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Design Methodology of Small Signal Power Amplifier using Linear S-parameter Model

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Abstract—This paper illustrates the linear design procedure and simulation of small signal power amplifier at frequency of 900 MHz based on an RF MOSFET device of type RD45HMF1 [15] fromMISTUSHIBUSHI. The linear S-Parameter model of this device is used in Agilent ADS to design the power stage includingthe stability analysis,complex conjugate matching and design of source and load matching networks. The linear model is specifically required to achieve the desired gain with better input and output return losses.The matching network is then designed to achieve specified performance figures.It is hoped that the understanding gained through the work will be useful in futureSSPA developments.

Keywords—*RF Power amplifier,EIRP(Effective Isotropic Radiated Power),MOSFET, Gain*

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I. INTRODUCTION

ThePower amplifier in a communication transponder along with transmit antennadecides the EIRP (Effective Isotropic Radiated Power) of the satellite. With the increased requirement of higher channel capacity and better coverage, these days a higher EIRP is required. The Effective Isotropic Radiated Power (EIRP) is availablefrom a communication payload generally depends upon theantenna gain, coverage requirements and output powercapability of the RF amplifier present in the downlinkchannel. The Gain of transmitting antenna is proportional to its sizeand larger antennas cannot be accommodated on the payload. So, the power amplifier plays an important role in meeting the EIRP requirement of the satellite. There are two types of power amplifiers used in the transponders viz. Travelling Wave Tube Amplifiers (TWTAs) or Solid State Power Amplifiers (SSPAs).For thehigher frequencies, generally TWTAs areemployed to do the job however size is a constraint at lowerfrequencies such as UHF band.For UHF band high power applications the TWTAs are not available and hencethe SSPAs are used.SSPA is the cascaded system of small signal amplifiers, medium power amplifiersand high power amplifiers.The most important considerations for RF and microwave power amplifiers are bandwidth,efficiency, gain, linearity and thermal effects. Sometimes, the gain is compromised over the efficiency requirement.

Typically, Silicon Bipolar junction transistors (BJT) are used at 900MHz Frequency. Then GaAs FETs and GaN also can be used fordeveloping this SSPAs. However,the dc-ratingrequirements of GaAs FETs is 8-9volts. Thus, to achieve higher output power, the high currentoperation is required. This makes the designof EPC challenging. The GaN device is not available at this frequency band so MOSFET is used for this operation.

II. AMPLIFIER DESIGNMETHODOLOGY USING S-PARAMETER MODEL

In the design of the power amplifier,it is often desirable to interconnect many active and passive elements together. The commonly used microwave solid devices are in the form of two ports consisting of H,Yor Z parameters. If the frequencies are in the microwave range , the H,Y or Z parameters can not be measured because of unavailability of equipment to measure the total voltage and current at the port of network. The short and Open circuits are very difficult to obtain over a broad band of the frequencies. So the new method is characterized to overcome these problems. The logical variables which are used at the microwave frequencies are the travelling wave rather than the total voltage and total currents. These are the S-Parameters are given below and two port network is shown in fig.1.

b1=S11a1+s12a2 (1)
b2=s21a1+s22a2 (2)

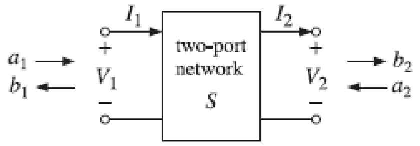

Fig.1. Two Port Network

III. STABILITY AND BIASING CONSIDERATION

A. Stability Consideration

It is necessary to checkthe stability of a device even beyond the operating bandof interest to check for the undesired potential oscillations . Thereforethe S-parameter simulation is done to check the stability factor and the source and load stability circlesfor the device. There are two types of stability:

Unconditional stability: The network is an unconditionally stable if $|\Gamma in| < 1$ and $|\Gamma out|<1$ for all the passive source and load impedances (i.e., $|\Gamma_S| < 1$ and $|\Gamma_L| < 1$).

Conditional stability: The network is conditionally stable if $|\Gamma_{in}| < 1$ and $|\Gamma_{out}| < 1$ only for a certain range of passive source and load impedances. This case is also referred asa potentially unstable.

The stability factor is given by following equation.

$$K = \frac{1+|\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{12}S_{21}|} > 1 \qquad (3)$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21} < 1 \qquad (4)$$

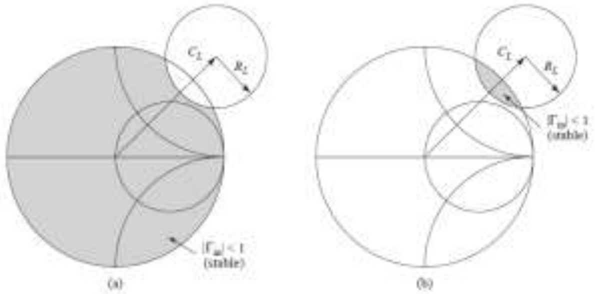

Fig.2.Output Stability Circles for a conditionally stable device

The stability condition of the amplifier circuit is usually a frequency dependent because the input and the output matching networks depend on frequency. So It is possible for the amplifier to be stable at its design frequency but unstable at other frequencies.

