

Design and Simulation of 9-11GHz High Power Amplifier Based on Microstrip and Power Combining Techniques

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Abstract

The aim of this work is the design and analysis of power amplifiers that operate in the microwave band (9-11GHz) within the X-band and used in the terminal stage of solid-state transmitters. The approach of the design and the analysis is entirely S-parameters dependent. Following the choice of a suitable (GaAs MESFET) transistor and investigation of its properties in the required frequency band, a modern computer package (Microwave office 2000, ver.3.22) is used to realize the compatible circuits possessing the desired characteristics.

In order to facilitate the achievement of high power transmission, two techniques are used, the Lange coupler and Wilkinson divider. The highest power achieved was 50W. The advantages of the designed amplifier included high power, high gain and gain flatness, good stability circles, low noise figure. The entire design is based on microstrip technology with biasing network having temperature compensation.

الخلاصة

يتناول موضوع هذه البحث تصميم و تحليل مضخمات القدرة للترددات المايكروية بالنطاق (9-11GHz) والتي هي ضمن الحزمة X التي تستخدم في المراحل النهائية لأنظمة الإرسال بالحالة الصلبة. إن طريقة التصميم و التحليل لمضخمات القدرة للترددات المايكروية تعتمد اعتمادا كليا على معلمات الاستطارة (S-Parameter). تم اختيار الترانستور الملائم (GaAs MESFET) و معرفة كل خواصه التي تؤهله للعمل كمضخم قدرة عالية بالنطاق الترددي المطلوب تم عندها تمثيل دوائر الموائمة لدائرة المضخم بالاستعانة بالبرنامج المتطور والحديث (Microwave Office 2000 ver.3-22) لأغراض التطبيقات المايكروية حتى يتسنى لنا الحصول على دائرة مضخم مطابقة للمواصفات المطلوبة.

تمت الحسابات و استخراج النتائج نظريا قبل تمثيلها بالحاسبة و لغرض الحصول على قدرة إرسال عالية قدر المستطاع تم استخدام تقنية التقسيم/التجميع للقدرة المايكروية حيث تم تصميم وتحليل نوعين من أنواع هذه التقنية و هما: (تقسيم Lange) و (تقسيم Wilkinson) وتم استخدام تقسيم Lange للحصول على القدرة المطلوبة. استخدمت طريقة التصميم المبينة أعلاه لتكريب مضخمات قدرة بقدرات خرج مختلفة و حسب الحاجة إليها داخل الحزمة X من الترددات المايكروية حيث بلغت قيمة أكبر قدرة خرج للمضخم هي: (50w) تميز المضخم المصمم بقدره العاليه وكسب عال إضافة إلى كسب منبسط ودوائر استقرارية جيدة مع قيمة ضوضاء واطئه. أستند التصميم الشامل على تقنية الشريحة المايكروية مع شبكة انحياز تمتلك تعويض لدرجة الحرارة.

1. Introduction

Microwave power amplifiers are being used increasingly in military and commercial communication such as radar systems, radio relay, and satellite communication that include voice, data, and DBS-TV (Direct Broadcast Satellite Television) they are operate at high frequencies in order to facilitate higher data rate and wider range of services ^[1]. The solid state transistor amplifier has been of interest for microwave applications because of the: Solid state transistor amplifiers have low noise and good stability, Solid state devices operate at much lower voltages (order of tens of volts) than RF power tubes (order of tens of kilovolts ^[2]. In order to obtain a linear amplifier that can be used in multi-mode transmitters' class-A at operation bias was selected. Computer aided design (CAD) techniques (microwave office 2000, version 3.22 ^[3] was used to optimize and tune the performance of the power amplifier.

2. The Procedure of Design of Single Stage Amplifier

The design of a single-stage microwave amplifier can be carried out step by step as follows:

1. Select a power transistor based on data sheet description of S parameters, linear output power, frequency response, noise parameters. The NEC SEMICONDUCTOR (GaAs FET) (NEZ1011-E5) transistor was chosen that meets the design objectives which are: high power, high gain and gain flatness, good stability circles, low noise figure.
2. Calculate the stability factor (K) from equation (1).

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|} \dots\dots\dots (1)$$

3. Calculate the delta factor (Δ) from equation (2).

It is always prudent to determine that both $|\Delta| < 1$ and $K > 1$ conditions are fulfilled to ensure an unconditionally stable design

$$|\Delta| = |S_{11} S_{22} - S_{12} S_{21}| \dots\dots\dots (2)$$

4. If ($K > 1$) the device is unconditionally stable, determining the maximum available gain (MAG) are to be determined from equation (3), and maximum stable gain (MSG) are to be determined from the equation (4), such that these gain figures should be greater than the desired power gain by using the S-parameters at the center frequency ^[4].

