Realization of an Amplifier in Slotline Technique

G. Tagne Saha, G. Zimmer
University of Applied Science Frankfurt am Main, Nibelungenplatz 1, D-60318 Frankfurt a. M., Germany
E-mail: zimmerg@fb2.fh-frankfurt.de

***Abstract*— In this paper the realisability of a hybrid amplifier using slotline technique is investigated. With the help of a linear circuit simulator and additionally implemented models for the slotline and its short circuit stub a design of the amplifier for a centre frequency of 5.8GHz is carried out. The measurements compared with the simulation show good agreement at the frequency of operation. Discrepancies above this frequency indicate that models for further slotline discontinuities have to be incorporated into the circuit simulator to reflect the measured frequency response.**

***Index Terms*— hybrid amplifier, slotline, slotline discontinuity, short circuit stub.**

I. INTRODUCTION

Since the initial demonstration of GaAs FET, microwave amplifier design evolved from hybrid microwave integrated circuits (MICs) to monolithic microwave integrated circuits (MMICs) operating in the range from 1GHz to well over 100GHz [1]. At the beginning amplifier design was based on distributed element matching techniques intensively using microstrip lines (MSLs) as basic elements to realize the MIC. At that time one of the most important topics was the accurate modeling of the inevitable microstrip discontinuities to stop the cut-and-try cyles in MIC design [2]. Approaching higher frequencies the poor ability to provide low inductance grounding of the active devices led to the use of the coplanar waveguide (CPW), an uniplanar waveguide on top of a dieletric substrate consisting of a centre strip conductor with two semi-infinite ground planes on either side of it [3]. Compared to the MSL the CPW shows several advantages as there are: it simplifies fabrication, it facilitates easy shunt as well as series surface mounting of active and passive devices and it eliminates the need for wraparound and via holes. As in the case of MSL the successfull design of circuits in coplanar technique is essentially based on knowledge about CPW discontinuities. Recently accurate models for e.g. open circuits, short circuits, tee- and crossjunctions have become commercially available [4] further supporting the design of MMICs in coplanar technique.

Most of the advantages of CPW compared to MSL circuits arise from the fact that it is an uniplanar waveguide as for example also the slotline is. In contrast to the CPW a slotline consits only of a pair of ground planes with a narrow slot between them. While the CPW structure supports a quasi-TEM wave (transverse electromagnetic) as dominant mode the basic mode of the slotline is of TE type (transverse electric) resulting in a considerable higher dispersion [8]. But one of the major problems with CPW lacks in slotline circuits, mode degeneration. This means, in a CPW circuit the mode of propagation can easily degenerate from the quasi-TEM into a coupled slotline mode. This may happen at discontinuities and must be avoided by incorperating additional air-bridges or underpasses between the ground planes making the fabrication process more complicated. Thus, if an amplifier is design using only slotline elements this drawback of CPW could be circumvented. Up to now the use of slotlines was mostly restricted to the realization of mixers [5], couplers, other passive stuctures [6] or for spatial power combining [7], but to the authors knowledge no amplifier was reported using only slotline technique. In this contribution we will describe the design, the realization and measurement results of a hydrid ampilfier using the slotline as basic component.

II. DESIGN

In order to do the design of the amplifier in slotline technique we incorperated models to describe the slotline [8] and slotline short circuit stubs [9] in our circuit simulator [11] capable of simulating lumped and distributed element circuits in the frequency domain. It was Cohn [10] who gave the first second-order solution for the characteristic impedance Z_{cs} of the slotline. Due to TE nature of the dominand mode he based the definition of the characteristic impedance on the ratio between the voltage across the slot and the power transported by the wave. Unfortunately the numerical solution given by Cohn involves iterative processing, which is not suitable for fast simulation. Instead we used approximations to Cohns solutions given in [8] for a variety of parameters to determine its charateristic impedance. As already mentioned above, the slotline shows a strong dispersion which can be accounted for by a frequency depended effective relative permittivity ε_{seff}. To model the slotline with the help of the circuit simulator its behaviour is decribed by transmission line equations based on the characteristic impedance Z_{cs} and the effective relative permittivity ε_{seff} of the slotline.

