Microwave Solid State Power Amplifier Technology

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***Abstract*—This paper is focused on our current research in the field of power amplifier technology for microwaves, especially the X-band. For this purpose we considered different active devices. Unfortunately, we did not manage to obtain super modern GaN transistors (chips) for these frequencies such as TGA2023-05 from TriQuint or module such as TGA-2554-GSG from the same producer. Instead we used internally matched GaAs FETs from Eudyna as well as GaAs module XP-1006A from Mimix. Subsequently we have designed, built and tested three power amplifiers with different active devices and output power of 4, 8 and 20 Watts on 10 GHz. In the paper we would like to introduce design and completion of the amplifiers as well as test results. The highest power we achieved by double stage with 90 degrees 3 dB hybrid couplers at the input and output. The microstrip technique on PTFE substrate has been used. Critical parts of layouts were optimized by using ANSYS modeling software. The dc circuitry needs to be designed according to the proper time sequence and high dc currents. Corresponding cooling system was taken into account.**

Keywords—microwave amplifier; solid state power amplifier; linear power amplifier;

I. INTRODUCTION

There are several application where high power on microwaves frequencies is needed, for example radars or space communication. An achievement of high power on these frequencies is neither simple nor cheap. In this paper we considered narrow band linear power amplifiers. At present, modern GaN chips are introduced [5] but are difficult to obtain, especially in small quantities. For this purpose the standard internally matched GaAsFETs are applicable. A problem there is a low effectiveness of the power amplifier. In order to achieve 6 – 7 dB small signal transistor gain, the power amplifier should operate in class A [1][2]. That means a big idle current. For this reason low efficiency and strong heat dissipation occurs. The standard push-pull double acting amplifier (in AB class) is critical from the balancing point of view. The Doherty amplifier concept needs a peaking amplifier in class C (low gain on the X-band) [3][7]. For this reason, quadrature dual-acting stage is better for higher power achievement but both halves are acting near to A class again.

II. LINEAR MODEL

Sets of expected parameters at recommended operating conditions including linear model are available for several

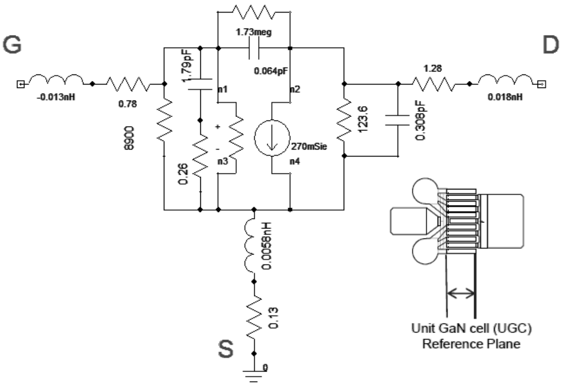

Figure. 1. TGF2023-05 linear model.

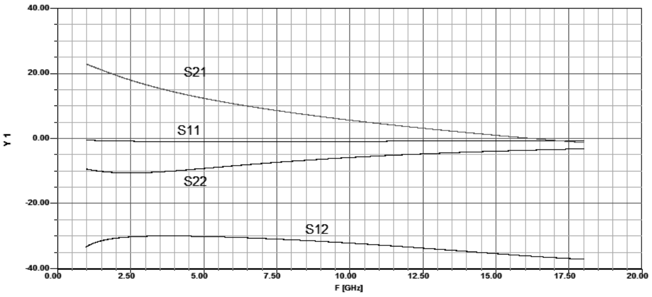

Figure 2. Calculated s-parameters.

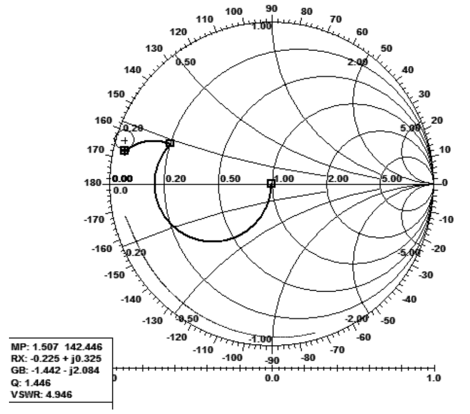

Figure 3. TGF2023-05 input matching to 50 Ohms on frequency 10.37 GHz.

microwave devices. 1.25 mm Unit GaN Cell TGF2023-05 can be shown as example [5], fig. 1.

