MESFET MMIC-SWITCHES FOR 28 GHz COMMUNICATION SYSTEMS

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ABSTRACT

The development of MESFET MMIC switches for 28 GHz communication systems is presented. Transistors with different channel parameters and gate geometries have been developed and characterized in a SPST series switch configuration. The equivalent circuit parameters are determined by fitting the measured S parameters in the ON and OFF states. A cutoff frequency figure of merit up to 500 GHz is obtained depending on the transistor parameters. Several 28 GHz SPDT switches have been designed and fabricated. Typical input return loss better than 15 dB combined with 3 dB insertion loss and 22 dB isolation has been achieved.

Keywords: MESFET switches, MMIC technology

1. INTRODUCTION

Future application in the field of communication systems will operate at frequencies around 28 GHz and/or 38 GHz. Typical examples for civil application are data communication links as a replacement for cable connections. Such a system is of special interest in difficult terrain like mountain or marsh areas or even in rural areas where, up to now, it is too expensive to include these areas into the standard and the future telecom data networks normally distributed by cable or glass fibers. A further application may be in city areas, where often additional and flexibel data links are required. In all these cases, the installation of cables on masts or buried in the ground become very expensive and require access to the complete path where the cable is installed.

In contrast to this, millimeter wave links with hop lengths of several km require the installation of the transceiver equipment at only relative few points. If necessary, the required power supply can be achieved via a solar cell arrangement.

A 28 GHz T/R module and its key components of such a short hop link system has been under development at Daimler Benz under ESPRIT. Especially the results on MESFET switches will be presented in this paper. The GaAs MESFET as control device demonstrates attractive features such as low bias power consumption and fast switching speed.

2. CHARACTERIZATION OF MESFETS FOR SWITCH APPLICATIONS

For the optimization of the MESFETs, to be used in the T/R switch, devices with different geometries have been characterized. The devices have been fabricated with recessed gate MESFET technology. A schematic cross-section is given in figure 1. Three different vertical structures have been examined. The different doping densities with the associated layer thicknesses are indicated in the figure. MESFETs with gate lengths of

0.3 μm and 0.5 μm and gate widths of 200 μm, 400 μm and 600 μm are available. The transistors are realized in a series switch configuration with drain source opposed. A 1 kΩ bias resistor is integrated in the gate terminal to assure a high frequency isolation.

The S parameters of the transistors have been measured up to 40 GHz in a microstrip test fixture. For accurate measurements, a TRL calibration using GaAs standards has been developed.

The equivalent circuits of the MESFET for the ON state and the OFF state are represented in figure 2. The value of the elements are obtained by fitting the measured S parameters from 1 GHz to 40 GHz. A very good agreement is obtained between the measured and the modeled S parameters. An example of the dependence of the ON state resistance

$$R_{ON} = R_{gs} + R_{gd} + R_{ch} \tag{1}$$

and the OFF state capacitance

$$C_{OFF} = C_{esd} + (C_{igs}C_{igd})/(C_{igs} + C_{igd}) + (C_{egs}C_{egd})/(C_{egs} + C_{egd}) \tag{2}$$

with the doping density and the gate width is shown in figure 3. The results obtained from an analytical model based on the technological parameters (Ref. 1) are also given in the figure. These calculated values are in fair agreement with the measured data.

The ON state resistance is decreasing by increasing the gate width and the doping density. It is also depending on the pinch off voltage. The OFF state capacitance is essentially depending on the gate width. The cutoff frequency figure of merit defined as

$$F_{CS} = 1/(2\pi R_{ON}C_{OFF}) \tag{3}$$

is shown in figure 4. It is increasing with the doping density.

The power handling limitations of the switch MESFET are in the ON state the maximum drain source current and in the OFF state the drain source breakdown voltage. The principal results of the DC measurements are resumed in the table 1. For lower doping densities the gate drain breakdown voltage is increased and allows a greater drain source voltage. The table indicates a trade off between the maximum drain source voltage and the cutoff frequency figure of merit.