As active device we chose the Transistor MGF 1302 from Mitsubishi. It is a low-noise GaAs FET with an N-channel Schottky gate, which is designed for use in S to X band amplifiers and oscillators. The recommended bias conditions are: $V_{DS} = 3$V and $I_D = 10$mA. An investigation of Rollet's stability factor K with the given s-parameter data set showed that it is not unconditionaly stable for frequency below 7GHz. In order to reach unconditional stability of the transistor we used parallel resistive loading with 180Ω at the transistors input. Compared to the unstabilized transistor a calculated maximum stable gain of 15.6dB at 5.8GHz is now reduced to a value 14.4dB, due to the resistive loading. The stability factor K has now over the total frequency range positive dB values, indicating unconditional stability of the loaded transistor.

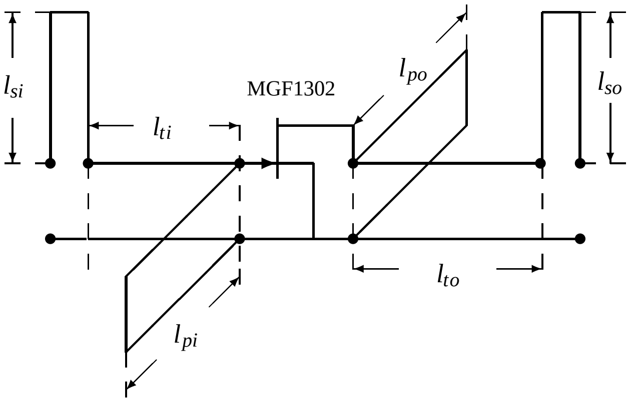

Fig. 1. Transmssion line model of the used matching circuit

To demonstrate the feasibility of the slotline technique for reactively matching we chose 5.8GHz as operating frequency for the amplifier. Fig 1 showes the equivalent transmission line model of the matching networks. At the transistors input as well as at its ouput we used a double stub tuner consisting of a serial short circuit stub (l_{si}, l_{so}), a transmission line

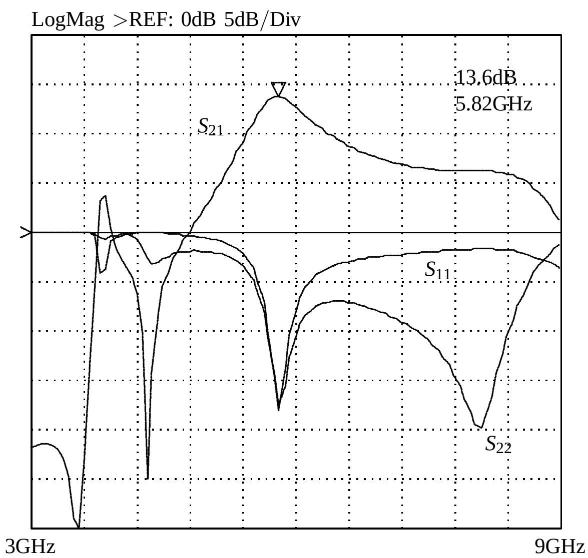

Fig. 2. Simulation results of the amplifier realized in 100Ω slotline technique

(l_{ti}, l_{to}) and a parallel short circuit stub (l_{pi}, l_{po}) next to the transistor to compensate for its parasitic capacitance. In order to end up with practicable slot width, we chose the characteristic impedances of all transmission lines to be 100Ω. As substrate we used TMM 10i from Rogers Corporation with a tickness of 0.635mm and a dielectric constant of $\varepsilon_r = 9.8$. Using this values results in a slot width of 0.587mm to get the desired caracteristic impedance. In order to find the appropriate physical length of the transmission lines and the stubs for matching we used the Smith chart and iterative simulation technique. Fig. 2 shows the results of the matching process, leading to the following physical length of the slotlines defined in Fig. 1: $l_{si} = 9.4$mm, $l_{ti} = 6.9$mm, $l_{pi} = 2.3$mm and $l_{po} = 2.6$mm, $l_{to} = 7.9$mm, $l_{so} = 11.9$mm. Both input S_{11} and output S_{22} reflection coefficients show good impedance matching resulting in a predicted gain of 13.6dB at the operation frequency. This is only approximately 1dB less compared to the predicted MAG.

