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Design and Simulation of Microwave Oscillator

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Abstract

This paper is concerned with the design and simulation of fixed frequency microwave oscillator. Scattering parameters of the active device (MESFET-Afm02n8b) are used to design and synthesize the oscillator. The computer aided design package (Microwave Office 2000 version 3.22) is employed to optimize oscillator subcircuits performance such as resonator, feedback, and output matching network. Two techniques are employed for the analysis purposes. The first method involves the open-loop gain and phase response versus frequency, the second method considers the oscillator as one-port with negative resistance. Fixed frequency oscillator at 7GHz is realized and tested.

Keywords: Microwave oscillator, Negative resistance, Open Loop Gain, Fixed Frequency, and Resonator.

تصميم ومحاكاة مذبذب الموجه المايكروية

الخلاصة

يتناول موضوع هذا البحث تصميم ومحاكات مذبذب الموجة المايكروية بالتردد الثابت. معاملات الاستطارة للترانسستور (MESFET-Afm02n8b) استخدمت لتصميم وتوليف المذبذب. تم اجراء حسابات الاداء والمحاكاة باستخدام الحقيبة البرمجية (Microwave office 2000) الاصدار 3.22لكي يضمن قدر ممكن لاداء الاجزاء التي يتكون منها المذبذب كدائرة الرنين (resonator) ودائرة التغذية العكسية (feedback) ودائرة الموائمة الخارجية (output matching network). تم استخدام طريقتين لغرض تحليل دائرة المذبذب الطريقة الاولى هي كسب الحلقة المفقودة (open loop gain) والطريقة الثانية هي المنفذ الاحادي بالمقاومة السالبة (negative Resistance). تم تحليل واختبار مذبذب الامواج للتردد الثابت عند التردد 7GHz.

Notations:

Symbol	Meaning	Units	Symbol	Meaning	Units
BJT	Bipolar Junction Transistor	-	Q	Quality Factor	-
C	Capacitor	PF	R	Resistance	Ω
C_{in}	Center of input stability circle	mm	r_{in}	Radius of input stability circle	mm
C_{out}	Center of output stability circle	mm	r_{out}	Radius of output stability circle	mm
DC	Direct Current	-	$S_{(11,12,21,22)}$	Scattering Parameters	-
f	Frequency	GHZ	V_{CC}	DC Voltage Bias	volt
FET	Field Effect Transistor	-	V_{DS}	Drain-Source voltage	volt
GaAs	Gallium Arsenide	-	V_{GSQ}	Gate –Source voltage at Q-point	volt
GHz	Giga Hertz	10^9Hz	V_{SQ}	Source voltage at Q-point	volt
I_D or I_{DS}	Drain to Source Current	Ampere	Z_L	Load Impedance	Ω
I_{DSS}	Drain-Source Saturation Current	Ampere	Z_S	Source Impedance	Ω
I_{DQ}	Drain Current at Q-point	Ampere	Z_{out}	Output Impedance	Ω
I_E	Emitter Current	Ampere	$\o_S$	Angle associated with Γ_S	Degree
j	Imaginary value	-	$\o_{in}$	Angle associated with Γ_{in}	Degree
K	Stability Factor	-	Γ	Reflection Coefficient	-
L	Inductor	Henry	Γ_{in}	Input Reflection Coefficient	-
MES	Metal Semiconductor	-	Γ_L,, Γ_S	Load, Source Reflection Coefficient	-

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1-Introduction

Microwave oscillator represents the basic microwave energy source for all microwave systems, such as radar communications, navigation, and electronic warfare. They can be termed as *DC*-to-*RF* converters or infinite -gain amplifiers [1]. Microwave oscillator topology shown in figure (1), consists of;

a- Microwave transistors are the active devices used as oscillators, GaAs FET generally has better noise figures and can operate at much higher frequencies (in excess of 100 GHz) [2]. At the present time GaAs metal semiconductor FET (GaAs MESFET) is the most popular GaAs FET for microwave applications above 3 GHz. It's the important active device for use in microwave analog and high-speed digital integrated circuits [3].A suitable device was selected which is (*Alpha, Afm02n8b*).

b- A good *DC* biasing is used to select the proper quiescent point and hold the quiescent point constant over variations in transistor parameters and temperature. An active bias circuit is shown in figure (2), in this circuit a pnp BJT is used to stabilize the operating point of the microwave transistor. R_2 and R_3 control the quiescent point. R_2 is adjusted for proper V_{DS} and R_3 is adjusted for proper I_D. The design procedure of biasing network obvious in [4, 5]. The pnp transistor (*2N2907*) is used as a general purpose and the operating *Q*-point required is V_{SQ} equal to 2v and I_{dQ} equal to 40mA.

c- There are two types of feedback; negative feedback and positive feedback. For positive feedback the gain will increase, which is useful for peaking the gain at the upper band edge or for making high-frequency oscillators [5]. Also a positive feedback is used to obtain an input reflection coefficient module greater than unity in input port of the device. For the greater the unity for $|S_{11}|$, which gives guarantee that the oscillations will be initiated and the active device's oscillatory process will be maintained [6]. The general common used in microwave oscillator is common gate, and to increase instability an inductor can be added as a positive feedback to gate port (for FET) as shown in figure (3). The two-port representation of feedback transistor circuit may be analyzed using *S*-parameters [7].