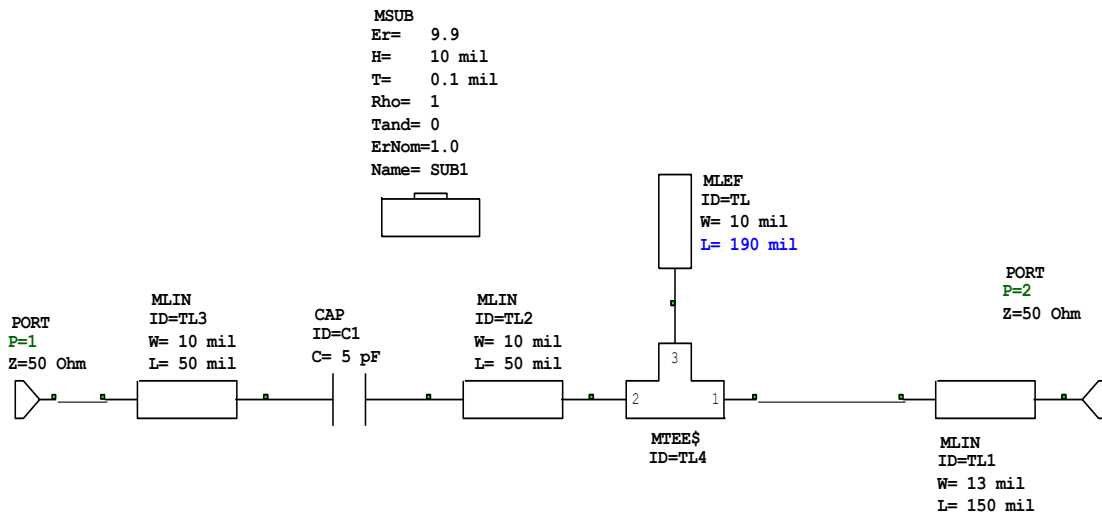
$$G_{T,max} = \frac{|S_{21}|}{|S_{12}|} (K - \sqrt{K^2 - 1}) \dots\dots\dots (3)$$

$$MSG = \frac{|S_{21}|}{|S_{12}|} \dots\dots\dots (4)$$

5. Design Input and out put matching networks at center frequency and calculating the optimum load and source reflection coefficients to achieve the maximum power gain and minimum VSWR at the input and output.
6. When the device (transistor) is potentially unstable ($K < 1$) then plot unstable regions, the load stability circle and the desired power gain circle. The load reflection coefficient on the desired power gain circle but outside the stability circle.
7. Design Input and out put matching networks at center frequency the matching networks is synthesized. The Immittance chart is the best graphical tool that can be used practically in constructing the matching network elements. This chart presents both impedance and admittance coordinates for any point and at the same time it can be constructed by superimposing two Smith charts printed in two contrasting colors with one Smith chart rotated 180° relative to the other.
8. Plot reflection coefficients versus frequency to verify stability.
9. Drawing a constant Q-circle on the Immittance chart. The radius of the Q-circle is $(1+(1/Q)^2)^{1/2}$ and the center is $\pm 1/Q$ on the imaginary axis of the chart. The mapping of the constant Q-curves on the Immittance chart is a necessary guide to estimate the desired low quality factor of the matching networks. To determine the quality factor the following equation can be used: f_o/BW where f_o center frequency (10.0 GHz). BW frequency bandwidth (2000 MHz). To draw a constant quality-curve on the Smith chart or Immittance chart., the equation $Q = X/R$, may be represented on a Smith chart or an Immittance chart by connecting points having equal values of R/X , where: X is the imaginary part (Reactance) and R is the real part (Resistance).
10. Design DC bias circuit determining the optimum bias point for the required output power is determined. The quiescent point should lie in the safe operating area of the DC drain characteristics to avoid exceeding the maximum power dissipation capability of the device [5].
11. Again verify stability.
12. Layout complete amplifier.
13. Verify realizability.

From the available transistor data sheets, the NEC SEMICONDUCTOR [GaAs FET] (NEZ1011-E5) transistor was chosen. It is an internally impedance-matched GaAs power FET especially designed for use in (X to Ku) band power amplifiers. The hermetically sealed metal-ceramic package guarantees high reliability. The features of this transistor are: Suitable for class-A of operation, internally matched to 50Ω systems, high output power $P_{1dB} = 5W$, high power gain (linear gain) 8dBm, high power added efficiency $\eta_{add} = 30\%$. After testing the device, the next step in the design process of the 5W amplifier is the synthesis of the matching networks. Evaluating the transistor parameter at the center frequency (10GHz), began the design of amplifier circuit. The design based on Microstrip Substrate Materials the teflon-fiberglass substrate is better than the Epoxy-glass substrate at high frequencies but it is

more expensive [6]. To reduce loss, Microstrip elements must be made as wide as possible [7], therefore $\epsilon_r=9.9$ or 9.8 was chosen. Dielectric loss tangent for this material was $T=0.0012$, which also helped to reduce dielectric losses. This material has low dielectric losses at such frequencies and is easy to process. After the substrate material is chosen, the stub elements in the input and output matching networks will be translated to Microstrip elements by using the theoretical procedure to design Microstrip element to find the dimensions of all elements as shown in Fig.(1), (2), (3) and Fig.(4).



Input Matching Circuit of NEZ1011-E5 Amp.

