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Impedance Matching Network Design for Class C Power Amplifier

Amenah I. Kanaan
M.Sc In Electronic And Communication Engineering
Assistant Lecturer
Electronics Engineering College
Electronic Department
Mosul University / Iraq
Amina.Edrees@Yahoo.Com

Abstract

Power amplifiers (PA) are typically the most power-consuming building blocks of RF transceivers. Therefore, the design of a high-efficiency radio frequency power amplifier is the most obvious solution to overcoming the battery lifetime limitation in the portable communication systems. In order to obtain the maximum output power, the reference impedance (usually 50 Ohm) must be transformed to the optimum input and output impedance of the selected transistor. Matching networks are therefore necessary at the input and at the output of a power amplifier circuit. In this research we designed a class C power amplifier operates in frequency range (200MHz -500MHz) with input power 0.63watt and output power 10watt. At high radio frequencies, the spurious elements (like wire inductances, interlayer capacitances, and conductor resistances) have a significant yet unpredictable impact on the matching network. In our design the matching network for input and output is implementing for frequency range (300MHz-350MHz) because of the wide band frequency range for transistor used. Two ways to implement the matching network: Theoretical calculations method (smith chart) and simulations using computer programs method are often presented.

Keywords: *amplifier design, High frequencies, microwave amplifiers, Class C power amplifier, smith chart, voltage standing wave reflection (VSWR).*

الخلاصة

مكبرات القدرة تمثل قوالب البناء النموذجية الأكثر استهلاكا للقدرة في المستقبل المرسل الراديوي. لذلك فان تصميم مكبر قدرة ذو كفاءة عالية يعمل ضمن الترددات العالية يمثل الحل الأكثر وضوحا للتغلب على تقييد عمل البطارية في أنظمة الاتصال النقالة، لذلك فان ممانعة المصدر (عادة ماتكون 50 اوم) يجب إن تحول إلى ممانعة الإدخال والإخراج المثالية للترانزستور المختار. لذلك فان شبكات الموائمة تكون ضرورية في دوائر الإدخال والإخراج لمكبر القدرة. في هذا البحث قمنا بقدرة إدخال (0.63واط) وقدرة اخراج (10واط) . (200MHz -500MHz) يعمل ضمن المدى C بتصميم مكبر قدرة في الترددات الراديوية العالية ، العناصر غير الحقيقية مثل محاثة السلك الكهربائية ومتسعات الطبقات الداخلية ومقاومة الموصل لها تأثيرات لايمكن التنبؤ بها لحد الآن على شبكات الموائمة. في هذا التصميم تم تنفيذ شبكات الموائمة للإدخال بسبب عرض حزمة الترددات للترانزستور المستخدم. (300MHz -350MHz) والإخراج لترددات تتراوح من قدمت في هذا البحث طريقتان لتنفيذ شبكات الموائمة: الطريقة التخطيطية(مخطط سمث) وطريقة المحاكاة باستخدام برامج الحاسوب.

الكلمات الدالة: تصميم مكبر، الترددات العالية، مكبرات المايكروويف، مكبر قدرة نوع C ، مخطط سمث، انعكاس موجة الفولتية الواقفة.

1. Introduction

Solid-state microwave amplifiers play an important role in communication. Usually, signals provided by the transducers are weak; typically, it is in the order of microvolt (µV) or millivolt (mV). It is not easy, and sometimes not possible, to have reliable processing for signals with low levels. For this reason, the need for a signal amplifier arises. In a transceiver circuit, a signal amplifier has different applications, including low noise, high gain, and high power amplifiers [1].

The intent of the research reported in this thesis is three-fold: to survey an amplifier classifications and definitions, to give an overview of some basic principles used in the analysis and design of the microwave transistor amplifier, and to design high efficiency power amplifiers for possible use in portable cellular telephone units.

Most RF power amplifiers fit into one of six common classes: A,B,C,D,E, or F. The distinctions between these classes lie primarily in the biasing conditions of the transistor and the design of the output network that couples the drain to the load. Each class has its own strengths and weaknesses, and choosing a class amounts to compromising between various power amplifier figures of merit, which include gain, linearity, and efficiency. For example, Class A and B power amplifiers offer high gain and a wide linear range, but are inefficient. On the other hand, class E and F power amplifiers can achieve high efficiency but do not provide linear amplification.

The applications of our proposed device include many products in the field of microwave

communications. One of the important applications of a Microwave power amplifier is in the output stage of a transmitter where a signal needs amplification before it is transmitted. A high power amplifier is needed for transmitting a signal through an antenna and a medium. The Microwave power amplifier amplifies the input signal after the signal has been modulated in the transmitter. The High power amplification step is necessary for every application of antenna transmission [2].

2. Class C Power Amplifier

The operating point of a class C power amplifier is located between zero and the pinch-off point in the transfer characteristic of an enhancement FET device. The conduction angle of a class C power amplifier is between 0 and π. The output waveform of a class C power amplifier using FET devices is shown in Fig. 1. Clearly, the drain-source voltage can also swing over its maximum range of zero to 2Udd [3, 4].

On the other hand, the entire negative part and a fraction of the positive part of the drain current are cut off; the current waveform is reduced to a train of short pulses, which have lower DC component compared to the other classes of power amplifiers mentioned above, but also a lower fundamental RF component. Consequently, very high efficiencies can be obtained, but at the expense of lower RF output power and heavy input drive requirements. The maximum drain efficiency of a class C power amplifier can even reach 100 % [4], if the operating points close to the zero point are selected.

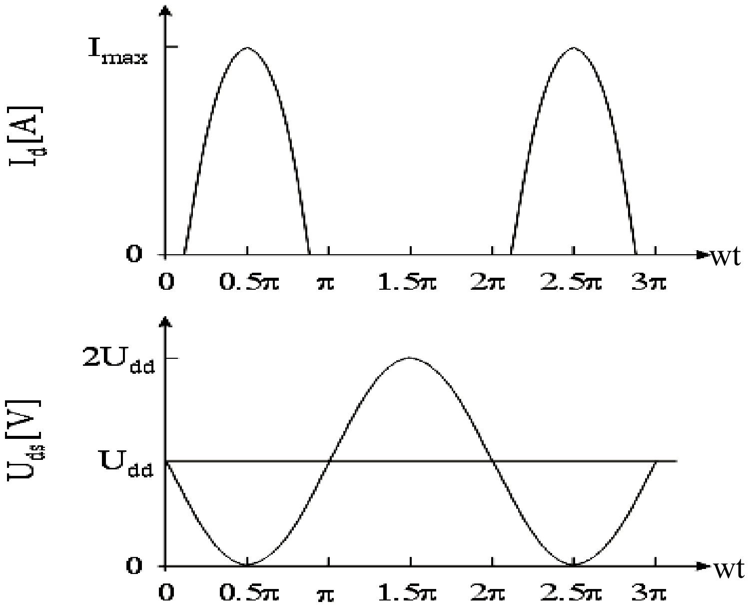


Fig .1. Waveforms of a class C power

For this design a class C power amplifier was chosen for various reasons. The class C amplifier is biased below its turn-on voltage and the input drives the device on for a small portion, which is less than half of the input cycle. This results into a pulsed current in the device. This current is filtered to extract the fundamental frequency component, which is then passed to the resistive load. The output waveform is thus at the fundamental frequency. It was noted that power consumption is a high concern for RF applications. Choosing a class D, E, or F design would then result in higher efficiency. This, in turn will lower power consumption. Despite the obvious benefit an agreement was reached to move forward with a class C design and perform optimization to maximize the achievable efficiency.