Stability Circles:
With the two-port small-signal S-parameters at a particular frequency and a particular bias condition, the input and output stability circles can be derived. The stability circles can be graphically represented on the Smith chart. These circles provide a set of source and load impedance such that the magnitudes of the reflection coefficients of the input and output are less than one.

Input Stability Circle:

$$r_s = \left|\frac{S_{12}S_{21}}{|S_{11}|^2 - |\Delta|^2}\right| \qquad (5)$$

$$C_s = \frac{(S_{11} - \Delta S_{22}^*)^*}{|S_{11}|^2 - |\Delta|^2} \qquad (6)$$

Output Stability Circle:

$$r_L = \left|\frac{S_{12}S_{21}}{|S_{22}|^2 - |\Delta|^2}\right| \qquad (7)$$

$$C_L = \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2} \qquad (8)$$

Fig 3 represents the unstable region in which the source and load stability circles are inside the smith chart and K is less than 1. Fig 4 represents the stable region that has source and load stability circles outside the smith chart and K is greater than 1achieved by putting the resistor of 3.5 ohm in series with the gate terminal of the device.

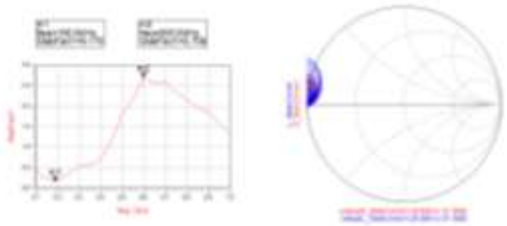

Fig.3. Stability Analysis (Unstable device)

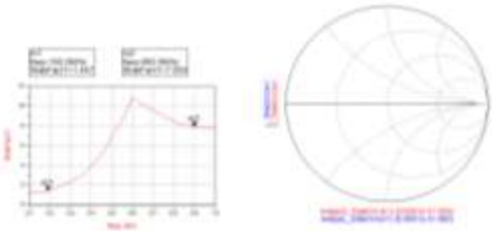

Fig.4. Stability Analysis (Unstable device)

B. *Biasing Consideration*

The device has to be biased such that it gives the maximum output power without clipping the input signal. The Biasing process decides the class of the operation and the operating point. The range of the output voltage or the current signal should not be limited by the device if it has to perform in the linear region.The active device requires a DC-bias in order to operate in the active region. Appropriate bias point is one of the most critical aspects in the Power Amplifier design. The bias network not only defines the Power Amplifier performance over RF drive, but also does over temperature, and presented with the two DC voltage supplies connected to the active device.

IV. MATCHING NETWORKS

These networks are designed for impedance transformation, typically between the transistor and terminations of 50 Ohm on the input/output of amplifier. Matching networks provide transformation from "Z_G" and "Z_L" to the standard 50Ω terminations at a limited bandwidth. These "Z_G" and "Z_L" values are required to provide the maximum desired power, gain or PAE. Therefore it is important to find these (6) optimum values through load pull measurements or simulations.

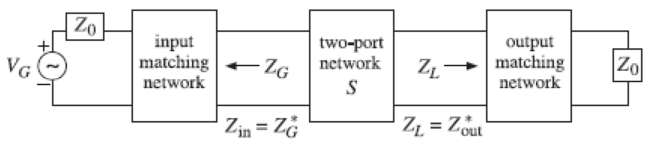

Fig.5.Impedance Matching Network

At this case, source delivers all its available power to the output shown in fig.5.
The transducer, the available, and the operating power gains become equal to themaximum available gain GMAG when both a generator and a load are matchedconjugately to the two-port, that is,

$$\Gamma_{in} = \Gamma^*_G \text{ and } \Gamma_{out} = \Gamma^*_L. \qquad (9)$$

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$$\Gamma_G = \frac{B_1 \mp \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} \quad (10)$$

$$\Gamma_L = \frac{B_2 \mp \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} \quad (11)$$

The optimum conjugate matched terminations are:

$$\Gamma_G = S^*_{11},\ \Gamma_L = S^*_{22} \quad (12)$$

In this project optimum load impedances are obtained through complex conjugate simulations using the device model. These values are then used to design the input and output matching networks for Maximum transfer of power from the source to the transistor and from transistor to the load that takes place when there is a conjugate matching at both the input and the output.