Figure (1) Schematic circuit of input matching network

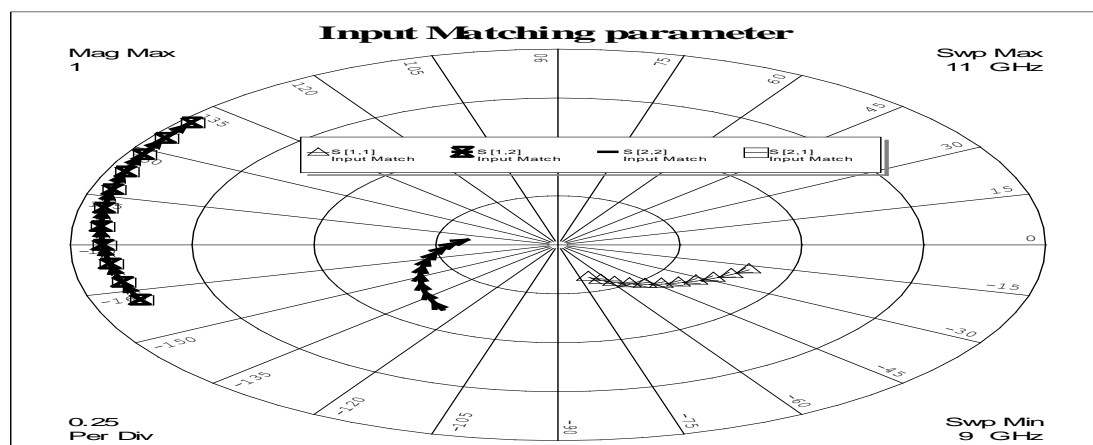


Figure (2) S-parameter of input matching network

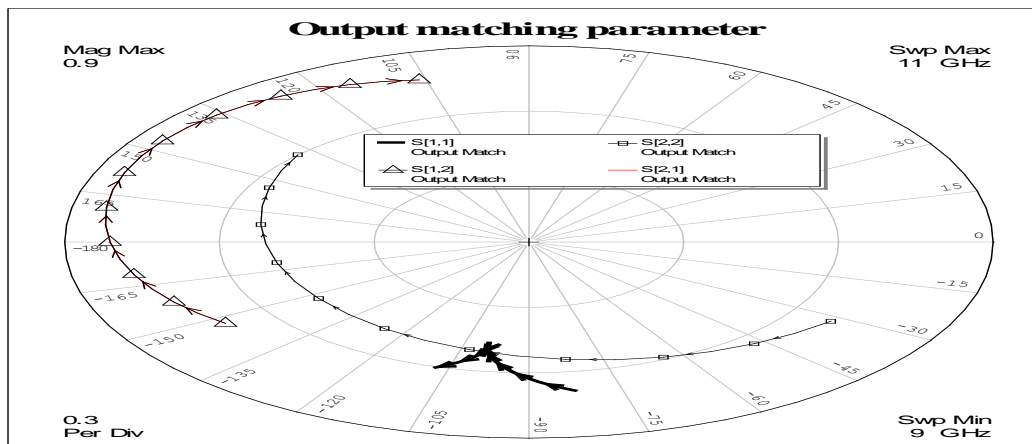


Figure (3) S-parameter of output matching network

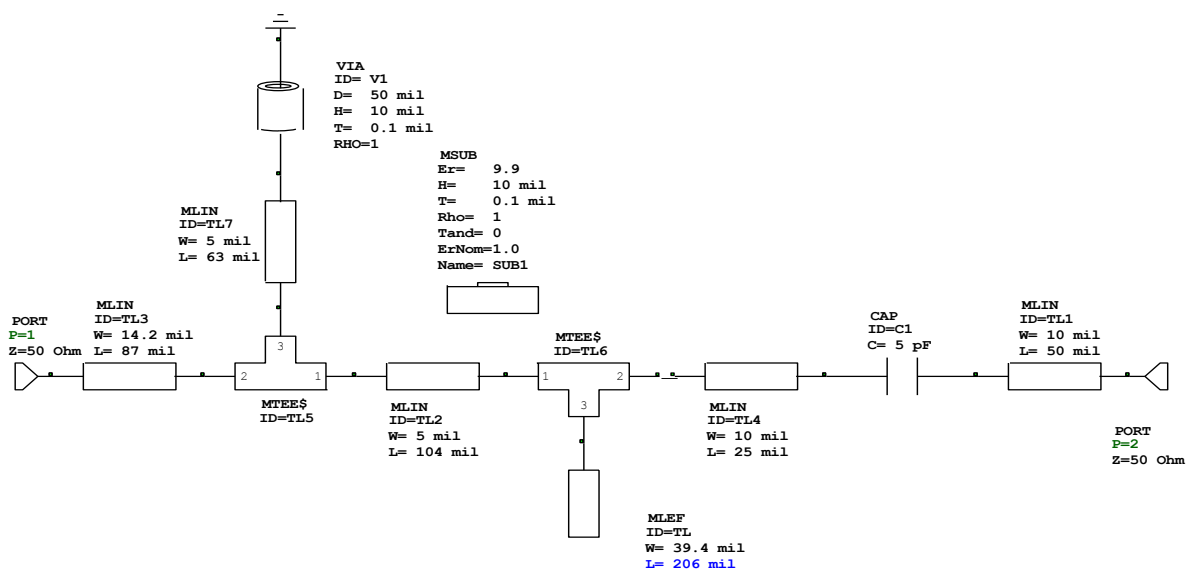


Figure (4) Output matching network of 5W power amplifier

The schematic Diagram of the MESFET amplifier shown in Fig.(5) and the schematic diagram of the optimized amplifier circuit of 5W (9~11GHz) power amplifier is shown in Fig.(6). The S-parameters of the 5W power amplifier are shown in Fig.(7), output power in dBm shown in Fig.(8), stability factor shown in Fig.(9). The measurement of power harmonic component Pcomp used to measure a harmonic component of the power measured with a power meter or at a port. The power value is returned as the complex magnitude of the r.m.s. power component at the harmonic frequency and the measurement of total power (sweep over frequency) PT used to measure the total power delivered to the power measurement element, including the power at DC and all harmonics [8] these measurements are shown in Fig.(8). The main features of our design of biasing circuit are; constant operating current, reduction of Part -to-part variation, temperature compensation, negative voltage generator.

