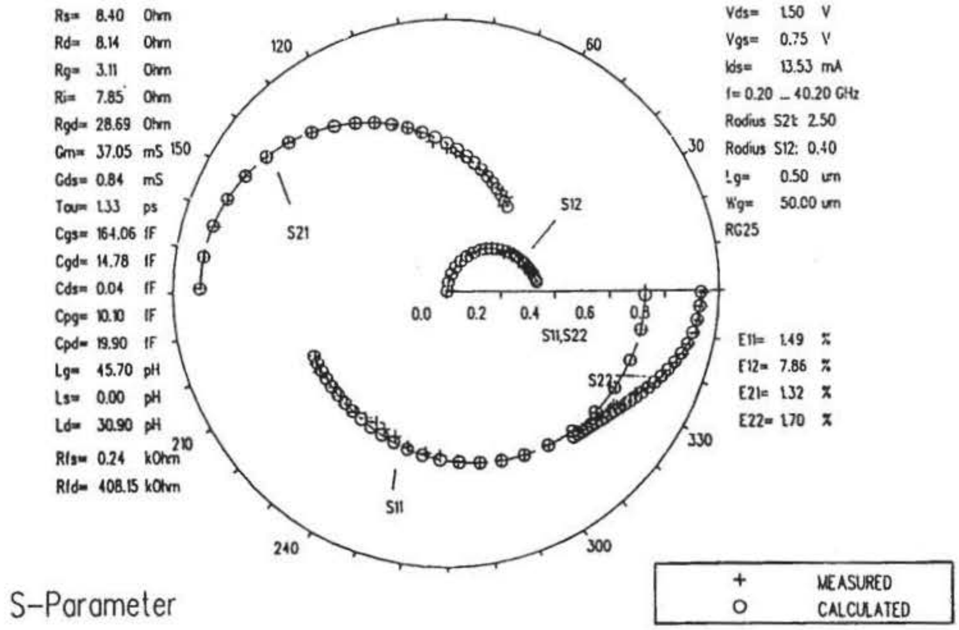


Fig. 6: Comparison of measured data of a 0.5 μm enhancement heterostructure field effect transistor (crosses) with simulation results of our procedure presented by circles.

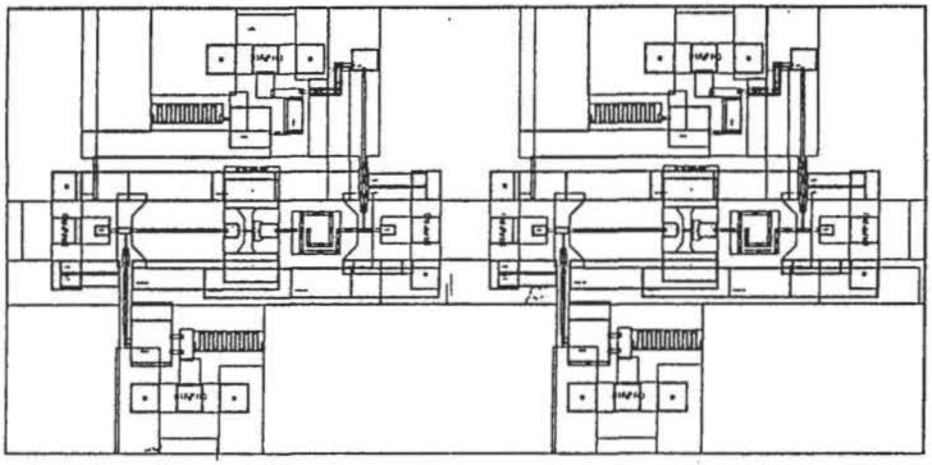


Fig. 7: Monolithic 27 GHz amplifier layout

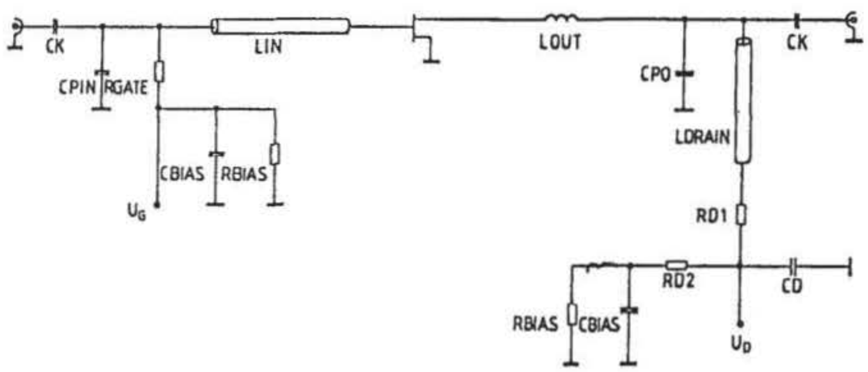
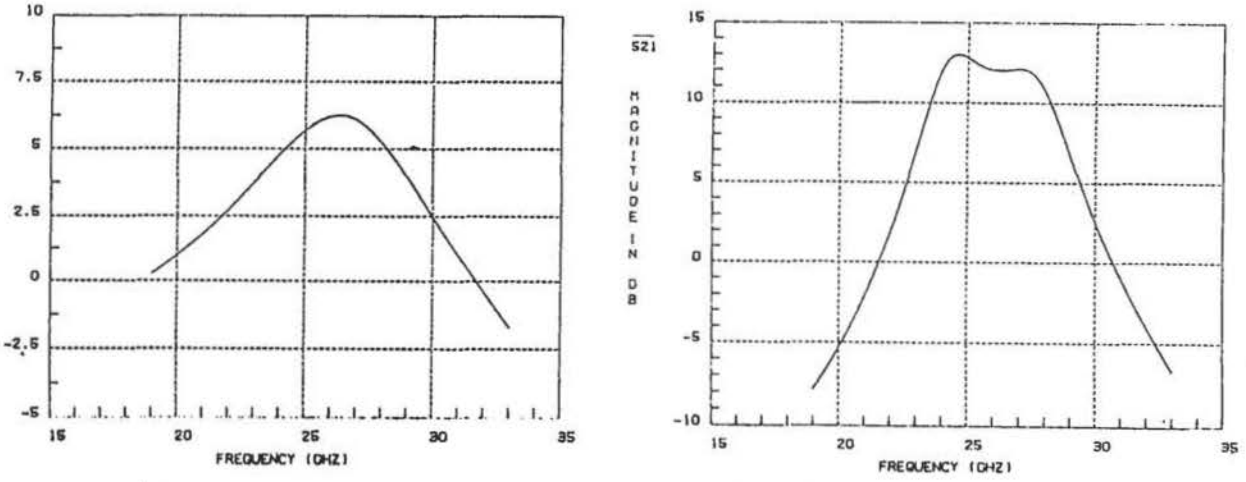


Fig. 8: Schematic circuit diagram of a single stage amplifier.



one stage

two stages

Fig. 9: Simulated gain of one and two stage HEMT amplifiers.