III. Layout

To realize and also to measure the amplifier in slotline technique we are faced with two problems. First, the transistor of the amplifier has to be brought into its DC operating point. Second, the amplifier is designed for a 100Ω slotline technique, but the measurement equipment uses a 50Ω coaxial line technique. How this problems are solved, will be explained with the help of Fig. 3, showing the layout of the realized amplifier. Clearly one recognizes the wide slots in the centre

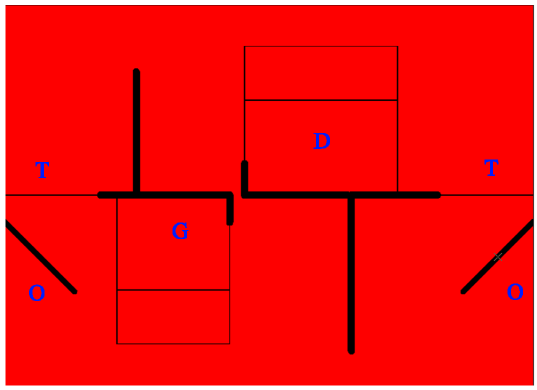

Fig. 3. Layout of the realized amplifier

of Fig. 3. These are forming the input and output matching circuits of Fig. 1. At the input (left hand side) as well as at the output (right hand side) of the amplifier are shown two narrow slots denoted with the letter T and two wide slots denoted with the letter O. The purpose of slot T is to form a quarter wave transformer at 5.8GHz transforming the 100Ω impedance of the amplifier to the 50Ω charactersitic impedance of the coaxial measurement equipment. This results in a slot width of 0.184mm to realize the 70.7Ω characteristic impedance of the quarter wave transformer. To operate at a frequency of 5.8GHz it has to have a length of 6.8mm. The slots O having a width of 0.5mm form short circuit stub with a length of 7.3mm. At the operating frequency they are a quarter wavelength long, transforming the short circuit to an open circuit at the plane of the coaxial transition. The purpose of the narrow slots connecting the wide slots of the matching circuits is to form conducting islands denoted by the letters G and D, to which the bias voltage of the gate and the drain is applied. In order not to disturb the rf operation of the amplifier surface mounted capacitors across the narrow slots are used to form short circuits. Thus the circuitry to biase a transistor in slotline technique turns out to be less complicated compared to microstrip line technique.

IV. Measurements

To measure the small signal gain, the input and output reflection coefficient of the realized amplifier we used a standard network analyser. Fig. 4 compares the measured results

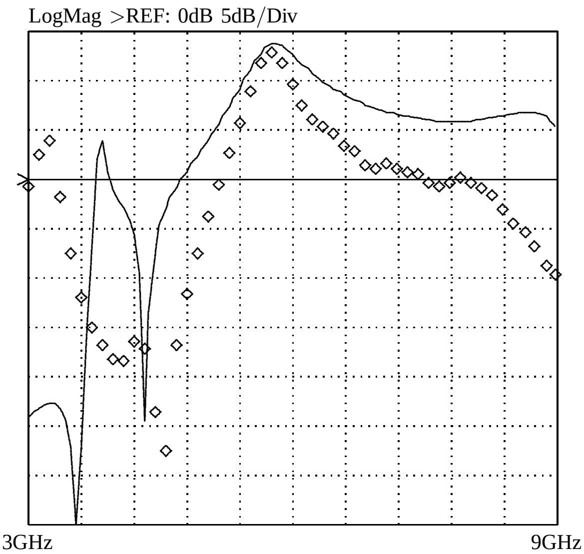

Fig. 4. Measured (◇) and simulated (−) transmission factor S_{21} of the amplifier

with simulated values incorperating also the behaviour of the quarter wave transformer and the short circuit stubs discussed in section III. At the operating frequency we measure a gain of 13dB, which is only 0.6dB less than the predicted value (Fig. 2). The difference between measurement and simulation directly below the operating frequency can be attributed to the slight mismatch of the input as shown in Fig. 5. The steep reduction of gain above the operation frequency is not described by the implemented models and must therefore be attributed to the frequency dependence of the slotline discontinuities that are not implemented.