Scattering parameters can be calculated from the model as shown in fig. 2. Then matching to the 50 Ohms at the input can be designed according to the linear model, fig. 3., as well as the output. Model which includes microstrips matching circuitry is shown in fig. 4. Calculated parameters of whole linear amplifier can be seen in fig. 5. The small signal parameters of linear power amplifier are as expected. The imitation stability criterion is fulfilled too. Large signal parameters like output power and efficiency should be 43 dBm and 0.5 respectively.

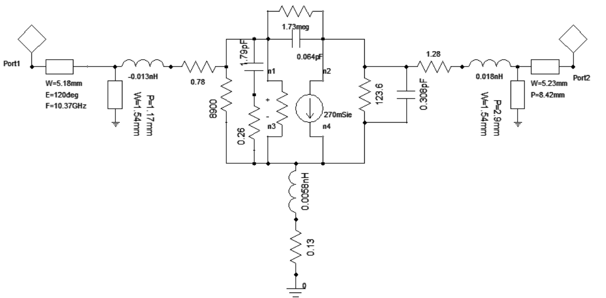

Figure 4. Model of whole linear power amplifier with the chip TGF2023-05.

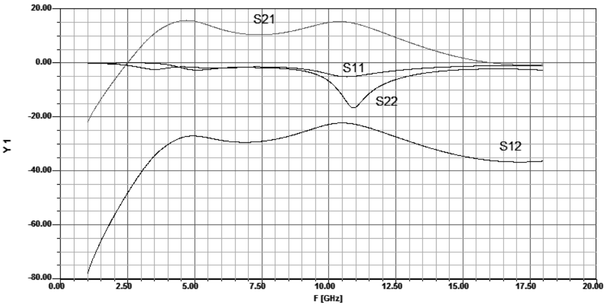

Figure 5. Small signal parameters of whole linear power amplifier based on chip TGF2023-05.

III. SINGLE STAGE POWER AMPLIFIER

Internally matched microwave GaAsFETs allow to provide relatively simple design of a single stage power amplifier, because operating class A tolerates to start the design with small signal analysis method [4]. This way we designed P_{1dB} = 36 dBm amplifier for frequency 10.37 GHz. At idle current about 0.65 I_{DSS} expected efficiency was $\eta = 0.3$ and IM3 < 40 dB. Model of the linear amplifier with FLM0910-4F is shown in fig. 6. 50 Ohms input and output microstrips are equipped with open end stubs. These stubs allow to find optimized matching on both ends as can be seen in fig. 7. Finally the right positions of the stubs were found experimentally, fig. 8. These metrics were very close to the calculated ones. Heat sink with small cooling fan was applied because the corresponding dissipated power is about 10 W. Proper dc circuitry design is very important. The negative gate voltage has to come first before the drain positive voltage.

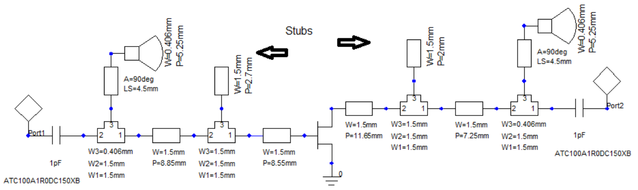

Figure 6. Linear model of the single stage power amplifier with FLM0910-4F

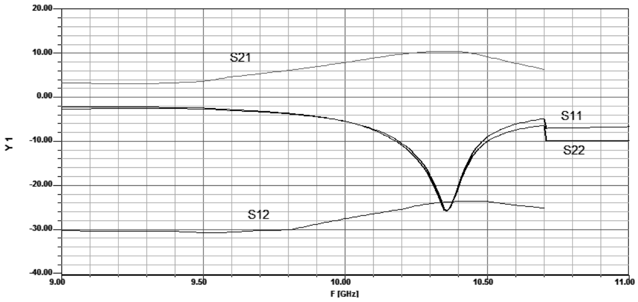

Figure 7. Good matching at the both ends of the power amplifier achieved by calculated stubs.

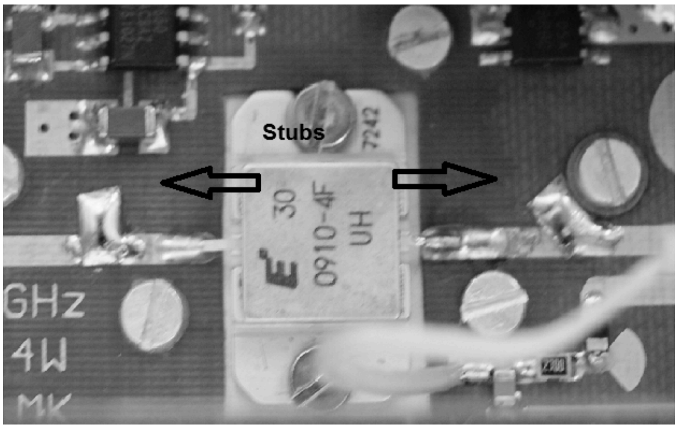

Figure 8. Detail of matching stubs.

