Microwave Amplifier Design for Solid State Radar Transceivers at X-band

T. J. Korfiati[1], **E. A. Karagianni**[2], **Ch. N. Vazouras**[2], **Ch. C. Lessi**[1], **and N. K. Uzunoglu**[3]

[1]Department of Informatics and Telecommunications
National and Kapodistian University of Athens, Panepistimioupoli, Athens 15784, Greece
[2]Department of Naval Sciences, Hellenic Naval Academy
Hatzikyriakou Avenue, Piraeus 18539, Greece
[3]Department Division of Information Transmission Systems and Material Technology School of Electrical and Computer Engineering National Technical University of Athens
Zografou Campus Heroon Polytechniou 9, Zografou 15780, Greece

Abstract— A design approach to amplifier bias circuits using a discrete GaN on SiC HEMT is presented is presented. Incorporating matching circuits to bias circuits, various simulations are carried out to minimize the effect of bias circuits on the overall behavior of the amplifier. Simulation results show good matching with $S_{11} = -12.2\,\mathrm{dB}$, $S_{22} = -14\,\mathrm{dB}$ and a gain value at 15.4 dB. The resulting S parameter values correspond to $K = 1.3$ and $D < 1$, demonstrating stability of the circuit. Using this approach, a single stage X-band amplifier design with only one MMIC amplifier is presented, exhibiting an excellent performance at 10 GHz, which can be utilized in Solid State T/R module for advanced Phased Array Radar Systems.

1. INTRODUCTION

Distributed architectures employing solid state power amplifiers (SSPA) using gallium nitride (GaN) device technology promise to play an important role in the next generation of military, civilian, and commercial radar transmitters These devices can support systems with higher sensitivity, increased detection range and improved reliability with lower cost and weight [1]. Use of GaN Monolithic Microwave Integrated Circuit (MMIC) in Transmit/Receive (T/R) modules enables improved resolution and DC power distribution efficiency [2, 3]. For solutions of this type, an important is fitting all the components in a package comprising a suitable amplifier.

The purpose of this paper is the analysis, the study and design of a single stage amplifier, with an operating frequency in X-band, band (or, with another terminology, in the I and the lower portion of J band); to demonstrate the proposed approach a typical design frequency is adopted at 10 GHz, around which a significant spectrum segment is usually allocated for radiolocation (on a primary or/and secondary basis). The final goal of the design is a reliable amplifier suitable for use in phase controlled arrays. A GaN transistor is selected to take advantage of several useful features [4], such as reduced heat sensitivity due to the high value of thermal conductivity [5], and hence elimination of cooling systems, reducing the weight and required board space of the overall circuit. Moreover, due to high impedance presented by GaN, fewer matching components are used, resulting in further cost and weight reduction.

2. ADVANCES OF GAN MICROWAVE AMPLIFIER TECHNOLOGY

The inherent power limitations of SSPA devices (as compared with traditional microwave tubes) may be circumvented, to some extent, by parallel module architectures based on parallel in-phase combination of several SSPA modules to achieve the desired output power level. High gain levels are achievable with this type of design (of the order of 70 dB or even higher). The parallel module concept may also be extended to the power supply, resulting in elimination of single points of failure in any active component within the SSPA; if one module fails, the SSPA can continue operation at reduced output power. This, of course, is made practical thanks to the low operating voltage required by SSPAs, as contrasted to extremely demanding voltage supply requirements of microwave tubes. In any case, higher power transistor designs enabling increased output power capability of an SSPA are highly desirable.

Recently, a range of high power wide band GaN amplifiers seem to gradually find their way into commercial availability. As the reliability of the devices improves, suppliers (see, e.g., [3, 8]) plan to push the advantages of GaN technology up in frequency to satisfy the need for improved efficiency in the X, Ku & K-Band communications market. The high energy gap (3.4 eV) of the GaN compared with GaAs, as well as the high critical electric field (3.5 MV/cm), are the main properties that can support high voltage applications such as a high power amplifier. What is more, GaN is suitable for high current density applications because it has high charge density ($10^{13}/\mathrm{cm}^2$) and high thermal conductivity (1.5 W/cm/K). High saturation velocity (2.7×10^7 cm/s) and medium mobility (1500 cm^2/V/s) are properties that allow the use of GaN in high frequencies applications.