We were encouraging of our decision because of the several reasons why class C can be considered an optimal choice for design. Compared to the A-B classes, there is significantly increased efficiency for a relative light degradation of linearity. As well, the class C is preferred over the switch mode PA's for the following reasons:

1. The output amplitude of the class C varies with a varied input level, whereas the output amplitude of the switch mode PA's is fixed, relative to the input amplitude.
2. Once the input is large enough, the class C PA switches on and stays on, whereas the switch mode PA's need voltage regulators for effective switching. This adds more complexity to the block.
3. The class C PA is able to transmit different power levels at different times, whereas the power levels of switch mode PA's are fixed [5].

4. Matching Circuits and High Power Components

Matching circuits are an important part of the design of high-power RF amplifiers. A number of different types are discussed in the following sections along with components capable of withstanding the voltage and current stresses encountered.

4.1 Transmission Line Matching

Figures (2) through (4) show a number of matching methods classified as transmission line transformers.

1. Figure 2(a) is a quarter-wave transformer whose characteristic impedance (Z0) equals the square root of the product of Zin × ZL.
2. Figure 2(b) is a quarter-wave transmission line used as a balanced to unbalanced transformer or balun.
3. Figure 3(a) is a transmission line used as a balun but loaded with ferrite cores to reduce the length. The choking reactance should be at least 4 × Z0 in order to present a high impedance to common mode currents and thereby preserve the balanced to unbalanced properties.
4. Figure 3(b) is a ferrite loaded to unbalanced 4:1 transformer known as an unun. Z0 equals ZL/2 and the choking reactance should be at least 4 × Z0.
5. Figure 4(a) is a high-power transformer balun is used to provide the balanced to unbalanced function. Z0 of the two coaxial cables is ZL/2.
6. Figure 4(b) is not actually of the transmission line class but is included for discussion.

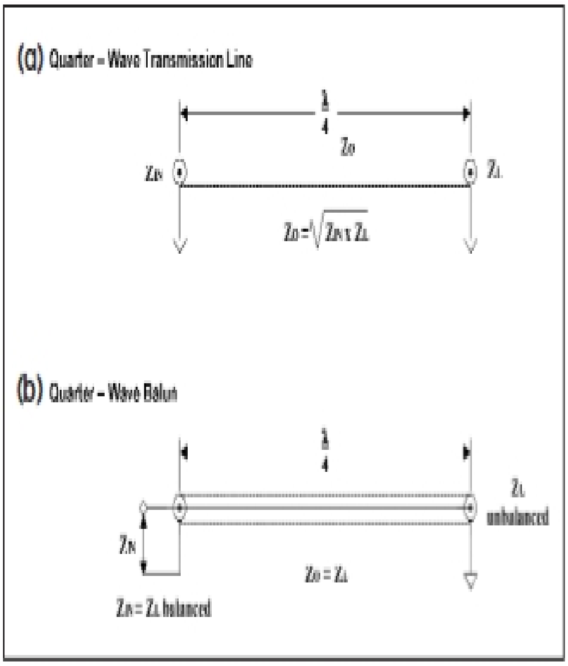


Fig. 2 · (A) A Quarter-Wave Transmission Line Transformer, And (B) A Quarter-Wave Line Used As A Balun[6].

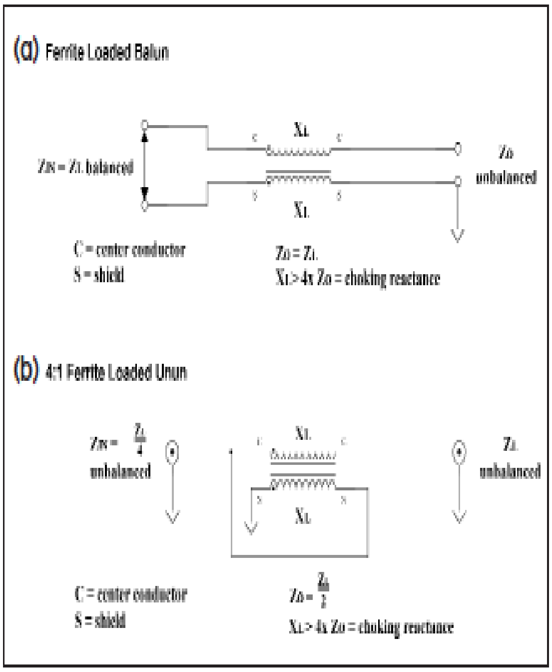


Fig. 3 · (A) Ferrite-Loaded Transmission Line Used As A Balun, And (B) A Ferrite-Loaded 4:1 Transmission Line Transformer [6].

A single turn primary uses brass tubes that are loaded with ferrite toroids. A secondary is

passed through the tubes and the impedance transformation varies as N2 where N is the number of turns. This is a popular selection because of its simplicity, but is limited in bandwidth and power. The bandwidth can be extended if the secondary is made to be an union as shown in Figure 3(b) using a semi-rigid coaxial cable. The outer conductor is insulated and placed inside of the brass tubes. The brass tubes and semi-rigid outer conductor then become a 1:1 transformer with close coupling and also provide the isolation requirements. This arrangement has been called a triaxial transformer and can extend the frequency response substantially.

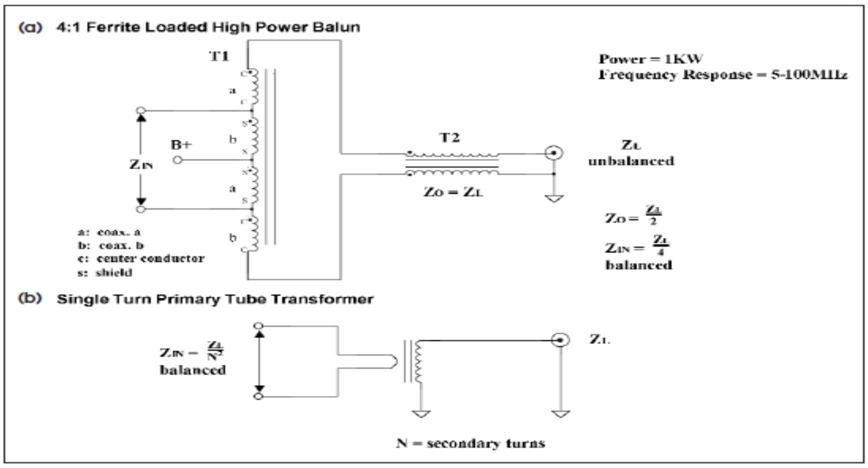


Fig. 4 · (A) An Improved High Power 4:1 Transformer With A Separate Balun, And (B) A Conventional Transformer With Tightly-Coupled Windings[6].

4.2 LC Matching Circuits

Figures (5) and (6) show various forms of LC matching circuits. The equations for calculating the matching components are included.

1. The circuits in Figure 5(a) and 5(b) transform RL to a higher input Rin using either a series L and a shunt C, or series C and shunt L.
2. The circuits in Figure 5(c) and 5(d) transform RL to a lower input Rin using either a shunt C and series L, or a shunt L and series C.
3. Figure 6(a) is a pi network that can match either a higher or lower input resistance. The pi can either be a high pass or low pass version. The low pass is a lum ped constant version of a quarter wave transmission line. The inductance and capacitance values are equal to the square root of the product of Rin × RL.
4. Figure 6(b) is the design of a high power pi match with a 10:1 ratio between RL and Rin.