d- A resonator is connected to the tuning port to give a desired resonator reflection coefficient Γs. The most common resonators are; Lumped element, Distributed element (microstrip or coaxial line), Cavity, Dielectric resonator, YIG, and Varactor. All of these structures can be made to have low losses and high quality factor *Q* [5].

e- A matching network circuit is not only designed to meet the requirement of minimum power loss but it is also based on additional constraints, such as minimizing the noise influence, maximizing power handling capabilities, and linear frequency response. The simplest possible type of matching network in this paper is two-component network (*L*-sections) due to their element arrangement. These networks use two reactive components to transform the load impedance Z_{load} to the desired impedance Z_L. Two methods can be used to design matching network (i) analytically (ii) using smith chart as graphical design tool [8]. Many design techniques for broad band tunable MESFET and Bipolar transistor oscillators have been presented for 5.9-12.4 GHZ and 2-8.4GHZ applications [5]. A computer aided design software has been created to design a fixed and stable microwave frequency oscillator [6]. A 19 GHz SiGe-based oscillator are presented using *S*-parameters and *DC I-V* curves. One and two-port oscillators conditions are explained [9]. A microwave oscillator design for 4.12-7 GHz application has been presented using one-port with negative real impedance technique [7]. A microwave oscillator design with second harmonic suppression has been provided at 2.11GHz [14].

In this paper, A fixed frequency

microwave oscillator, which operates at 7GHz, has been presented as a candidate for use in a various applications. The presented oscillator was assumed to employ [*Alpha (Amf02n8b)*] as a microwave active device with lumped elements as an oscillator.

2- Theory

The input stability circle is a contour in the source plane that indicates source termination values that will make the output reflection coefficient have a unity magnitude. An output reflection coefficient less than unity will indicate a stable device, while an output reflection coefficient greater than unity indicates a potentially unstable device. The display of the stability circle indicates the unstable region using a circle drawn with a dashed line in the unstable region. If the dashed circle is inside the solid circle, then the outside of the circle indicates the stable region, while if the dashed circle is outside the solid circle, then the inside of the circle represents the stable region . A solution of an input stability circle on a complex plane, whose radius (r_{in}) and center (c_{in}) are given by [11]

$$r_{in} = \frac{|S_{12} . S_{21}|}{\left| |S_{11}|^2 . |\Delta|^2 \right|} \qquad (1)$$

$$c_{in} = \frac{\left(S_{11} - S_{22}{}^* . \Delta\right)^*}{|S_{11}|^2 - |\Delta|^2} \qquad (2)$$

where

$$\Delta = S_{11}.S_{22} - S_{12}.S_{21}$$

The output stability circle is a contour in the load plane that indicates load termination values that will make the input reflection coefficient have a unity magnitude. An input reflection coefficient less than unity will indicate a stable device, while an output reflection coefficient greater than unity indicates a potentially unstable device [11].

$$r_{out} = \frac{|S_{12} . S_{21}|}{\left| |S_{21}|^2 - |\Delta|^2 \right|} \qquad (3)$$

$$c_{out} = \frac{\left(S_{22} - S_{11}{}^* . \Delta\right)^*}{|S_{22}|^2 - |\Delta|^2} \qquad (4)$$

For two-port oscillator circuits, as shown in figure (1) there are two important conditions for oscillation;

1. Startup condition: For oscillation to begin, the criterion for oscillator startup at resonance is written as

$$|\Gamma_{in}| . |\Gamma_s| > 1 \quad \text{and} \quad f_s + f_{in} = 0 \qquad (5)$$

Where $f_s + f_{in}$ are the angles associated with Γ_s and Γ_{in}.

2. The steady-state condition: In the long run, oscillation growing and reaches steady state. The criterion becomes [12].

$$|\Gamma_{in}| . |\Gamma_s| = 1 \quad \text{and} \quad f_s + f_{in} = 0 \qquad (6)$$

Finally the conditions for oscillation can be summarized as [13]

$$K = \frac{[1 + |S_{11}S_{22} - S_{12}S_{21}|^2 - |S_{11}|^2 - |S_{22}|^2]}{2|S_{12}||S_{21}|} < 1 \qquad (7)$$

$$\Gamma_{in} . \Gamma_s = 1 \qquad (8)$$

$$\Gamma_{out} . \Gamma_L = 1 \qquad (9)$$

3- Microwave Oscillator Design and Simulation

The design procedure is concentrated on the following constrains:

- The device is selected to be [*Alpha (Afm02n8b)*]
- The desired frequency of oscillator (7 GHz).

Therefore many parameters have to be measured and specified such as, the *S*-parameters, stability factor, input and output Stability Circles. Microwave office is used to simulate and analyze most of these factors.

3-1 Design Technique

The design of the microwave oscillator starts with an initial analytical technique ,and can be carried out step by step as follows:

a- Select a suitable device GaAs FET that meets the design objectives that is shown in table (1).

b- From device data sheet shown in table (1), determine the optimum bias point for the required output power (that is obvious in section 3-2). The quiescent point should lie in the safe operating area of the *DC* drain characteristics to a void exceeding the maximum power dissipation capability of the device.

c- Obtain the S-parameters at desired frequency to check the stability factor *K* of the device (common-source). If the S-parameters at the desired frequency do not ensure this requirement, common-gate configuration must be switched.

d- To increase the instability behavior, it can be obtained by connecting a feedback inductor to the gate (positive feedback), even though $K<1$ indicates that the transistor is potentially unstable.

e- Evaluate the new *S*-parameters of active device (MESFET) with a feedback inductor connected to the gate.

f- The input stability circle plotted to choose reflection coefficient for input matching network (resonator). Theoretically, any Γs residing inside of the unstable region $\Gamma_S \leq 1$ would satisfy the requirements. To choose Γ_S such that it maximizes the output reflection coefficient [13].