3. PHASED ARRAY RADARS

There are two types of phased arrays: Passive and Active (Figure 1). Passive phased arrays have a central transmitter and receiver, with phase shifters located at each radiating element or sub-array. The passive array is the least expensive phased array because of its low number and cost of components. Active arrays use T/R modules mounted directly on the antenna to provide the last stage of amplification for transmitted signals, the first stage of amplification for receive signals, and provide both amplitude and phase control at each radiating element. Use of T/R modules in active arrays provides advantages of amplitude control, low loss, and graceful degradation over passive arrays. Notwithstanding these advantages, high cost and low efficiency of the modules poses an obstacle to development of active phased array antennas. A typical T/R module [2, 7] for pulsed radar applications (Figure 2) comprises an electronically controlled attenuator and phase

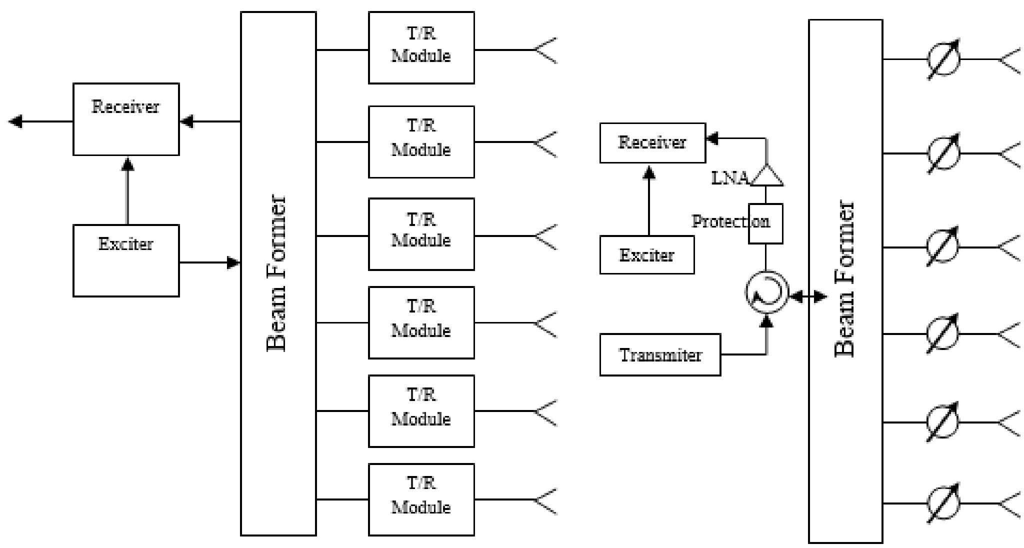


Figure 1: Block diagrams of active and passive phased arrays.

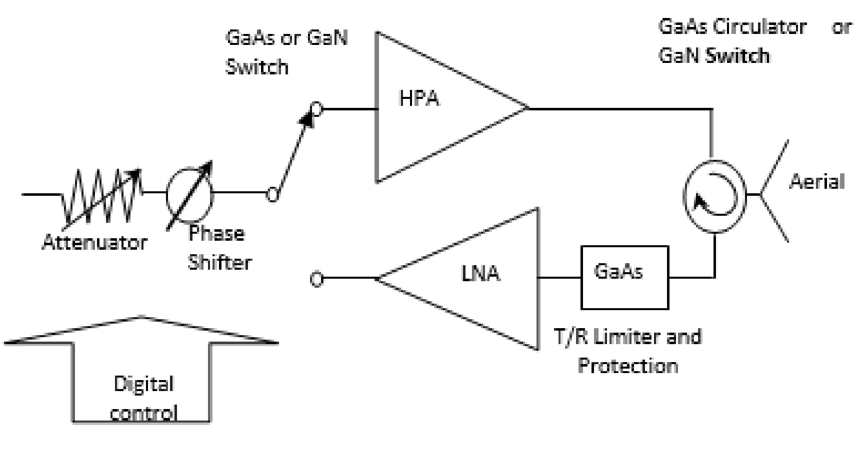


Figure 2: Typical T/R module components for both GaAs and GaN technologies.

shifter (used in both transmit and receive mode by means of appropriate switching), along with the high power amplifier (HPA) at the output branch and the low noise amplifier (LNA) at the input branch. A switch (probably combined with a circulator) acts as a duplexer for transmit and receive. A limiter is sometimes added before the LNA to reduces very strong incoming signals from jammers or unusually large targets too close to the radar. All components are assembled in one single T/R module.