The component values, current and voltages have been calculated and the performance using two coaxial cables wound on a common ferrite core that has a 4:1 impedance transformation. The cores are connected as shown. The power capability is 1 kW and its frequency response is (5-100) MHz A separate ohm, and a power dissipation of 50 watts.

The 220 pF chip capacitor has a breakdown rating of 3600 volts and a current rating of 10 amps. A FET with a breakdown voltage of 900 volts is used to switch the pin diode on and off. A 450 volt DC voltage is used to back bias the diode in the off position. Switching speed is on the order of 10µsec. An optoisolator connects the input to the switching circuit [6].

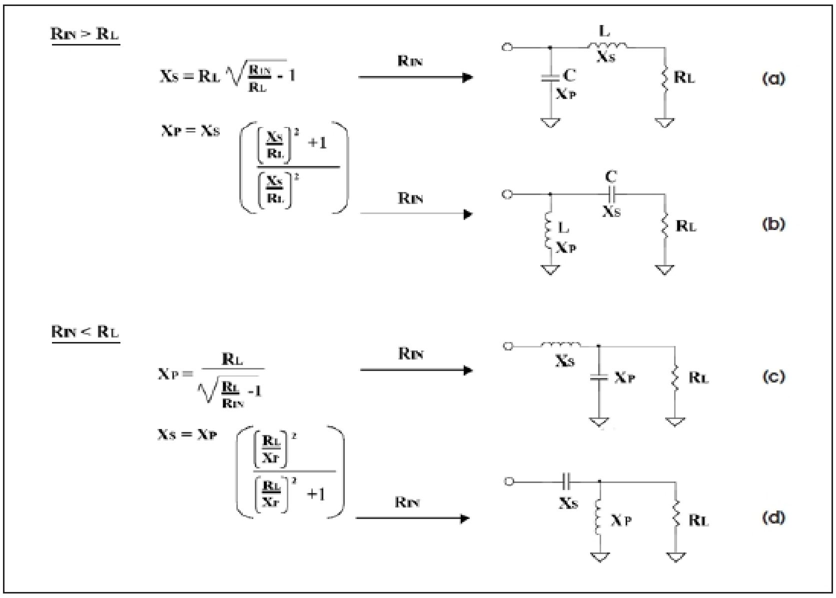


Fig.5· LC Matching Networks: (A) And (B) Provide Transformation To A Load Resistance Lower Than Rin, While (C) And (D) Provide Transformation To Higher Resistances[6].

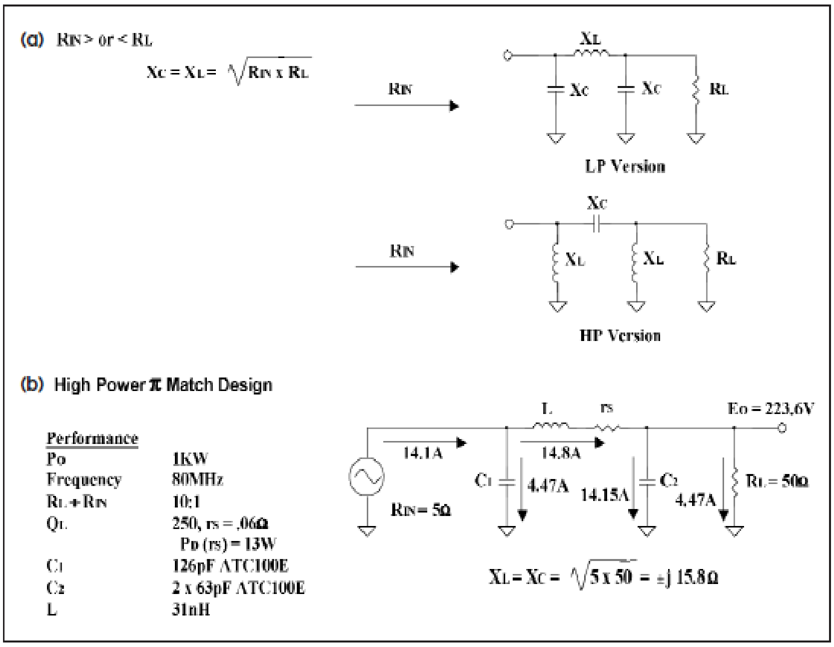


Fig.6. High power pi network matching circuits. (a) shows the highpass and low pass configurations; (b) is a high power pi network for a 10:1 Transformation and 90-degree phase shift[6].

5. Design Environment: Microwave Office 2000

It was obvious from the start that the propose amplifier would need to be designed in the software environment if we actually wanted to build it. There are several software packages in the industry that are used for the design and simulation of RF circuits. The one that we chose to use was Applied Wave Research's Microwave Office. The primary reason for this choice was that we could obtain our own trial copy which gave us much more flexibility in the design process.

Microwave Office is one of the top three industry standard RF design and simulation packages which also made it very attractive. Learning the use and capabilities of the software through the design process turned out to be very time consuming but the experience gained with the software will no doubt be invaluable in an RF career.

6. Obtaining nonlinear model of transistor

The first step in the whole design process was to choose a transistor. We chose the RF Line NPN silicon RF power transistor MRF321. The MRF321 is a packaged Aluminum Gallium Arsenide / Indium Gallium Arsenide (AlGaAs/InGaAs) pseudomorphic High Electron Mobility Transistor (pHEMT). This transistor was chosen because it met all of the requirements for our target specifications.

The most unexpected problems that we encountered when we started our design was that there are no perfect non-linear models for microwave transistors. We found the solution to this problem by consulting a professional in the design field. We were advised to optimize the non-linear device model for our design frequency by adjusting various parameter values in the non-linear model. It should be noticed that optimization would not necessarily be needed if the amplifier circuit were only to designed and tested in the software environment. Fig.7. shows some of the proposed model transistor show it successful in particular field.

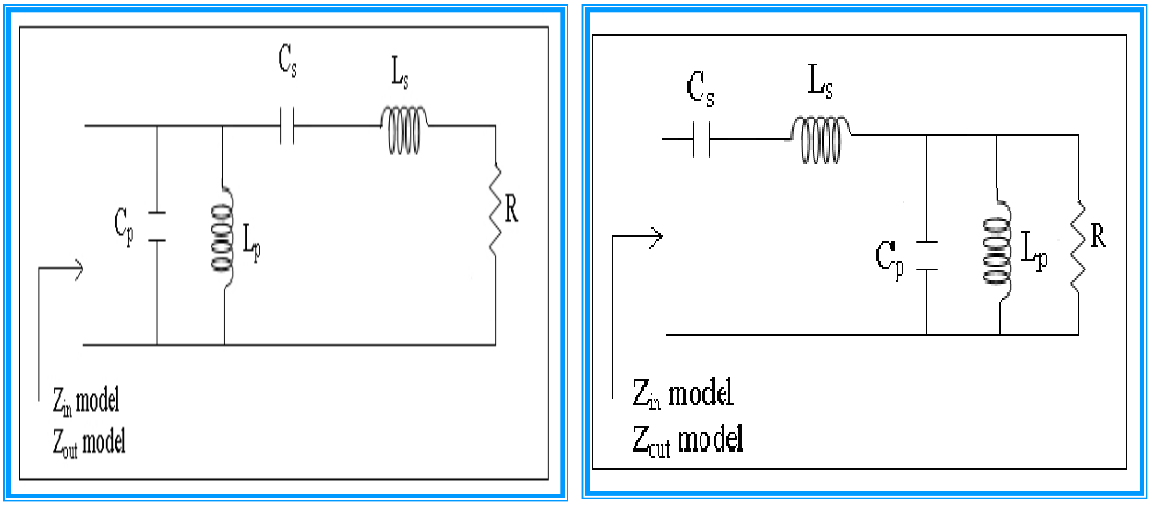


Figure.7. Input And Output Impedance Model For Transistor

Theoretical smith chart is used to design matching network for class C power amplifier by using Chebyshev low-pass ladder circuit with number of sections depends upon the bandwidth and required impedance transfer ratio, each section have quality factor Q increase by increasing transfer ratio given in expression[7]:-