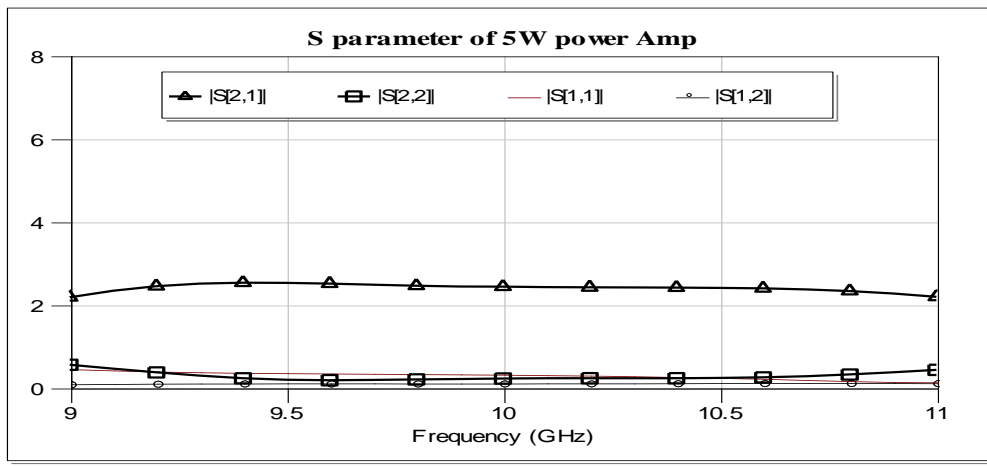


Figure (7) S-parameters of (9-11GHz) 5W power amplifier

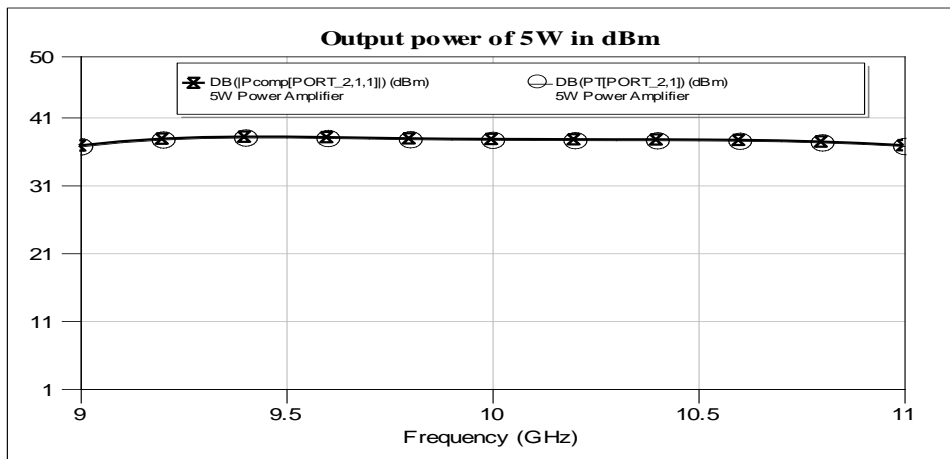


Figure (8) Output power in dBm of (9-11GHz) power Amp

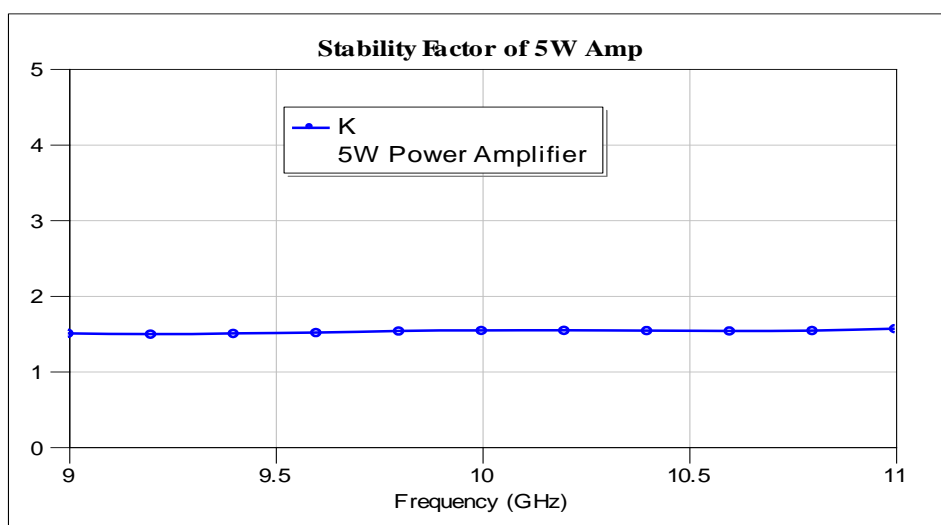


Figure (9) Stability factor of (9-11GHz) 5W power amplifier

3. Power Combining Techniques

To obtain high power and broad band, the simplest and easiest method is to use power-combining techniques in amplifier design [9]. Microwave power combining is of particular importance in radar and satellite earth station transmitter applications, where many power sources are combined by various techniques to obtain high power, especially at microwave frequencies where a large amount of power might not be available from a single source [8]. For future airborne phased-array radar and space borne communication system applications, a large number of identical components are required and the balanced amplifier is the most desirable candidate for achieving the projected goals. In this research several commonly used microwave power combiners/dividers, such as Lange coupler and Wilkinson power combiner, and the balanced amplifier design are discussed.

1. Determining the desired coupling coefficient K .
2. Choosing the characteristic impedance Z_0 .
3. Calculating the strip length l for a quarter wavelengths at the center frequency of the operating band.
4. Finding the gap spacing S and the strip width w for a given substrate height h and with a relative dielectric constant ϵ_{r1} .

4. Design, Simulation and Layout of Lange Coupler

Using computer aided design, the results are presented in Fig.(10) and Fig.(11). In this figures the transmission loss for both outputs have deviation of $\pm 1.5\text{dB}$. The isolation between the output ports of the coupler is better than -38 dB in the (9-11GHz) band frequency range. The VSWR of the input and output ports are equal to 1.028. The layout design of the transmission loss for both outputs is deviated by $\pm 2\text{dB}$. The isolation between the two output ports of the coupler is better than -24dB . The VSWR of ports 3 and 4 are less than 2 and port 1 and 2 are less than 1.16.