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}}{1 - S_{11}\Gamma_S}\Gamma_S \qquad (10)$$

It is obvious that Γ_{out} achieves its maximum value when $\Gamma_S = S_{11}^{-1}$, this results an infinite output reflection coefficient. The oscillator becomes increasingly sensitive to change in the load impedance, and slightest deviation from the 50Ω value results increasing all oscillations. To overcome this problem Γ_S somewhat close, but not exactly equal to S_{11}^{-1}.

g- Compute the source impedance Z_S.

h- Compute the output reflection coefficient. To determine output matching network must be compute load reflection coefficient Γ_L (where $\Gamma_L = \Gamma_{out}^{-1}$) and then compute Z_L. The transformation of the 50Ω to Z_L is done through an output-matching network.

i- To increase the output power, $R_{out} = Real\ (Z_{out})$ .Thus, it is necessary to choose $R_L = Real\ (Z_L)$ such that $R_L + R_{out} < 0$ .In practice, a value of $R_L = -R_{out}/3$ is often used.

3-2 Biasing Circuit

Biasing circuit is required to set the *DC* bias level for the microwave transistor usually passive or active biasing technique may be used. The design procedure for the active biasing circuit is explained in [5].

a-The operating *Q*-point required is $V_{SQ} = 2$v and $I_{dQ} = 40$mA.

b-The transistor *DC*-parameters are $I_{DSS} = 80$mA.

c-The pnp transistor (2N2907) device is used as a general purpose; this transistor has an hfe of approximately 50.

d-The active biasing circuit is shown in figure (4).

e- Based on the previous design calculation, I_{E2} equals 1mA then $I_3 = 41$mA.

f- $V_{EE} > 2$v (let $V_{EE} = 3$v) then $R_3 = 24.39\Omega$ the power dissipation in R_3 equal to $I_3^{\,2}$. $R_3 = 24.4$ mw.

g- $V_{DSQ} = 2$v then $V_{R2} = 1.3$v and $I_{B2} = 19.6$ µA then $R_2 = 6.632$KΩ and $R_1 = 8.673$ KΩ.

h-The gate voltage is $V_{GSQ} = 0$v. Let $V_{CC} = -1$v then $R_5 = 1$KΩ select $R4 = 1$KΩ and $R6 > 1$MΩ ($R_6 = 1.25$ MΩ) the final structure of biasing circuit includes necessary by pass capacitors and the required values are indicated.

3-3 Fixed-Frequency Oscillator

The first steps in the design of Fixed-Frequency microwave oscillator is checking stability factor *K* of the device as shown in the figure (7), by using equation (7) the value of $K = 0.418$ at frequency 7GHz. Input stability circle and output stability circles shown in the figure (8), it can be observed that the unstable region for input stability circle and output stability circle is not located on smith chart, also can be observed S_{11} less than unity as shown table (1). The small stability circles make the design complicated and constrained. Therefore a common-gate configuration is now analyzed. The common-gate structure *S*-parameters given in table (2). The new stability factor is K=0.584 (less than 0.418 for common-source) as shown in the figure (9), and the input and output stability circles are both unstable regions and greater than unstable regions for common-source as shown in the figure (10).

It can be seen from table (2) that the value of the common-gate S_{11} is less than unity. To obtain suitable stability factor and good unstable regions for input and output stability circles a positive feedback is employed to increase the instability this can be performed by connecting inductor to the gate of the transistor. A new parameters shown in table (3). Optimization using microwave office is employed to obtain the optimum value of feedback element (inductor) that gives a stability factor K as small as possible and reduces toward final value of optimization is L = 0.18nH and the corresponding value of K = -0.918 as shown in the figure (11). It is clear in figure (12) that shows the unstable regions for both input and output are increased. Increasing in unstable region for input stability circle makes it easy for the designer to select source reflection coefficient that will gives the maximum output reflection coefficient. The value of source reflection coefficient Γs selected is $\Gamma_S = 0.99\angle -142.25, Z_S = -j17.3\Omega$ which is realized by shunt capacitor 1.32pF where obtained on maximum output reflection coefficient as shown in figure (13). The output-matching network is $\Gamma_L = \Gamma_{out}^{-1} =$ 0.012∟-83.6. This corresponds to the impedance Z_L= 50.01325-j0.119 = $-Z_{out}$, but due to the power dependence of the transistor's *S*-parameters, choosing the real portion of the load impedance Z_L=48-j0.119 Ω to be slightly smaller than R_{out}.

Before design output matching network must be know the movement on the Immittance chart, this chart presents both impedance and admittance charts printed in two contrasting colors with one smith chart rotated 180° relative to the other [10] for determining lumped matching elements is shown in figure (14) .The output-matching network can be realized after knowing Z_L by using analytical approaches to design *L*-section matching network. The value of inductance is 0.3014nH and the value of capacitance is 0.121pF, the oscillator circuit including resonator and output matching network is shown figure in (15).