$$Q = f0 / fH - fL \quad = fL + fH/2(fH-fL) \qquad ...(1)$$

Where:
fo: middle frequency of frequency band.
fH: high frequency of frequency band.
fL: low frequency of frequency band.

The input and output impedance of transistor as given in the data sheet for band from 200MHz-400MHz given in the table (1), which is used as initial point, than from this point one can move on the smith chart circuit and Table (2) gives input and output impedance values calculated for MRF321 through frequency band (300MHz- 350MHz).

Table (1): Input And Output Impedance Of MRF Band321 (200-500) Mhz Transistor

Frequency (MHz)	Zin	Z*Lo
200	0.68- j 0.75	14.2 – j 22
400	0.89+ j 2.7	9.8 – j 14.4
500	1.3 + j 4.3	9.3 – j 13

Table (2): Input And Output Impedance For MRF 321 Through Frequency Band (300mhz-350mhz) Without Matching.

Frequency(MHz)	Zin	Z*Lo
300	0.812 + 1.03	11.267 – j17.486
325	0.774 + j 1.419	10.843 – j 16.786
350	0.875 +j 1.816	10.271 – j 15.943

We draw the Q circuit with radius equal to $\sqrt{1+1/Q2}$ and center at point ±1/Q on the Imaginary axis. Figures (8) and (9) show the theoretical input matching circuit for bandwidth (300MHz-350MHz).

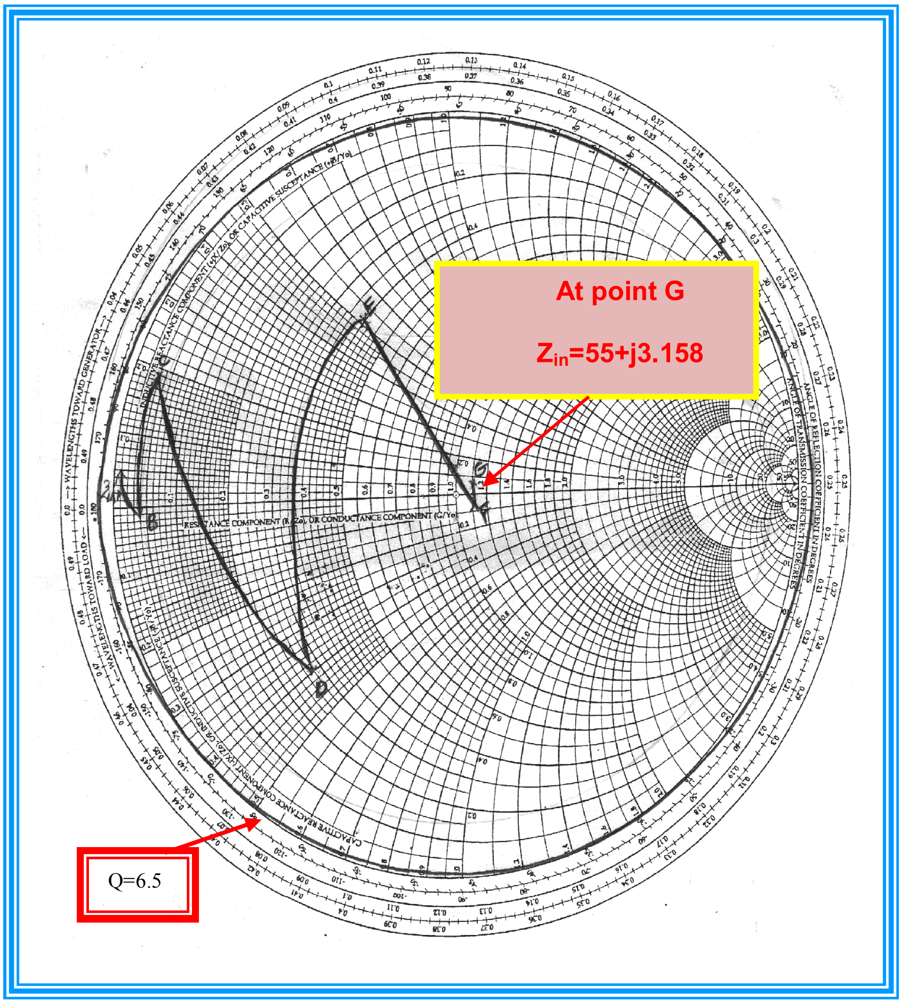


Fig.8. Input Matching Network Design Using Smith Chart

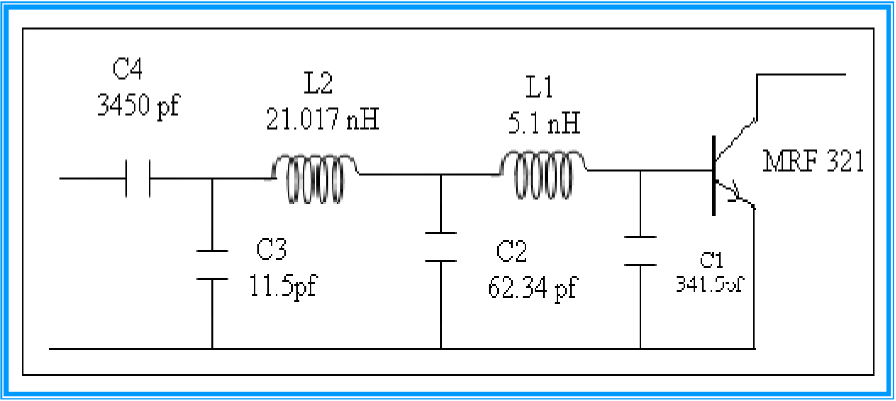


Fig.9. Input Matching Circuit Result From Using Smith Chart

We note from figure (8) that at point G the value of Zin equal to 55+j3.158 at 325 MHz. figure (10) show output impedance design using smith chart method and fig.11. state the output matching circuit result.