4. MMIC DESIGN

The approach to design amplifier bias circuits is presented in this work. A discrete GaN on SiC HEMT was used [8]. Figure 3 depicts the simulation results for the bias circuit and Figure 4 the ones for the matching circuits of the amplifier. Incorporating matching circuits to bias circuits (Figure 5, Figure 6), various simulations are extracted to find what bias circuits do not affect the overall behavior of the amplifier [9].

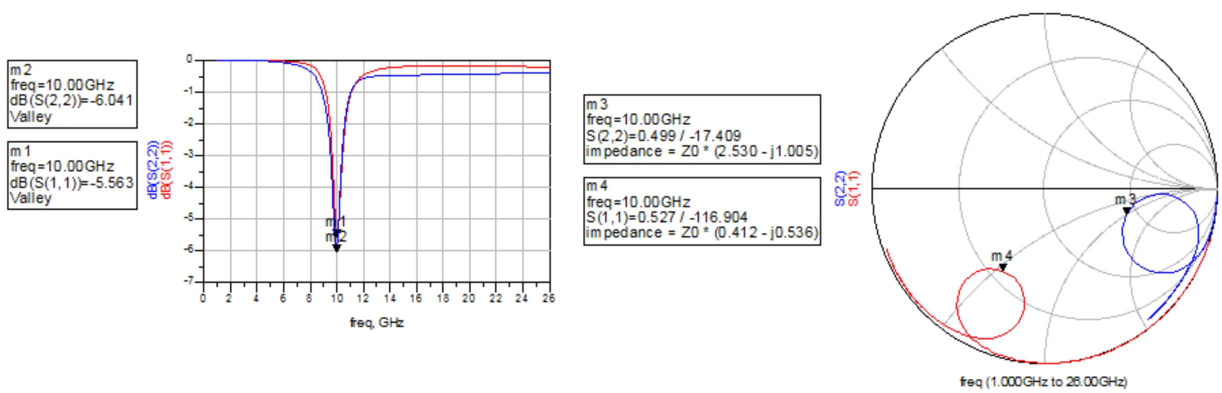
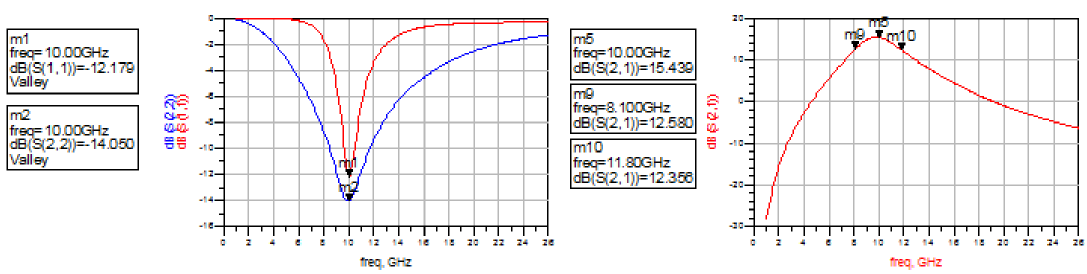


Figure 3: Simulation results — tuning circuit.



freq	MaxGain1	PwrGain1	Mu1	StabFact1	VSWR1	VSWR2
10.00 GHz	16.225	15.439	1.394	1.299	1.653	1.495

Figure 4: Simulation results — matching circuits.