3. SWITCHES

Using the MESFET model described in the previous part, different 28 GHz SPDT switches have been designed.

Figure 5 shows an example of a switch design. Each arm consists of two shunt-FETs with 400 μm gate width in conjunction with a quarter-wave length transformer. While the FETs in the OFF-arm are biased in the ON-state, the FETs in the ON-arm are pinched off and act as shunt capacitances. In order to provide low insertion loss, these capacitances have to be resonated out. This is achieved by separating the shunt FETs by inductive transmission lines (characteristic impedance greater than 50 Ω) forming a filter/travelling wave structure. The $\lambda/4$-line of each cell transforms the low resistance R_{ON} in the OFF-arm to an open at the common port and the input of the ON-arm.

The typical measurement results of the first run are represented in figure 6 for the ON state and OFF state. The best results are obtained at about 25 GHz. An input return loss better than 15 dB combined with 3 dB insertion loss and 22 dB isolation has been measured.

With the measurement of different test structures realized on the wafer, the shift of the frequency from 28 GHz to 25 GHz and the 3 dB insertion loss can be explained. For the second run an insertion loss of 1 dB is expected.

4. CONCLUSION

Different switch MESFETs have been modeled using S parameters measurement up to 40 GHz. First MMIC switches for 28 GHz communication systems have been fabricated.

A typical input return loss better than 15 dB combined with 3 dB insertion loss and 22 dB isolation has been achieved.

5. REFERENCES

[1] Jain N., Gutmann R.J., 1990, Modeling and Design of GaAs MESFET Control Devices for Broad-band applications, IEEE Trans Microwave Theory and Techniques Vol. 38, No. 2, pp 109-117.

6. ACKNOWLEDGEMENT

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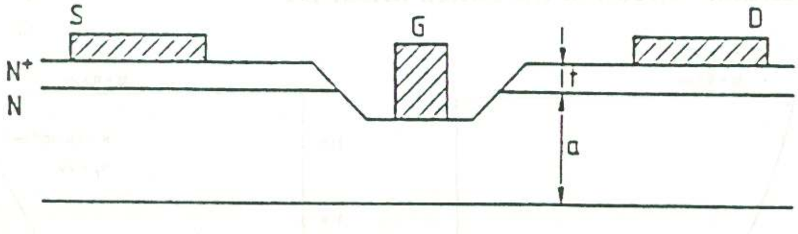


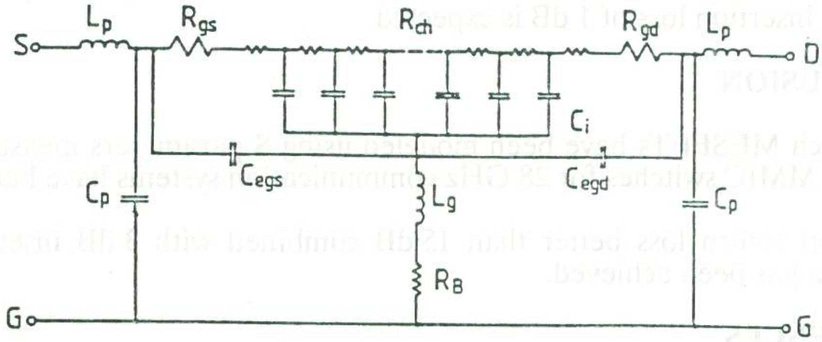
1. $N^+ = 2.0 \times 10^{18}\ cm^{-3}$ $t = 0.08\ \mu m$
   $N = 1.0 \times 10^{17}\ cm^{-3}$ $a = 0.32\ \mu m$

2. $N^+ = 2.0 \times 10^{18}\ cm^{-3}$ $t = 0.08\ \mu m$
   $N = 3.5 \times 10^{17}\ cm^{-3}$ $a = 0.20\ \mu m$