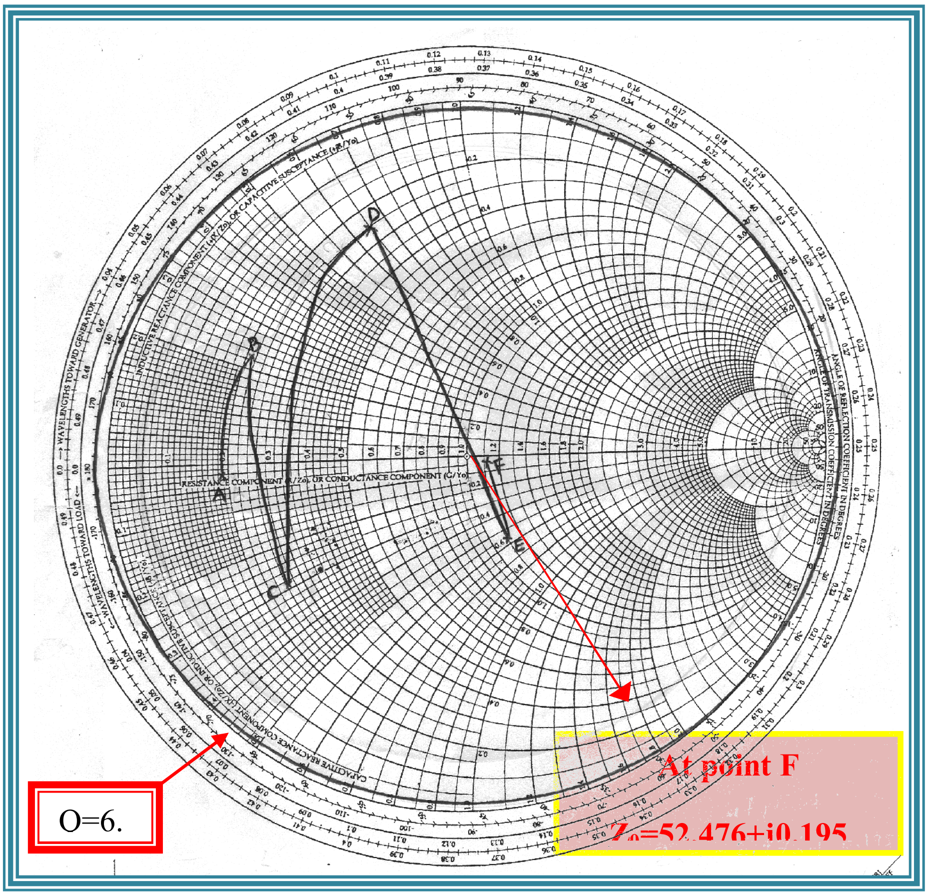


Fig.10. Output Impedance Network Design Using Smith Chart.

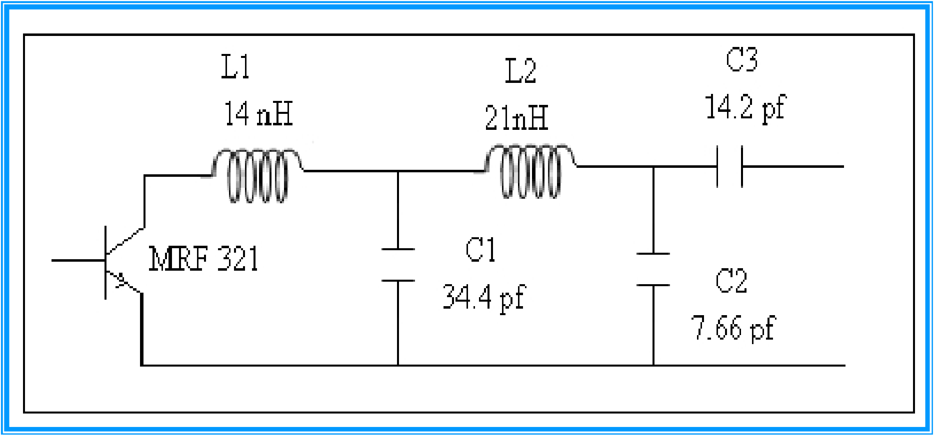


Fig.11. Output Impedance Circuit Result From Using Smith Chart

From figure (10) we note that Zo equal to 52.476+j0.195 at point f at frequency equal to 325MHz. after that we used microwave office 2000 to build the impedance matching network for the transistor.

We use the propose model shows in fig.7. to represent the transistor in the program, give initial value for component then make optimizations to get a suitable value that cover the values of the input and output impedance for transistor as shown in fig.12. The optimization procedure of the non-linear model involved changing arbitrary values one at a time using these model we get the nonlinear model to represent transistor in the microwave office 2000 and we get the exact value of input and output impedance for transistor as shown in figures (13) and(14).

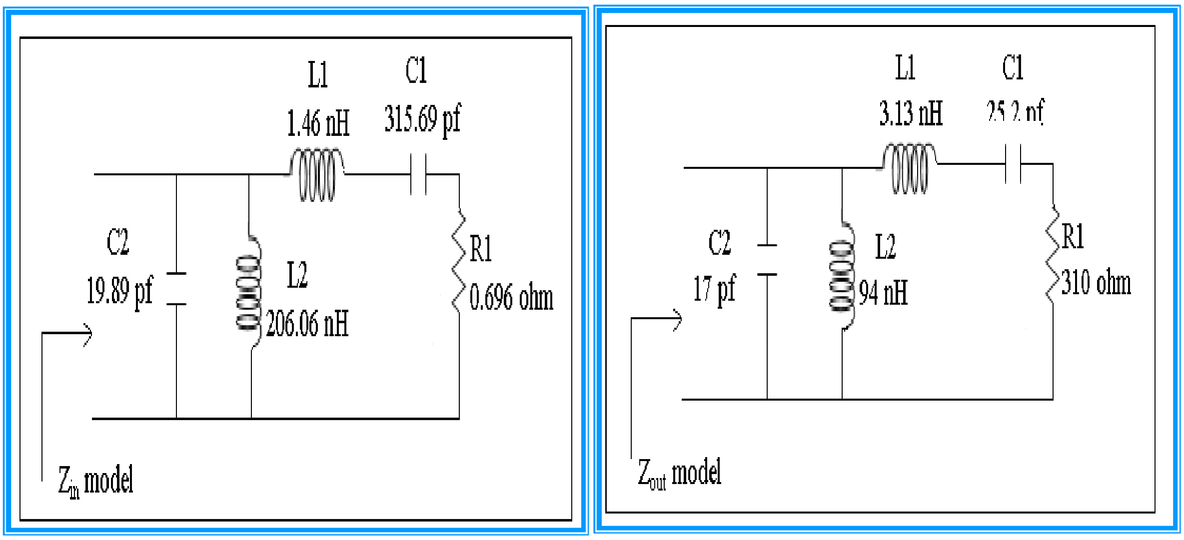
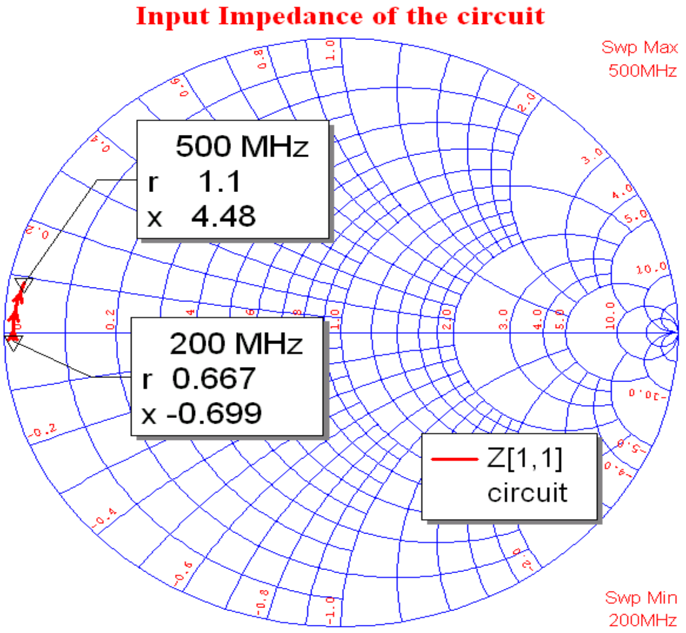
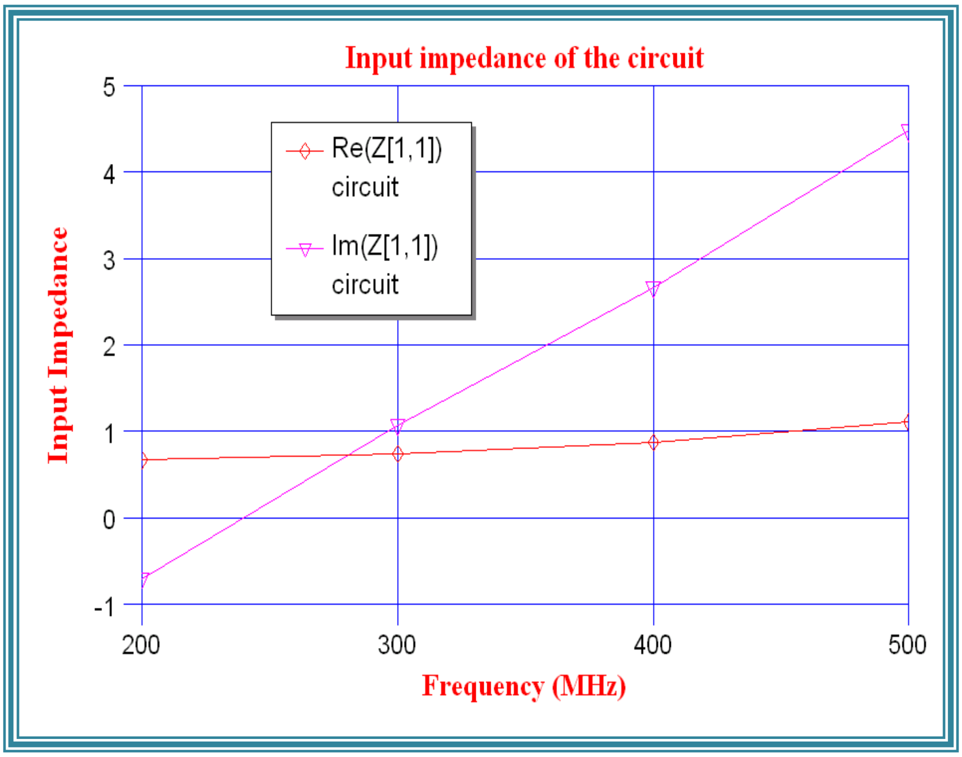