3-4 Response of Oscillator

Two methods can be used to analyze oscillator structure. The first method involves the open-loop gain and phase response versus frequency. This analysis provides the frequency characteristics of the oscillator magnitude and phase of S_{11} for the complete oscillator see figure (16). The second method considers the oscillator as one-port with negative real impedance to which a resonator is attached. Figure (17) show analysis of negative resistance. The open-loop method provides more complete and intuitive analysis while the negative resistance method is more suitable for broad tuning oscillator operating above several hundred megahertz.

4- Discussion

1- It can be observed that the common-gate with feedback increases instability than the common-source and even common gate without feedback.

2- For input stability circle the $|c_{in}| > |r_{in}|$ and $|\acute{S}_{11}|$ >1, therefore the stable region inside solid circle. For output stability circle the $|c_{out}| < |r_{out}|$ and $|\acute{S}|$ >1, then the stable region outside solid circle.

3- In figure (16) at which the phase of S_{11} goes to zero correspond to possible frequencies of oscillation, and can be observed multiple zero phase crossing.

At each zero phase crossing, if $|S_{11}|>1$ then the circuit has the potential to oscillate at that frequency. If $|S_{11}|<1$ then the open-loop gain is less than unity and the circuit will not oscillate at 7GHz frequency.

5- Conclusions

In this paper a solid state microwave oscillator has been investigated. The presented oscillator circuit has been modeled and simulated using microwave office 2000 version 3.22 for c-band applications. Simulation results show that a simple tuning has been carried out to get the required oscillator performance. It has been verified that the feed back inductor connected to the gate (positive feed back) that rises the instability for $K<1$ to get a good oscillation.

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Table (1) *S*-Parameters of *Afm02n8b* Common-Source

V_{DS} = 2V, I_{DS} = 40 (mA) Ta-25 C^O *S*-Parameters								
	*S*11		*S*21		*S*12		*S*22	
f(GHz)	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle
7	0.433	-115	3.467	51.77	0.099	32.57	0.306	-72.32

Table (2) S-Parameters of *Afm02n8b* Common-Gate

S-Parameters								
	*S*11		*S*21		*S*12		*S*22	
f (GHz)	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle
7	0.8808	138.34	2.3314	-37.704	0.27376	94.585	1.354	-30.832

Table (3) S-Parameters of *Afm02n8b* Common-Gate with Gate Inductor

S′-parameters								
	*S*11		*S*21		*S*12		*S*22	
f (GHz)	Mag.	Angle	Mag.	Angle	Mag.	Angle	Mag.	Angle
7	1.0083	142.25	2.5514	-37.246	0.29735	108.63	1.4676	-30.491