V. Conclusion

We realized a hybride amplifier using only slotline elements. The measured amplifier gain of 13dB was only 1dB lower than its predicted value by simulation. Further comparison of the measurements and simulation showed that the implemented modells are sufficient to describe the frequency behaviour up to operation frequency of 5.8GHz. Beyond this value the lack of appropriate models to describe slotline discontinuities becomes obvious, encouraging further research in this area.

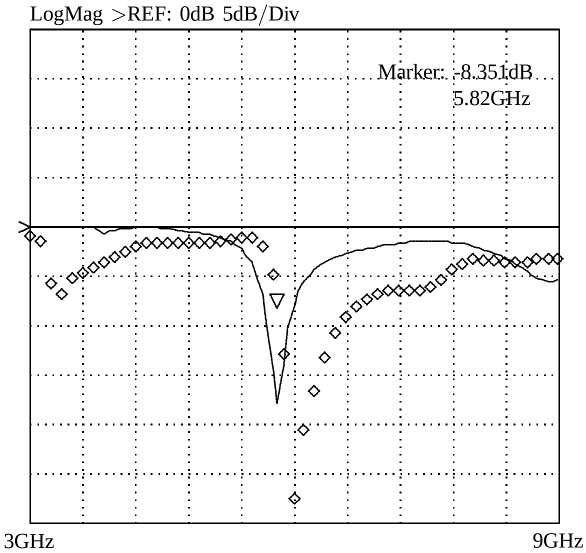

Fig. 5. Measured (◇) and simulated (−) input reflection S_{11} of the amplifier

Acknowledgement

The authors would like to thank Dipl.-Ing. D. Hess, Dipl.-Ing. R. Schickel and H. May from FH-Frankfurt for the technical assistance.

References

[1] I. D. Robertson, S. Lucyszyn, *RFIC and MMIC design and technology*, The Institution of Electrical Engineers, London, 2001.

[2] K. C. Gupta, M. D. Abouzahra, *Analysis and Design of Planar Microwave Components*, IEEE Press, New York, 1994.

[3] C. P. Wen, *Coplanar Waveguide: A Surface Strip Transmission Line Suitable for Nonreciprocal Gyromagnetic Device Application*, IEEE-MTT., Vol. 17, No. 12, pp. 1087-1090, Dec. 1969.

[4] T. Sporkmann, *The Current State of the Art in Coplanar MMICs*, Microwave Journal Vol. 41, No. 8 pp. 60-74, Aug. 1998.

[5] B. Schppert, *Analysis and design of microwave balanced mixers*, IEEE-MTT. Vol. 34, pp. 120-128, Jan. 1986.

[6] C.-H. Ho, L. Fan, K. Chang, *Broad-Band Uniplanar Hybrid-Ring and Branch-Line Couplers*, IEEE-MTT. Vol. 41, pp. 2116-2124, Dec. 1993.

[7] P. Jia, et. al., *Multioctave Spatial Power Combining in Oversized Coaxial Waveguides*, IEEE-MTT., Vol. 50, pp. 1355-1360, May 2002.

[8] K. C. Gupta, *Microstrip Lines and Slotlines*, Artech House, Boston, 1979.

[9] G. Duchamp et al., *An Alternatice Method for End Effect Characterisation in Shorted Slotlines*, IEEE-MTT., Vol. 46., Nov. 1998.

[10] S. B. Cohn, *Slot Line on a Dielectric Substrate*, IEEE-MTT., Vol. 17, pp. 768-778, Oct. 1969.

[11] G. Zimmer, *Hochfrequenztechnik Lineare Modelle*, Springer, Berlin, 1999.