3. $N^+ = 2.0 \times 10^{18}\ cm^{-3}$ $t = 0.05\ \mu m$
   $N = 7.0 \times 10^{17}\ cm^{-3}$ $a = 0.10\ \mu m$

Figure 1: Schematic cross-section of a MESFET

ON-state



OFF-state

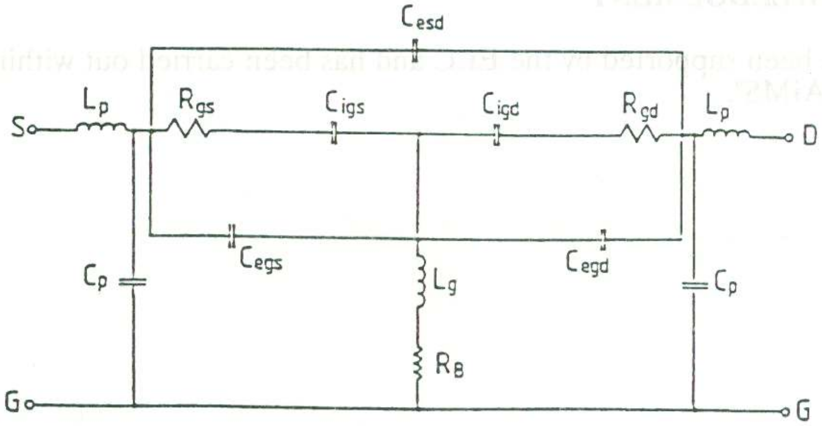


Figure 2: Equivalent circuit of the switch MESFET

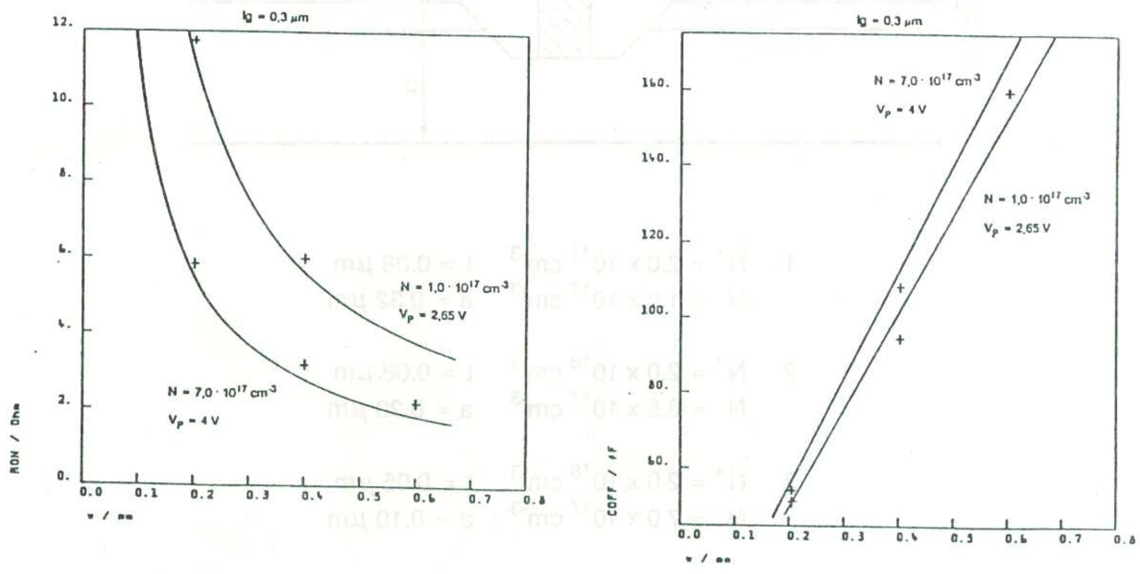


Figure 3: ON-state resistance R_{ON} and OFF-state capacitance C_{OFF} versus gate width + measurement -analytical model