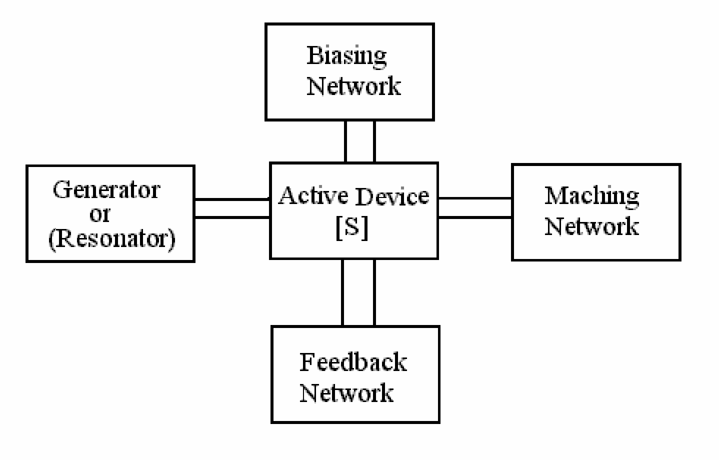

Figure (1) Block Diagram for a Two-Port Transistor Oscillator

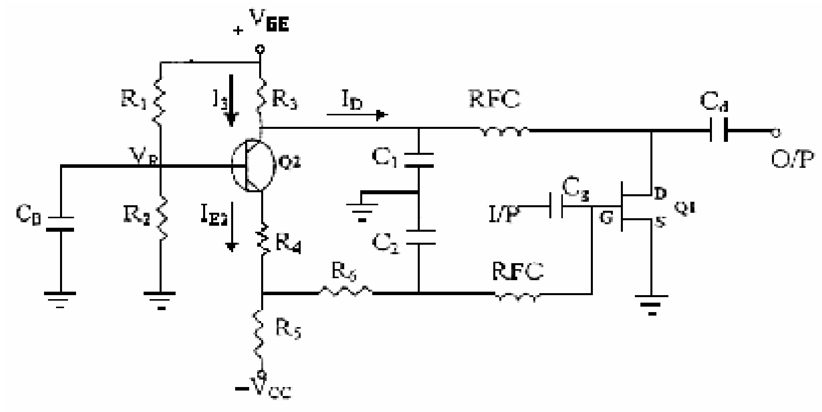

Figure (2) Active *DC*-Biasing Circuit for GaAs MESFET

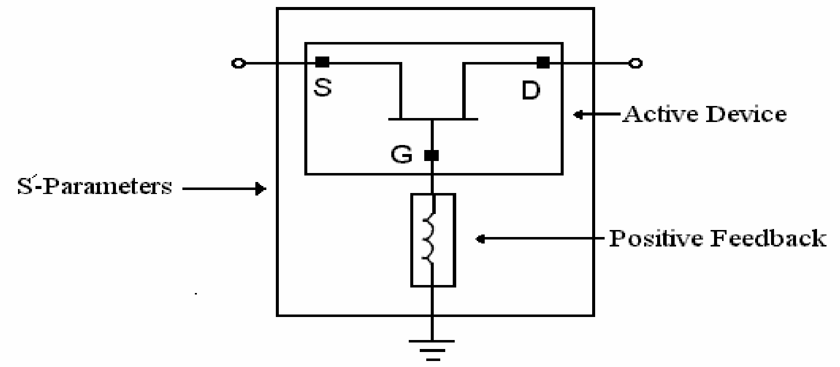

Figure (3) Active Device with Gate Inductor

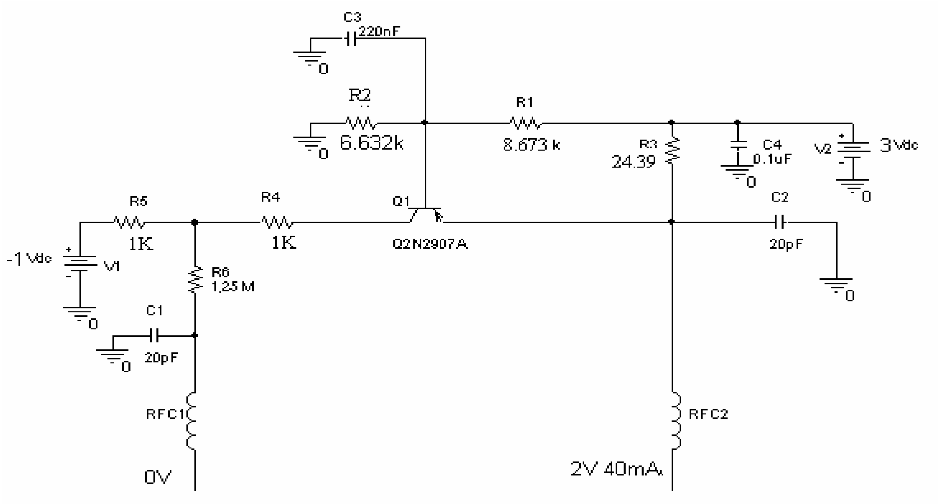

Figure (4) Drain-Source Current (I_{DS}) Active Biasing Circuit (using Pspice Package)

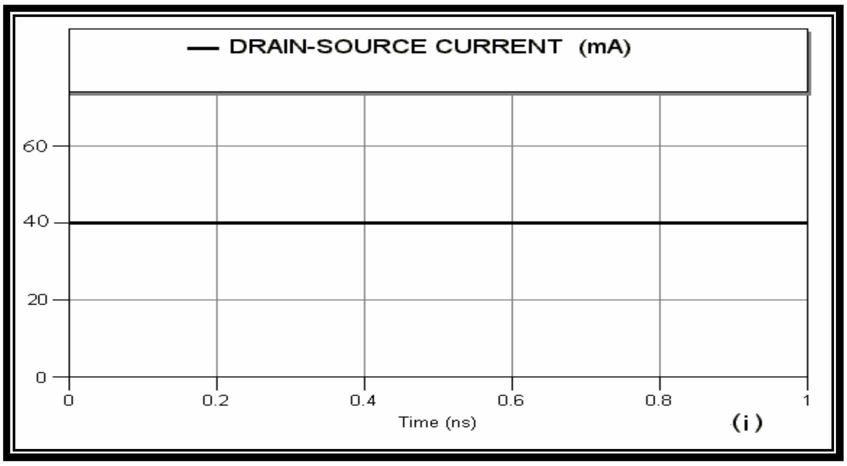

Figure (5) Drain–Source Current (I_{DS}) Active Biasing Circuit (using Pspice Package)

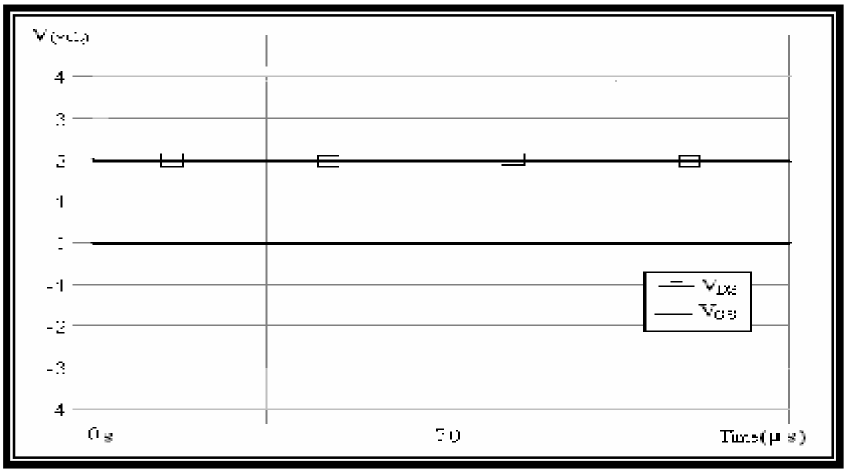

Figure (6) Drain–Source Current (I_{DS}) Active Biasing Circuit (using Pspice Package)