Fig .12. Input And Output Impedance Model Propose For MRF321 Transistor

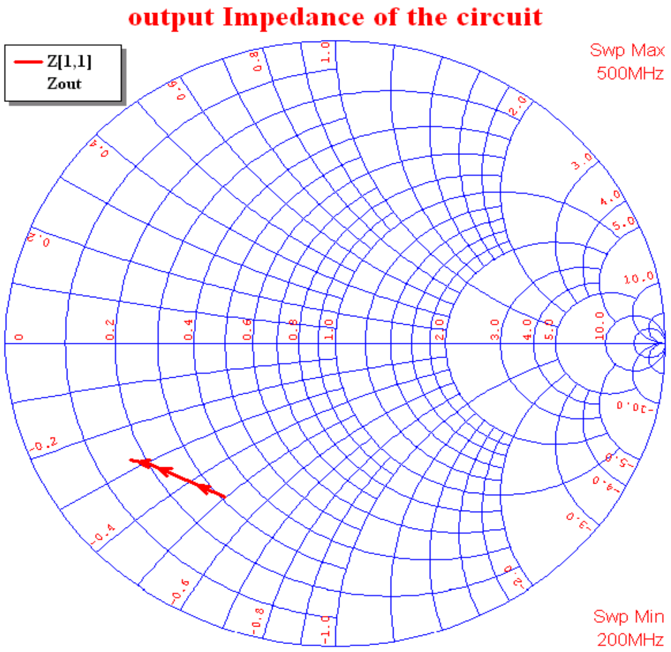


(a)

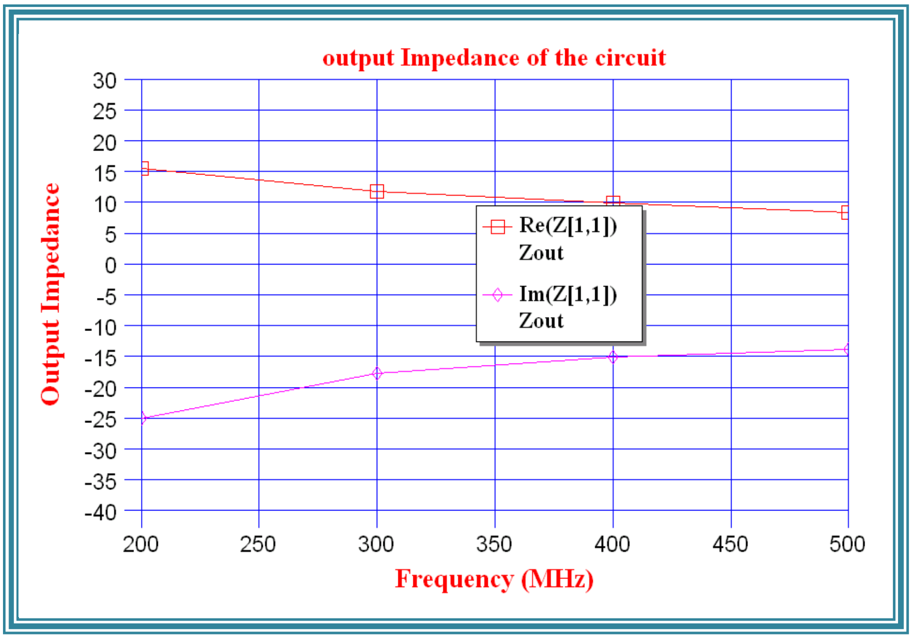


(b)

Fig.13. Input Impedance For Transistor For Frequency Band(200mhz-500mhz) Using A) Smith Chart. B) Rectangular Form.



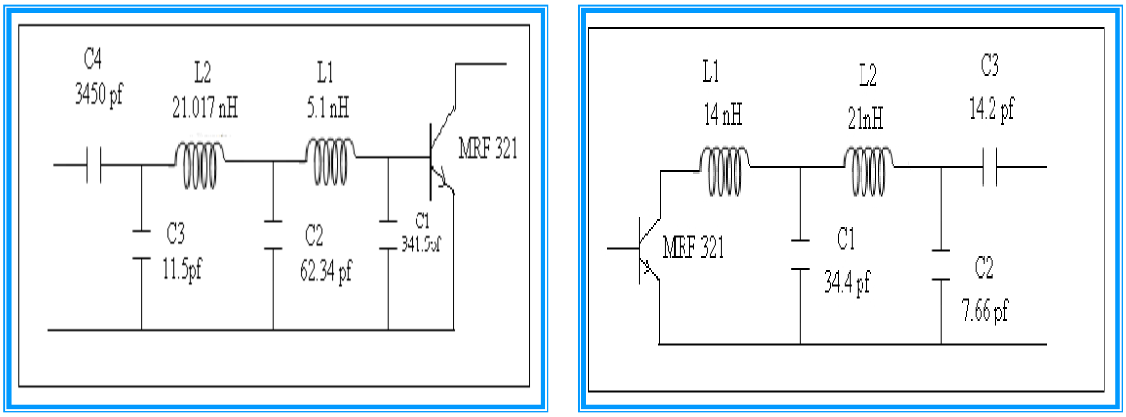
(a)



(b)

Fig.14. Output Impedance For Transistor For Frequency Band (200mhz-500mhz) Using A) Smith Chart. B) Rectangular Form.