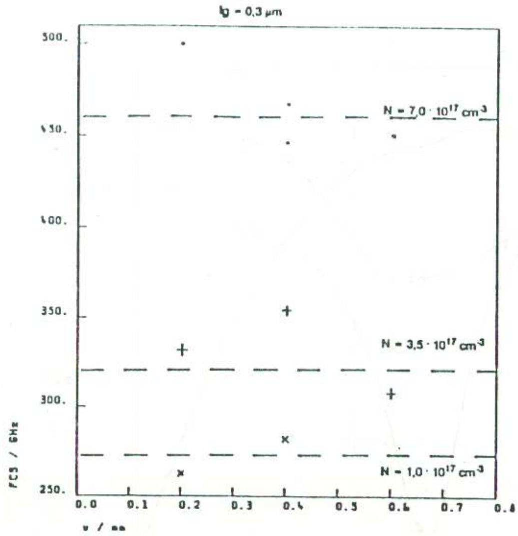


Figure 4: Cutoff frequency figure of merit versus gate width

$V_{DG(BR)}$: drain gate breakdown voltage in Volt

V_{DSmax}: maximum drain source voltage in Volt

N/cm^3	$V_{DG(BR)}$	V_{DSmax}	F_{CS}/GHz
$1.0\ 10^{17}$	20	15	270
$3.5\ 10^{17}$	16	12	320
$7.0\ 10^{17}$	13	10	460

Table 1: Voltage handling capability and cutoff frequency figure of merit

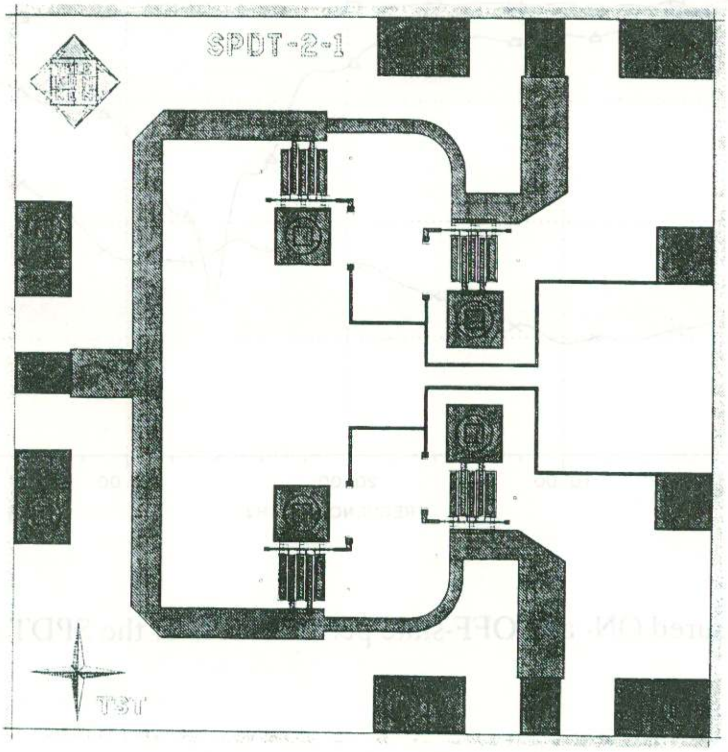
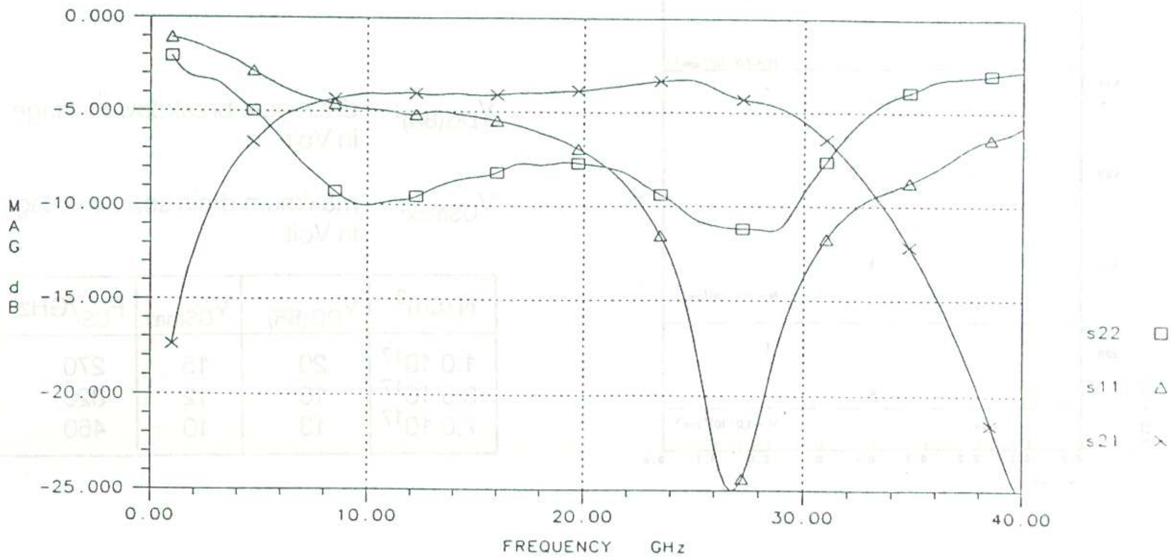