IV. THREE STAGE POWER AMPLIFIER WITH MIMIX MODULE

Several producers have developed more stages MMIO power amplifiers usually for specific applications. Radars with adaptive antenna arrays are such an application. Each antenna element has own power module and high radiated power is obtained as a sum of primary power contributions.

Mimix offers three stage 8.5-11.0 GHz GaAs MMIC power amplifier giving large signal gain of 21 dB with a 40 dBm saturated output power [6]. It also includes on-chip gate bias circuitry. This MMIC uses 0.5 µm GaAs PHEMT device model technology and is based upon optical gate lithography to ensure high repeatability and uniformity. The low duty cycle is recommended while this device is well suited for radar application. We obtained the packaged device P1006-FA, which comes in a 10 pin, high frequency, LCC flange package. The built power amplifier is shown in fig. 9. Unfortunately, we achieved only P_{1dB} = 38 dBm and large signal gain about 17 dB. The efficiency was about $\eta = 0.3$.

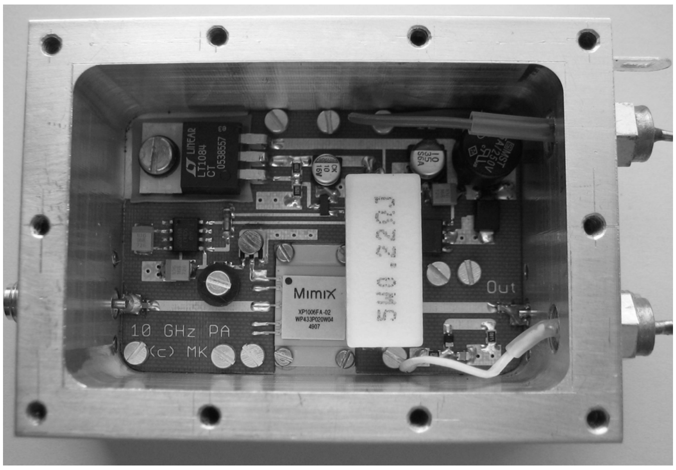

Figure 9. Power amplifier with MMIO P1006-FA by Mimix.

V. HIGH POWER MICROWAVE AMPLIFIER

The aim of this project was to develop a power amplifier with P_{1dB} = 43 dBm and large signal gain about of 20 dB on frequency 10.37 GHz. Selected concept of this amplifier is three stage amplifier with last stage operating in quadrature mode. Precisely designed 3 dB microstrip hybrid coupler is essential for this mode. This configuration ensures a high degree of isolation between the two output ports and the two input ports at the input as well as at the output of the quadrature stage.

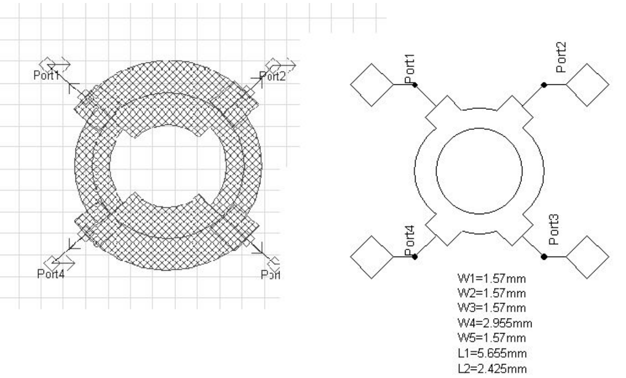

Figure 10. Optimized layout of 3 dB hybrid coupler for quadrature stage.

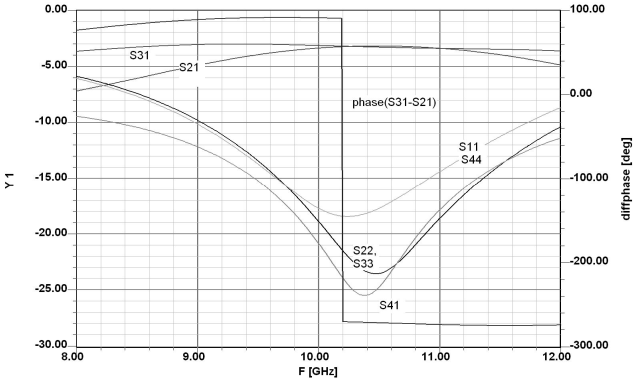

Figure 11. Calculated parameters of the optimized 3 dB hybrid coupler.