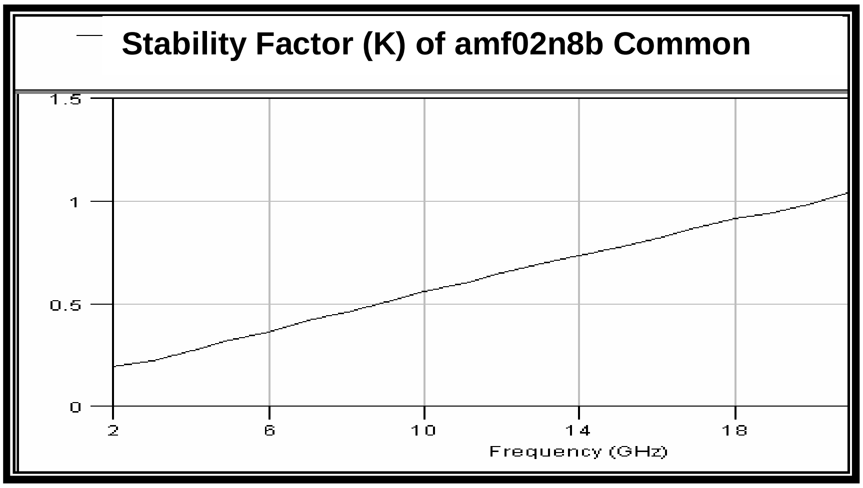

Figure (7) Stability Factor of *Afm02n8b* the Common-Source

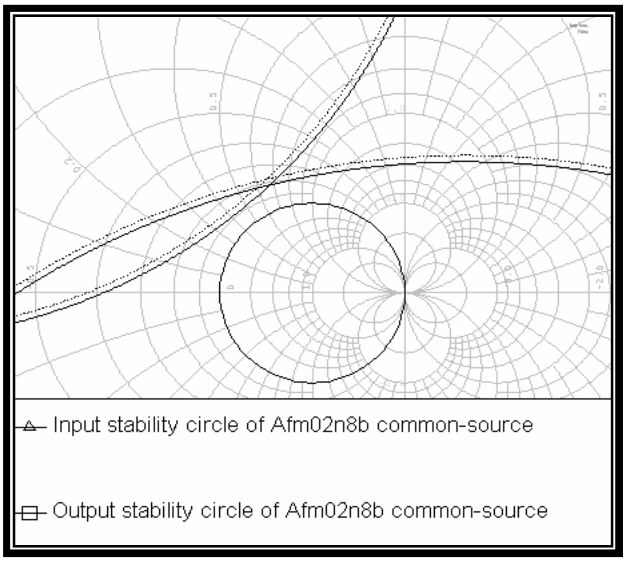

Figure (8) Stability Circles of *Afm02n8b* the Common-Source

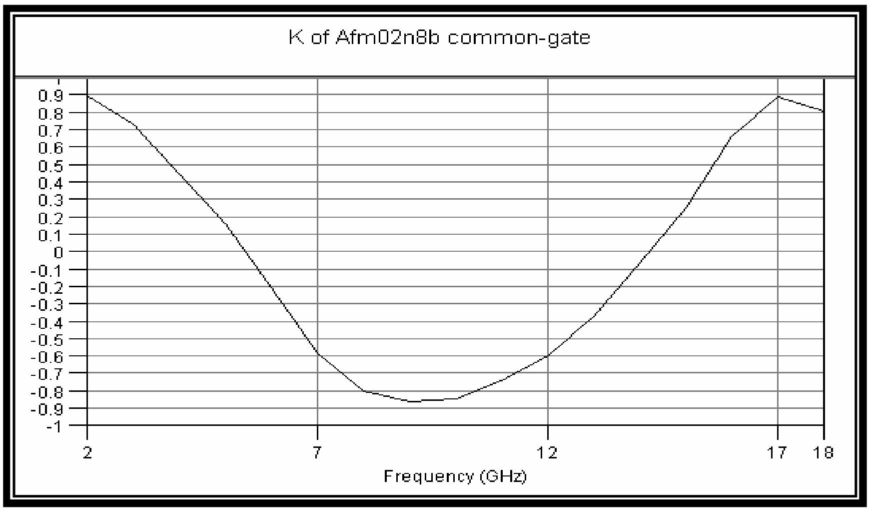

Figure (9) Stability Factor of the *Afm02n8b* Common-Gate

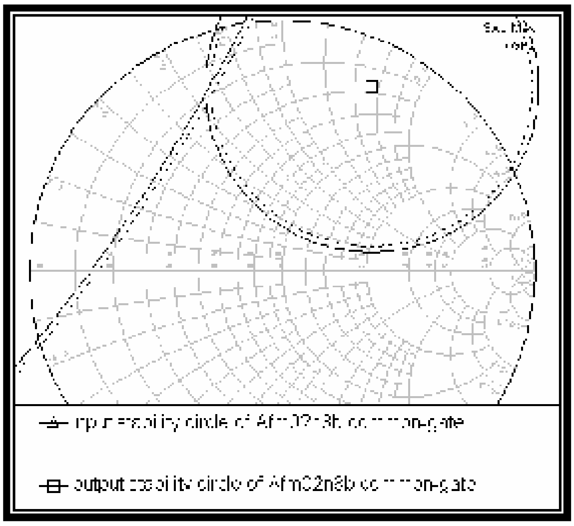

Figure (10) Input and Output Stability Circles of *Afm02n8b* Common-Gate

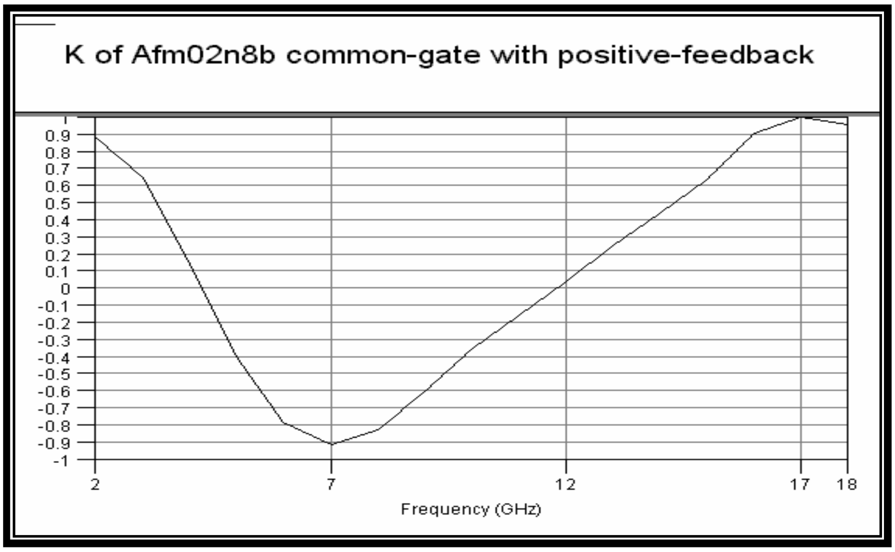