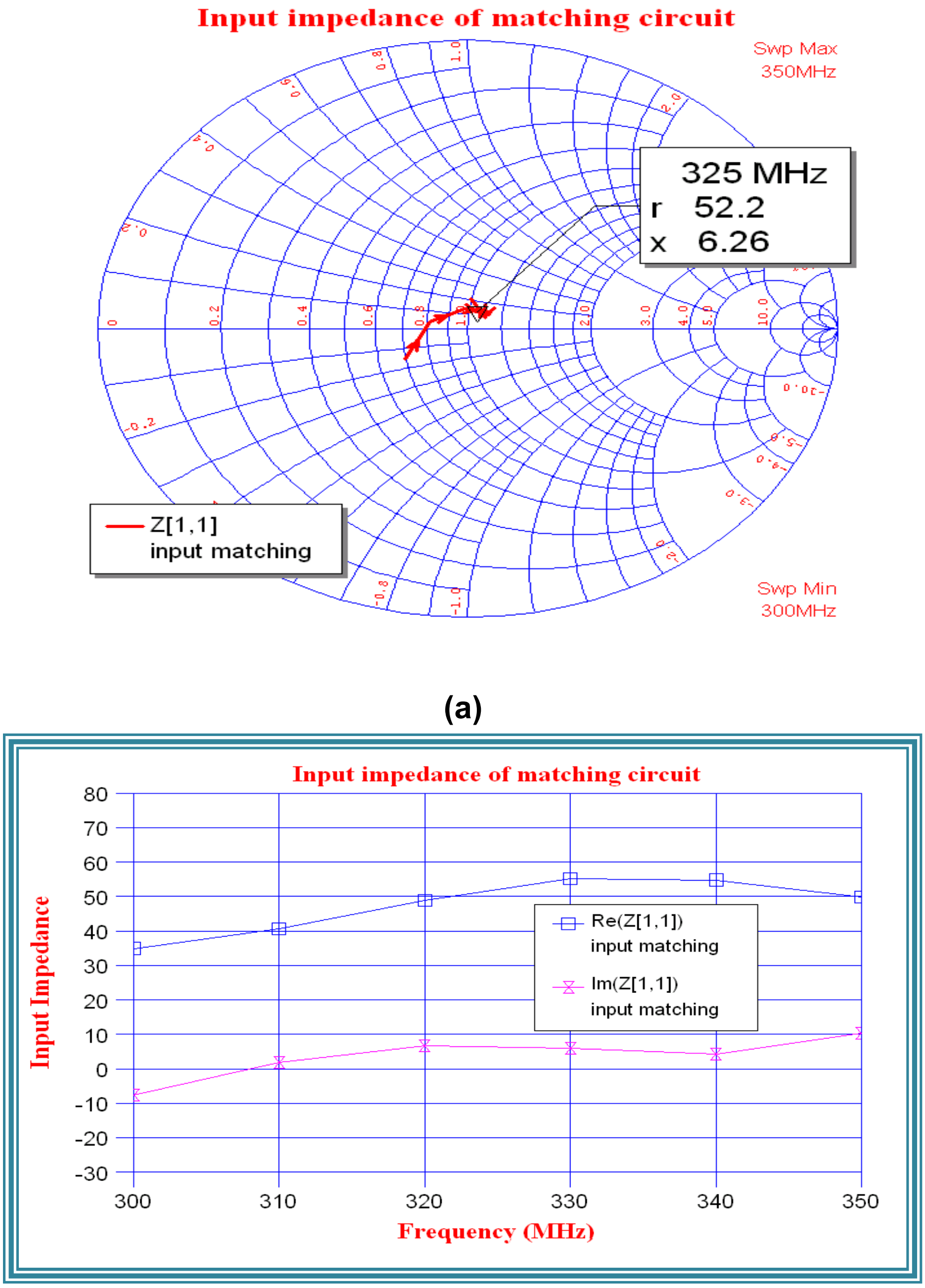
Then we insert the impedance network for input and output equivalent circuit of the transistor, make optimization to get the best value for matching network component as shown in figure (15).



a) Input matching **b) Output matching circuit**

Fig .15. Matching network circuit for MRF321 transistor for frequency band 300MHz-350MHz after optimization

Figure (16) show the total input impedance for MRF321 transistor after adding designed matching circuit and we note that it closed to 50Ω that's mean we satisfy matching condition.



(a)

(b)

Fig.16. Total Input Impedance Of MRF321 For Frequency Band (300mhz-350mhz) A) Smith Chart B) Rectangure Form.

We note from Fig.17. That the VSWR that belong to the input circuit have constant value close or equal to 1 along the desired frequency band, that means there is no reflection on the input circuit. Figure (18) show the total output impedance for MRF321 transistor after adding designed matching circuit and we note that it closed to 50Ω that's mean we satisfy matching condition for output.