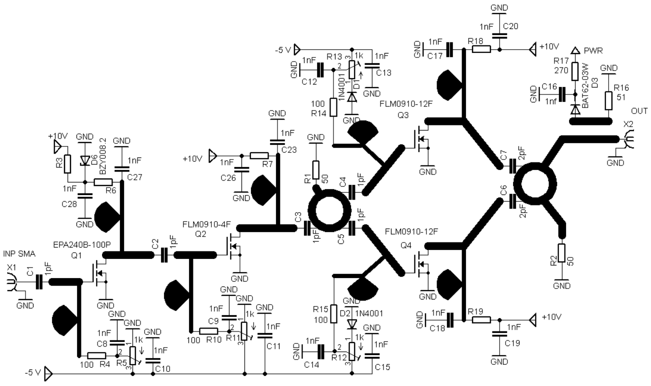

Figure 12. High power linear power amplifier schematic.

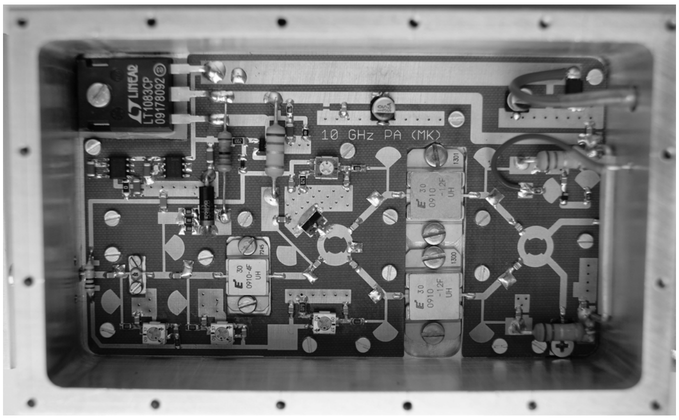

Figure 13. Linear power amplifier with 43 dBm output power.

Active device of the first stage is EPA240B-100P from Excelics Semiconductors. Next stage is set up with FLM0910-4F and the last stage operates with two GaAsFETs FLM0910-12. For good linearity and gain achievement all stages work in class A.

Power amplifier schematic is shown in fig. 12 as well as its final performance in fig. 13. P_{1dB} output power has been achieved 43.2 dBm at IM3 < 40 dB and gain 19 dB. Total dc current from 12 V power source is 8.2 A. The efficiency of the whole amplifier (all three stages) is about η = 0.2 and dissipation heating power about 80 W. For this reason the amplifier is mounted on a proper massive heat sink and cooled by two 80 mm fans. The temperature is then up to 70° C at CW operation. Microwave power amplifier test-bed in our laboratory is shown in fig. 14.

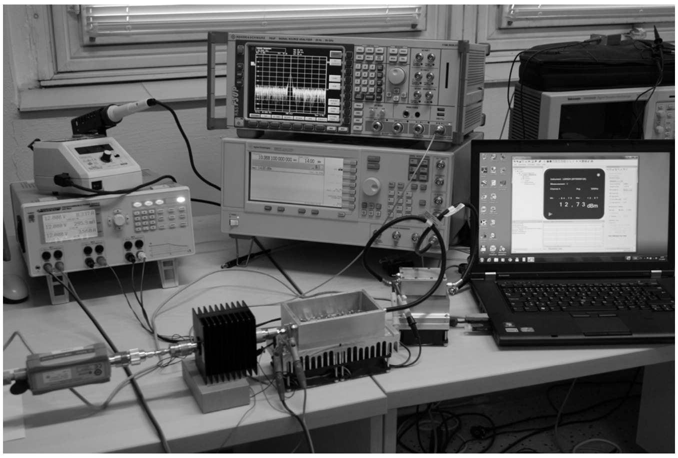

Figure 14. Power amplifier test-bed measurement

VI. CONCLUSIONS

In this paper we introduced design and implementation of several power amplifiers on microwave frequencies. Standard GaAsFETs allow to carry out power amplifiers up to tens Watt on 10 GHz. Operating class A of all stages makes it possible to obtain suitable large signal gain but at low efficiency. On the other hand a linear model can be applied for such power amplifier design. We are excited to see a production of new GaN devices which promise higher gain as well as higher efficiency of the microwave power amplifiers at excellent thermal stability.

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