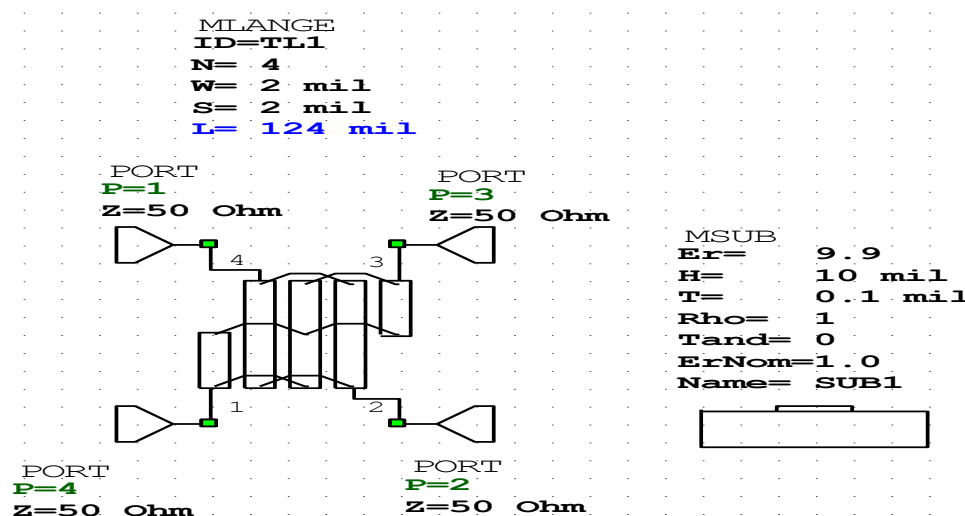


Figure (10) Schematic of lange coupler

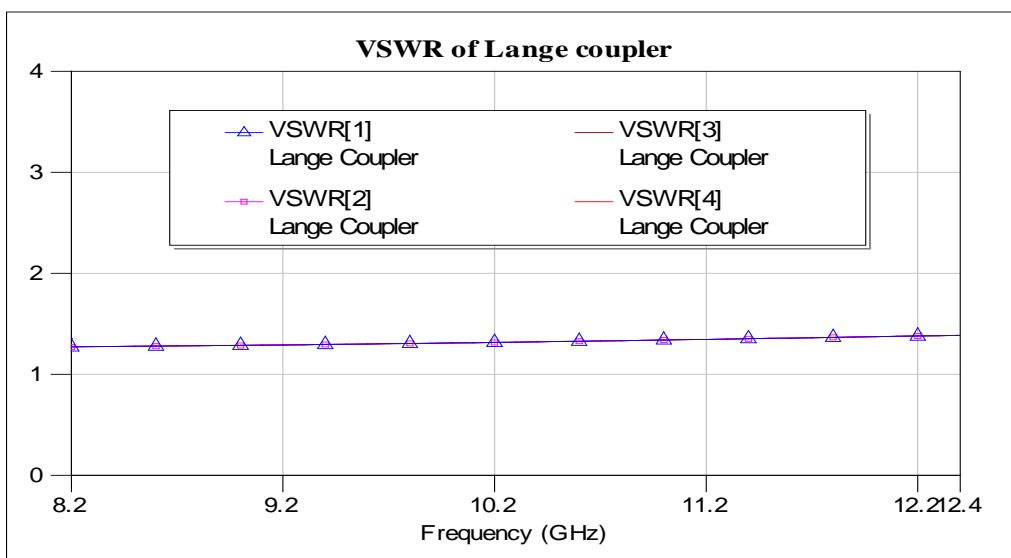


Figure (11) Voltage standing wave ratio of lange coupler

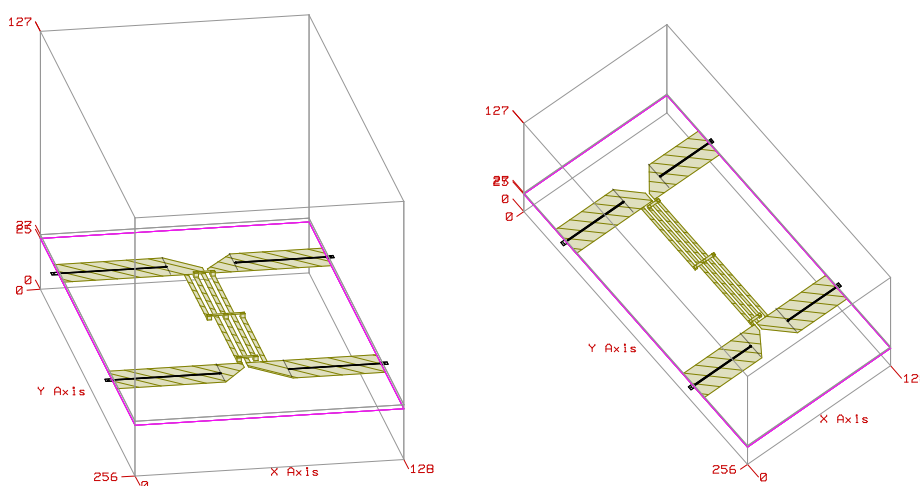


Figure (10) Layout design of lange coupler

5. Design and Simulation of Wilkinson Power Divider

Following a similar steps, the design of Wilkinson Power Divider is shown in **Fig.(11)**. The input VSWR is less than 1.9 and the output VSWR are less than 1.6. The input power is split into two equal output powers with phase difference equal to zero.