Figure (11) Stability Factor of the *Afm02n8b* Common-Gate with Positive Feedback

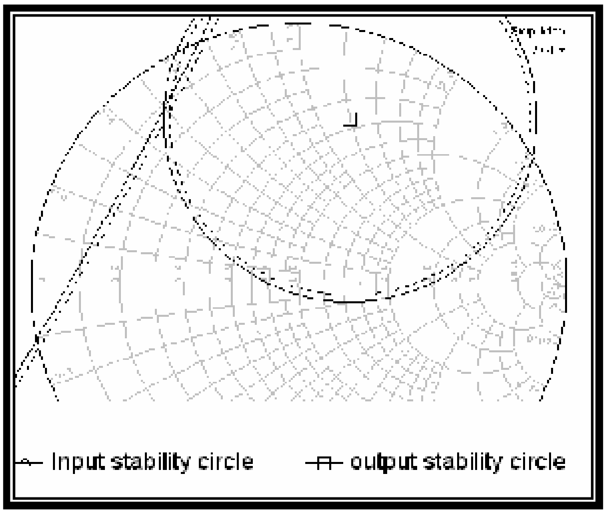

Figure (12) Input and Output Stability Circles of *Afm02n8b* Common-Gate with Positive Feedback

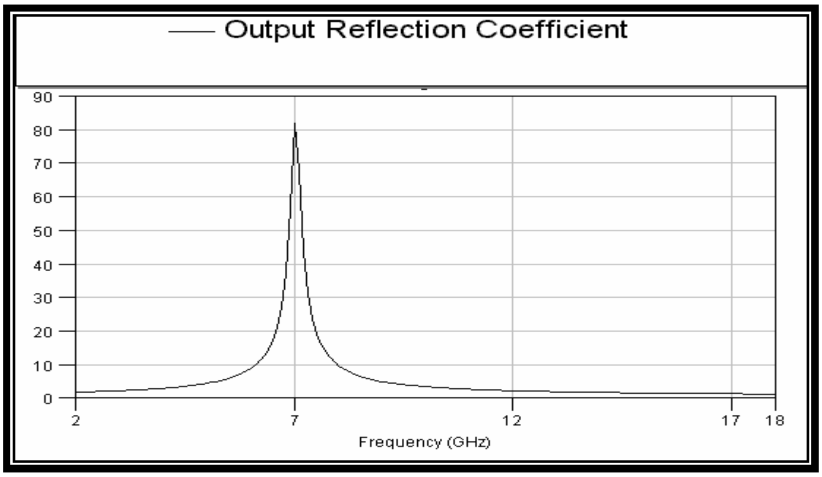

Figure (13) Output Reflection Coefficient

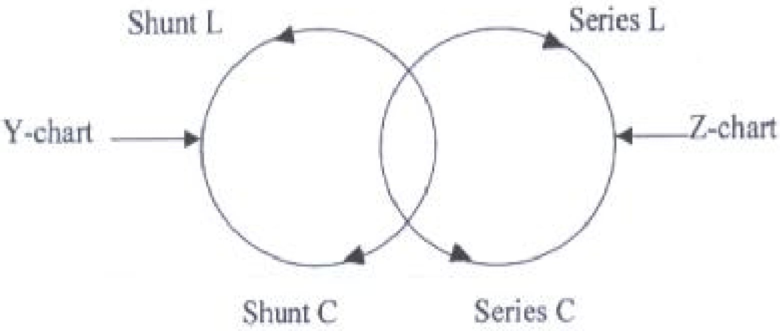

Figure (14) Determining Lumped Elements by the Movement on the Immittance Chart (L: Inductors, C: Capacitors)