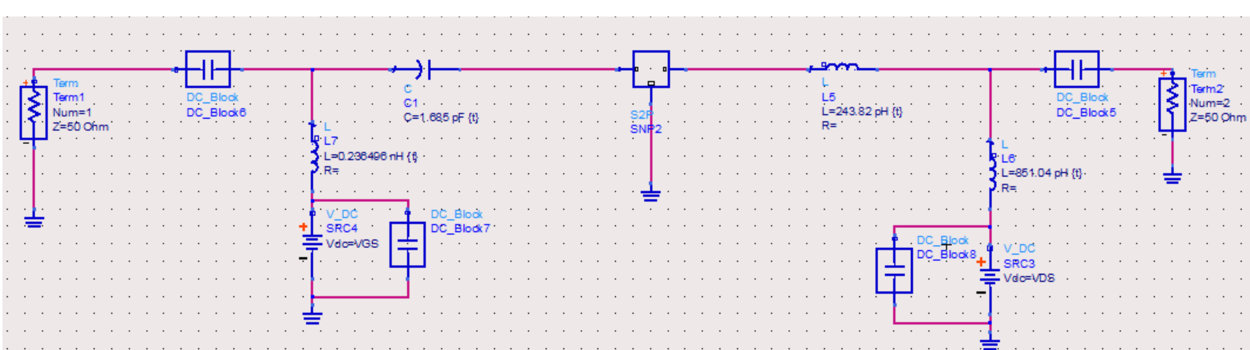
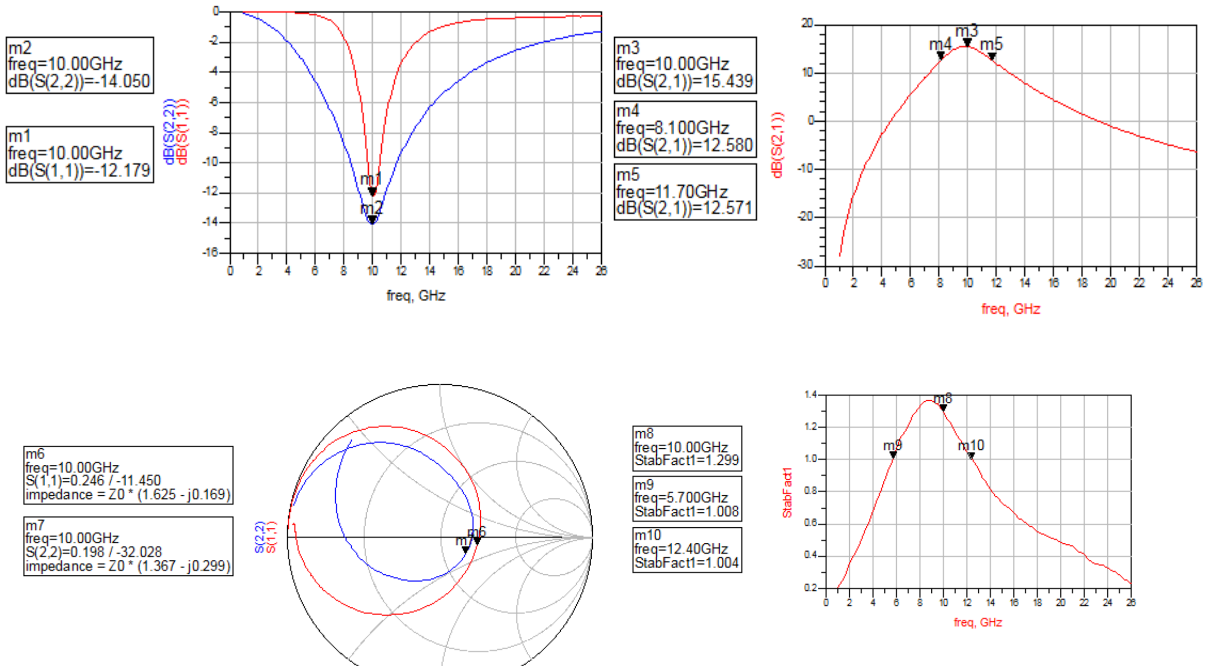


Figure 5: Final circuit.



freq	MaxGain1	PwrGain1	Mu1	StabFact1	VSWR1	VSWR2
10.00 GHz	16.225	15.439	1.394	1.299	1.653	1.653

Figure 6: Simulation results — final circuit.

5. CONCLUSIONS

In this paper, a single stage X-band amplifier design which using only one MMIC amplifier has been shown to exhibit an excellent performance at 10 GHz for possible utilization in Solid State T/R modules for advanced Phased Array Radar Systems [9–11]. From simulation results we have a good matching, $S_{11} = -12.2$ dB, $S_{22} = -14$ dB and a gain value at 15,4 dB, almost the maximum supported. With the corresponding S parameter values S resulting from the design, we found $K = 1.3$ and $D < 1$ implying circuit stability. So in conclusion, we note two parameters. In view of the important need for lightweight and small sized amplifiers (one or two transistors) as an important factor in the structure of T/R modules, we may conclude that selection of the GaN technology as demonstrated above, positively contributes to amplifiers with low weight, size and cost, and with very good performance adjustment, gain, and bandwidth, presenting noteworthy application potential.

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