Figure 5: SPDT switch layout with λ/4 line and two shunt-FETs for each arm

ON-state



OFF-state

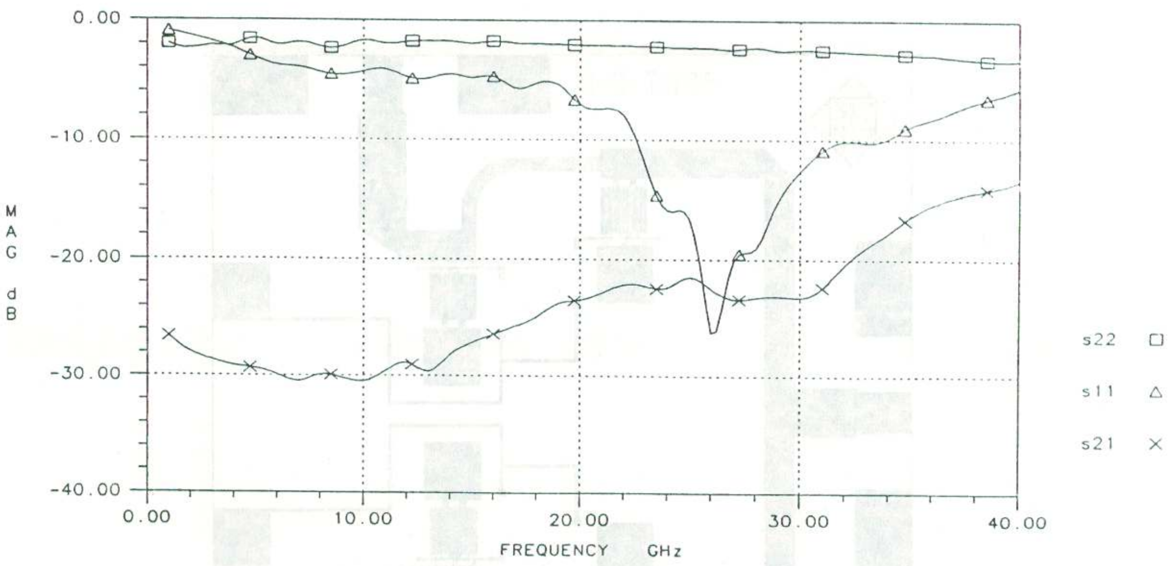


Figure 6: Measured ON- and OFF-state performances of the SPDT switch of figure 5