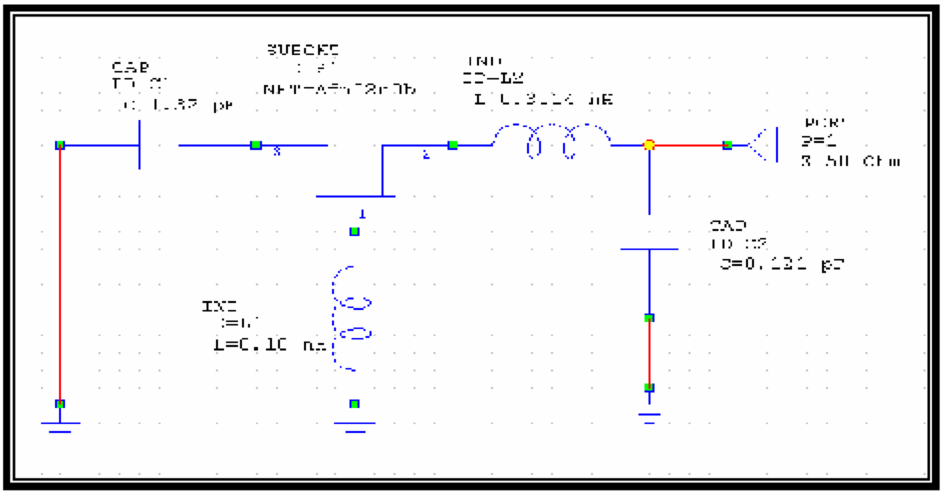

Figure (15) Oscillator Circuit

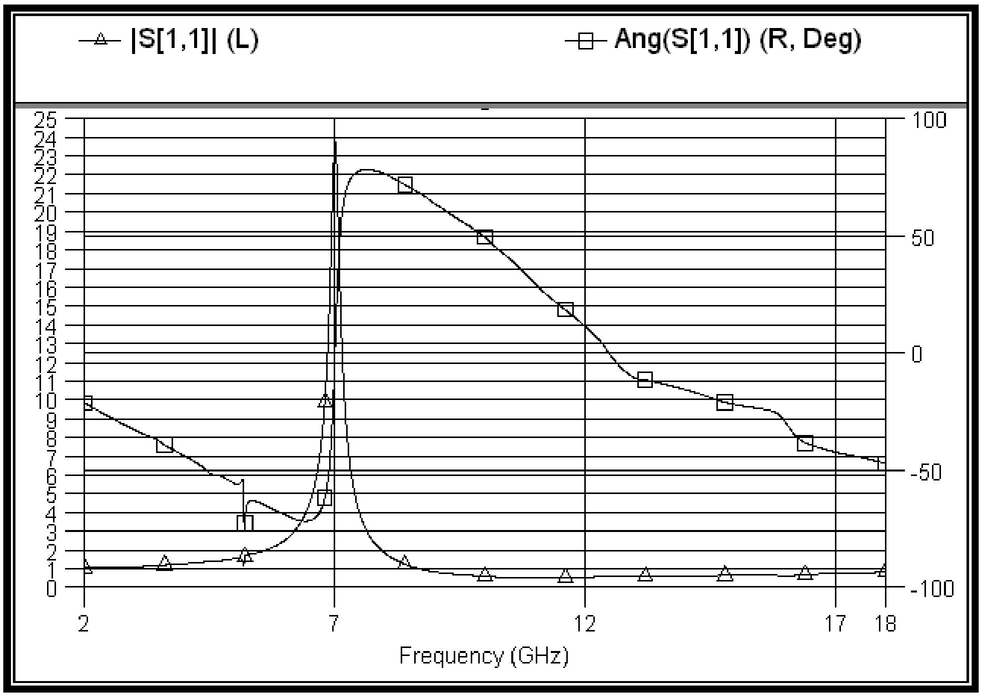

Figure (16) Open-Loop Gain and Phase Response versus Frequency

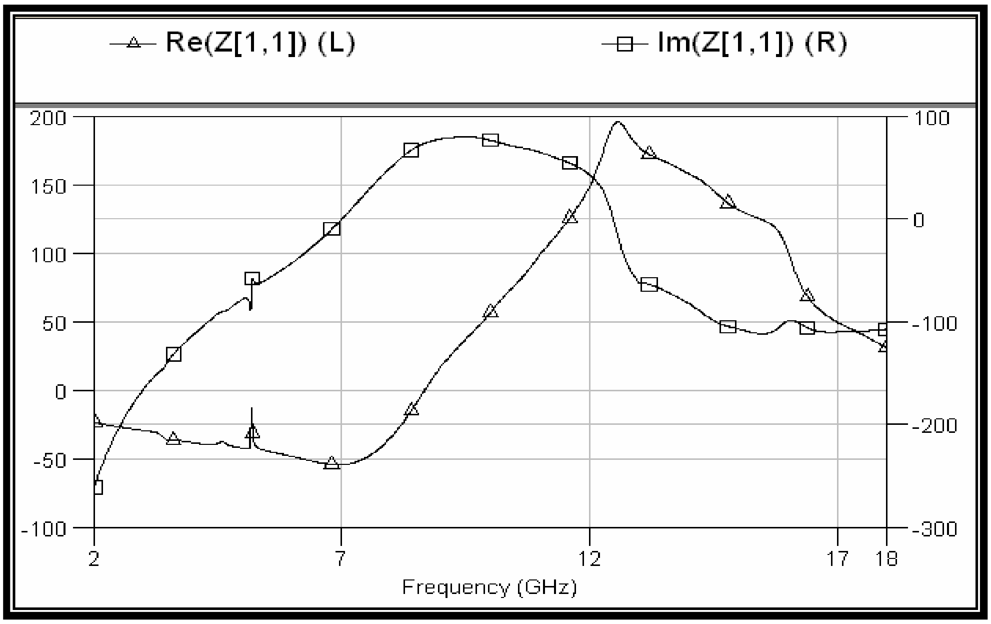

Figure (17) Negative Resistance Response versus Frequenc