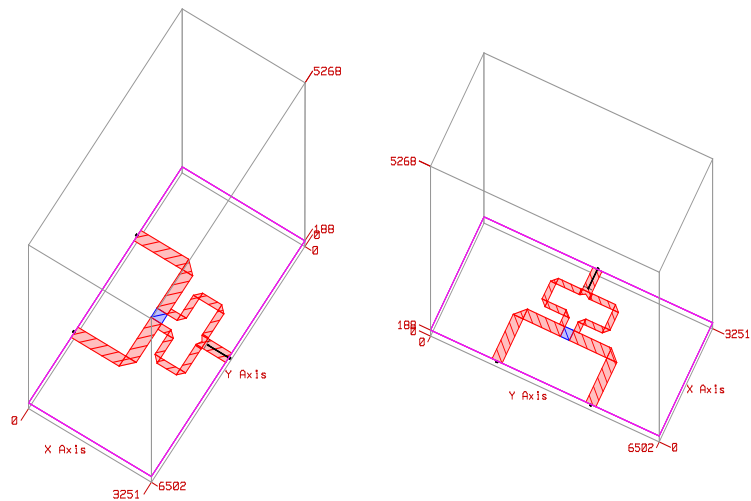


Figure (11) Layout design of Wilkinson power divider

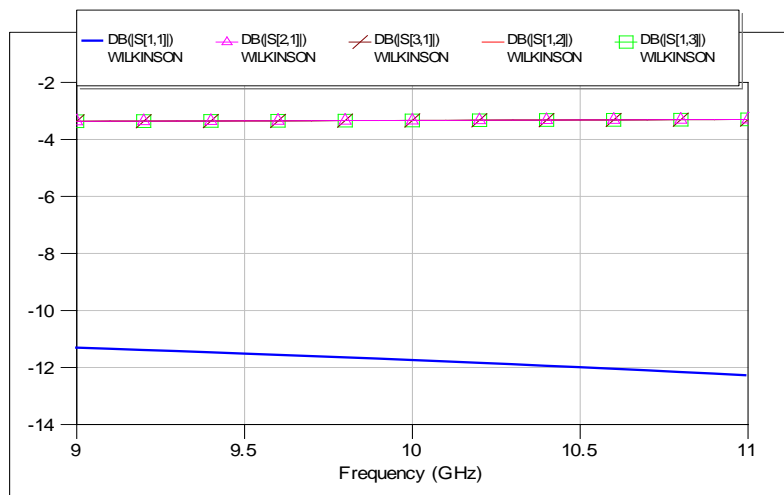


Figure (12) S-parameter of Wilkinson power divider

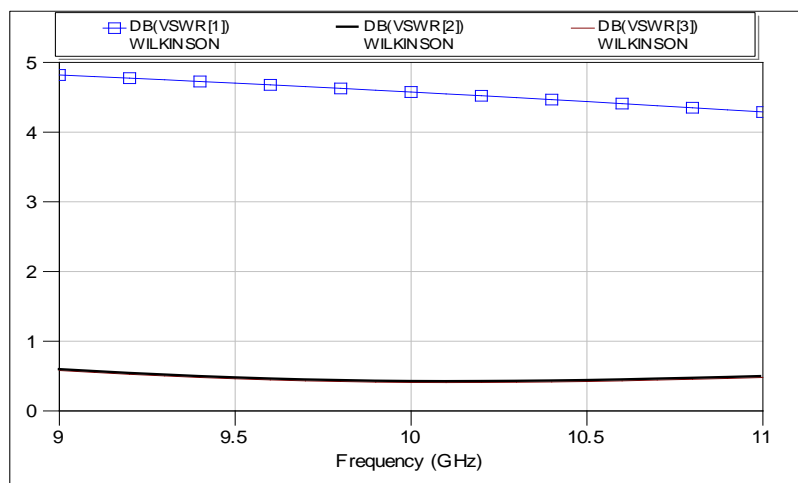


Figure (13) Voltage standing wave ratio of Wilkinson power divider

6. Design of Power Amplifier by using Lange Coupler as a Dividing/Combining Circuit

For cascading power amplifier it's customary to use 2-way Wilkinson divider, Lange couplers, or a combination of them [10]. After the complete design of (stable power amplifier), using combining techniques (Lange coupler) are used in order to get twice the power at constant gain minus the losses associated with the power divider/combiner network (approximately -0.3dB for a single network).