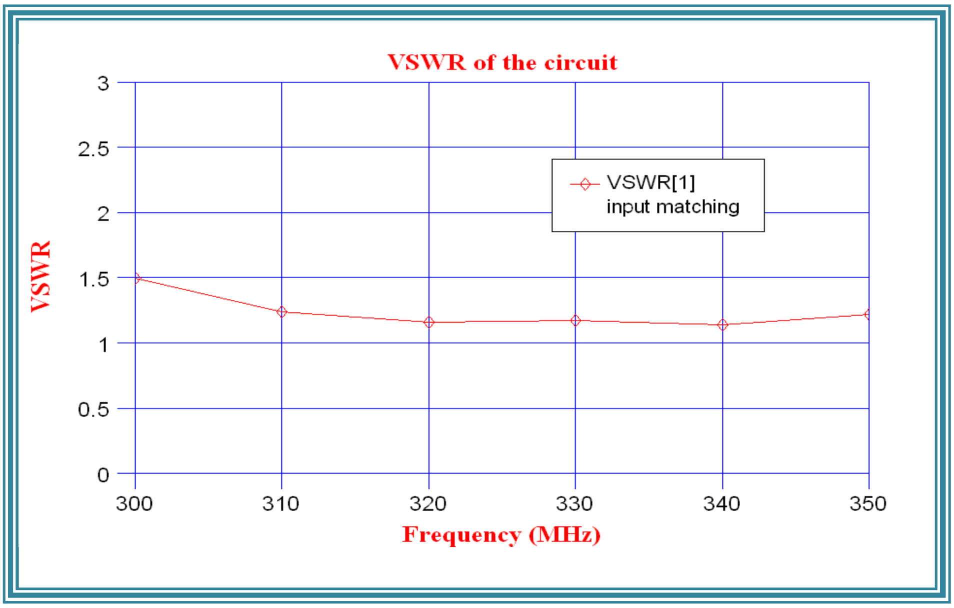
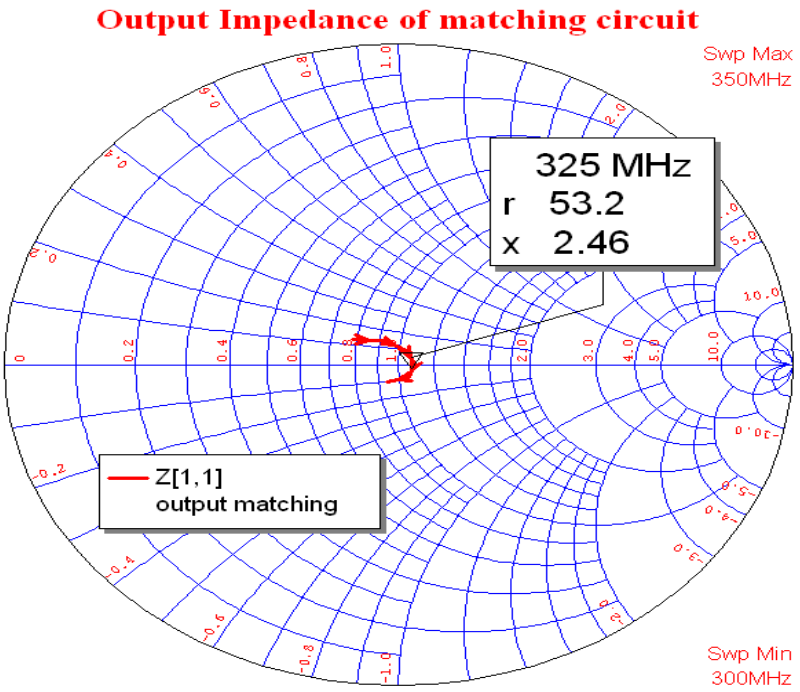
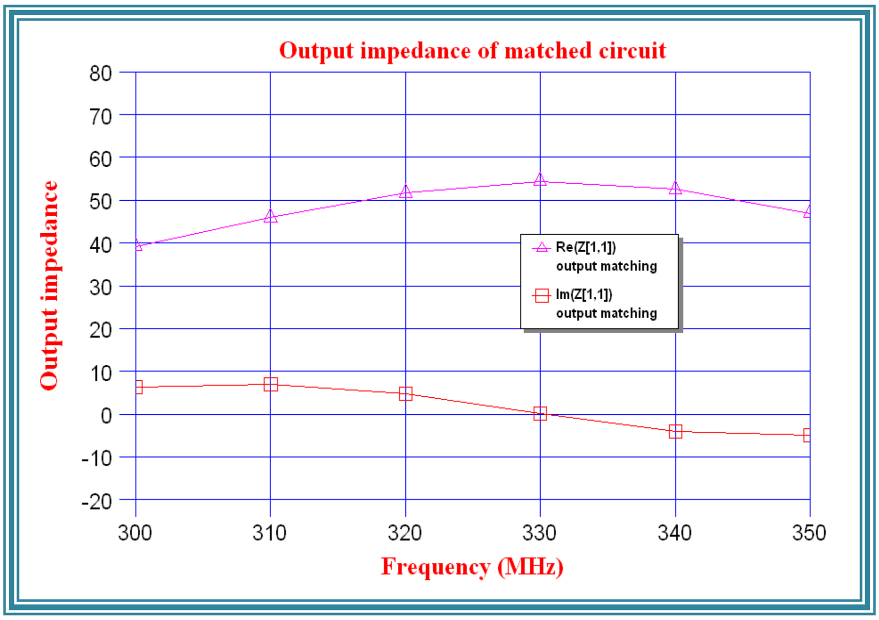


Fig.17. Total VSWR Of MRF321input Circuit For Frequency Band (300mhz-350mhz).



(a)



(b)

Fig.18. Total Output Impedance Of MRF321 For Frequency Band (300mhz-350mhz) A) Smith Chart B) Rectangure Form.

We note from Fig.19. That the VSWR that belong to the input circuit have constant value close or equal to 1 along the desired frequency band, that means there is no reflection on the output circuit and we have maximum power transfer to the output.

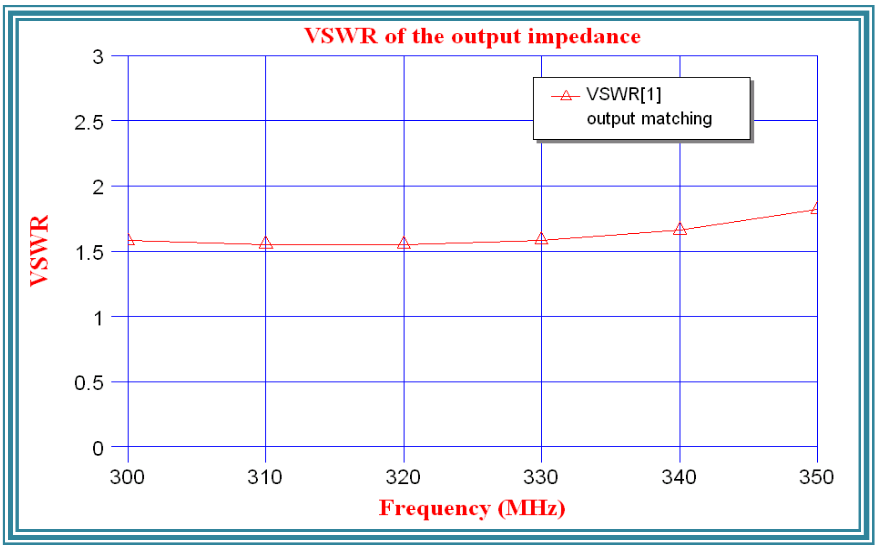


Fig.19. Total VSWR of MRF321output circuit for frequency band (300MHz-350MHz)

7. Conclusion

Many designers believe that the analysis of the nonlinear characteristics of class C amplifiers is not practical with popular simulators such as microwave office2000. However, with the proper modeling of the RF transistors and proper accounting of parasitic, virtually every aspect of the class C amplifier can be studied.

This paper explores some unique techniques and models for simulating amplifiers running in class C operation using the general purpose microwave office2000 circuit simulation program. Results of the simulation of an 300MHz-350MHz amplifier including impedance and impedance matching circuit and waveform are given.

8. References

1. S. Saad, "DESIGN OF CLASS-E RADIO FREQUENCY POWER AMPLIFIER" Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University, July 2001 Blacksburg, Virginia.
2. Steve; C. Jaime "Microwave Amplifier Design (part 1)", Inderpreet Obhi December 15, 2003.
3. B. Manfred, "Design of Radio Frequency Power Amplifiers for Cellular Phones and Base Stations in Modern Mobile Communication Systems", Institut für Elektrische und Optische Nachrichtentechnik 2009.
4. S. Cripps, "RF power amplifier for wireless communications," 1999 Artech House, Inc.
5. S. FATHI "POWER AMPLIFIER DESIGN", GROUP PROJECT, PRESENTED FOR THE COURSE ECE802-607 FS05.
6. W. Richard, "Matching Networks for Power Amplifiers Operating into High VSWR Loads", May 2004 High Frequency Electronics Copyright © 2004 Summit Technical Media, LLC.
7. A.N. Riddle and R.J. Trew,'' Abroad- band amplifier output network design'', IEEE trans. On microwave theory and tech, vol.1, MTT.30, No.2, February, 1982.