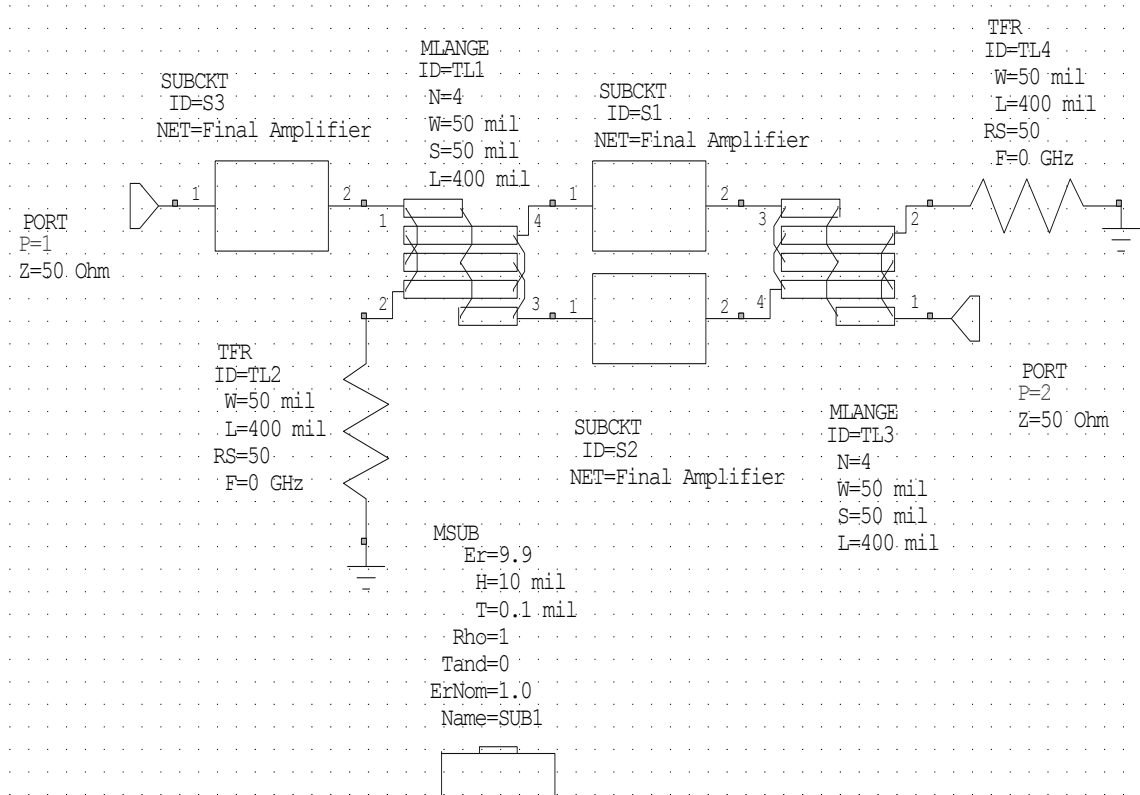


Figure (14) Schematic diagram of power amplifier using Lange coupler

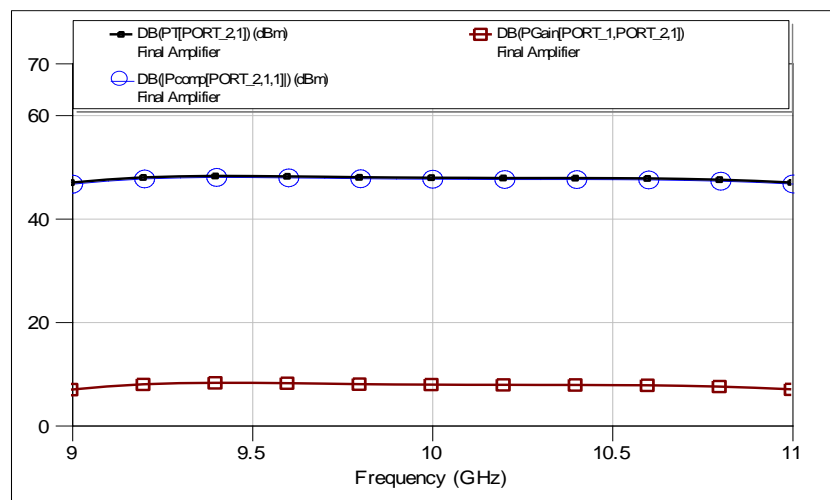


Figure (15) Output power of final power amplifier in dB

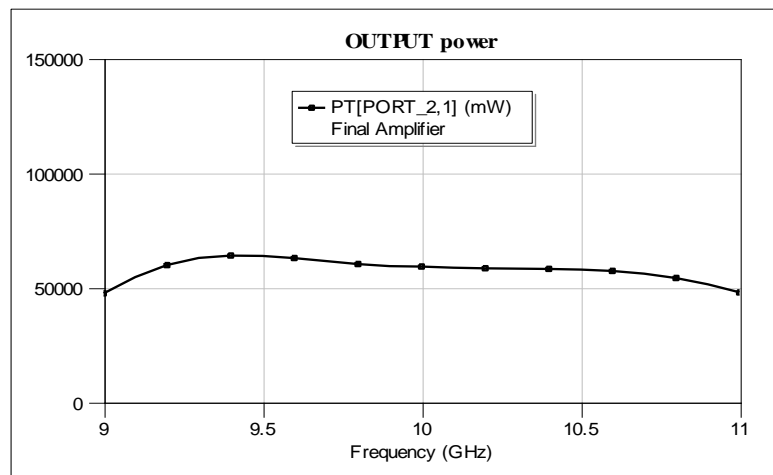


Figure (16) Total output power in mW

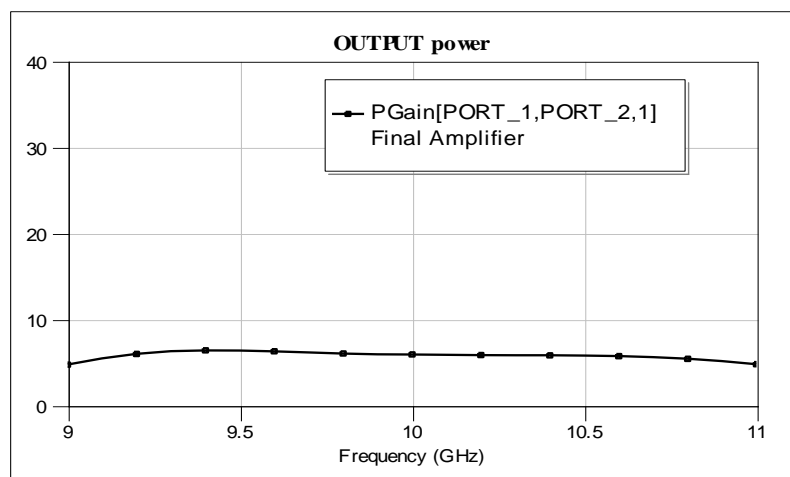


Figure (17) Power Gain of final power amplifier

7. Conclusions

Prior to stating the conclusions, it is worth while to outline relevant statements, regarding the approach adopted in the realizing the designed power amplifier. The translation from lumped element matching network to microstrip matching networks are used in microwave frequencies by use of suitable substrate material because it offers low loss, ease of construction and reproducibility verified by using CAD program microwave office 2000. The tuning and optimization of the theoretical design verify the validity of layouts of final power amplifiers, and then finalized using the microwave office 2000. The biasing network should be designed as such to ensure, the Q-point of transistor is held at a prescribed value, against variations in temperature and other transistor parameters. The power combining technique used to achieve the required output RF power. The multistage connection used in achieving the required RF power output, while the multistage connection is utilized in obtaining suitable gain. This is facilitated by the use of Lange coupler for combining networks. On the basis of the design approach, outlined above, a power amplifier operating in

(9-11GHz) frequency range is realized. An RF power output of 50W. The conclusions arrived at from this work are as follows:

Any error, however small, in the dimensions of the microstrip lines in the amplifier matching network will affect the amplifier performance resulting in erroneous results. The choice of substrate material is highly important, for good design and to obtaining suitable dimensions the use of Tee and cross-junction is very convenient for obtaining suitable layout with correct dimensions.

Obtaining flatness of gain and low VSWR proved difficult in the design of high power amplifiers in microwave frequency range and the losses in a single Lange coupler is approximately a large, so configuration will need a large number of Lange couplers, which will generate a high loss in the circuit that is equal to -0.4dBm.

In practice, the first step in the design of power amplifier must ensure the mounting of the transistor and printed-circuit board (PCB) to be such as to minimize parasitic inductances of the transistor and printed circuit board (BCP) ground path. The space between the printed circuit board and the transistor should be minimized.

8. References

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