Selection of Load & Source Impedances:

After Stabilizing the device there is a need to find the input and output impedance of the device so that appropriate matching network can be designed. ADS provides a tool that gives the value of the conjugate matched input and output impedance that must be presented to the device so that the device can be matched to 50ohm line. Fig.6 shows the input and the output impedances that must be presented to the input and output ports respectively to conjugate matched the device. This is the condition for attaining maximum gain for the amplifier. The reflection Coefficient of the Source (S11*) and the Load (S22*) are simultaneous matched reflection coefficients that must be presented to the input and output ports respectively to achieve the maximum gain from the device.Depending upon the design of the source impedance is selected as Zs=4.545-j*1.894 Ohm and Z_L=1.258-j*2.618 ohm

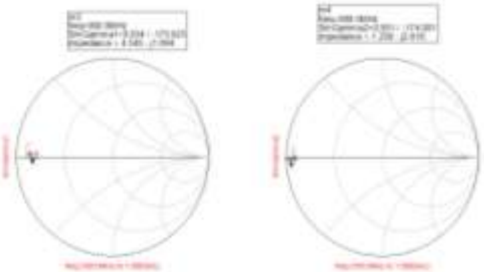

Fig.6. Source and Load Impedances

Design of Matching Network

The impedances given by SmGamma1 and SmGamma2 obtained in previous step are 4.545-j*1.894 Ohm and 1.258-j*2.618 ohmrespectively. It implies that 50 ohm input and output lines have to be transformed into4.545-j*1.894 ohms and1.258-j*2.618 ohms respectively. The matching network is designed for its performance and for the high power output and the power added efficiency.

Input Matching Network:

The 50ohm source termination is matched to the specific impedance of 4.545-j*1.894 ohm by putting series inductor and shunt capacitors using the complex conjugate theorem shown in fig.7&8.

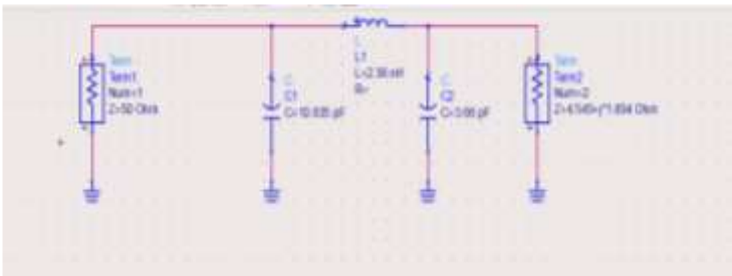

Fig.7. Input Matching Network

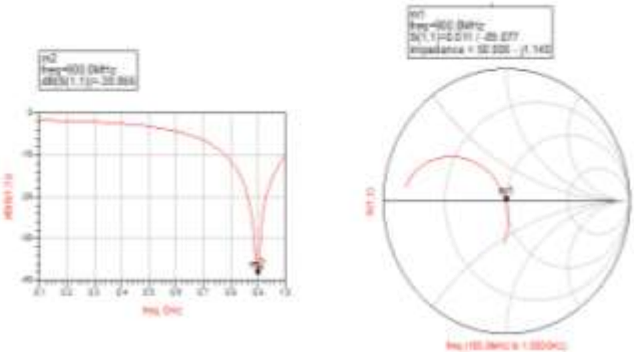

Fig.8. Response of input Matching network

Output Matching Network:

The load termination of 50ohm is matched to a specified impedance of 1.258-j*2.618 by putting series inductor and shunt capacitors using complex conjugate theorem shown in fig.9 & 10.

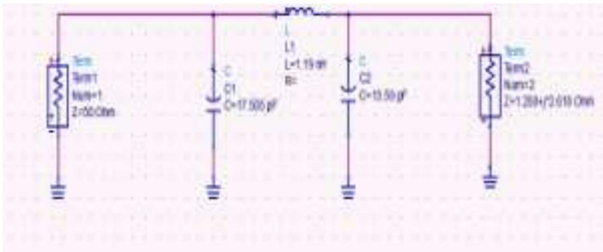

Fig.9. Output Matching Network

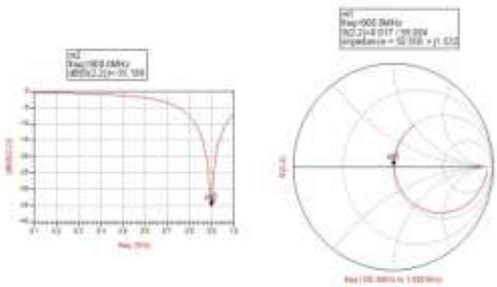

Fig.10. Response of Output matching Network

The complete amplifier design using S-Parameter model is achieved by combining both the input and output matching networks. The response in form of gain,input & output return loss and isolation is represented in fig 11.

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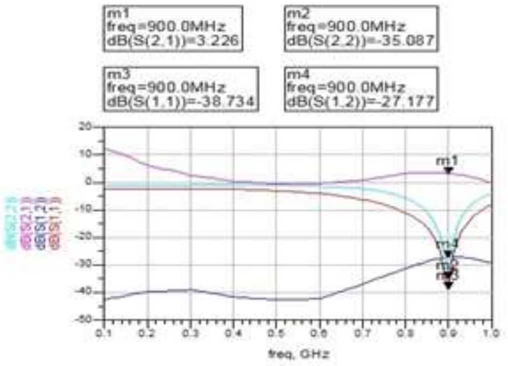

Fig.11.Response of amplifier using Linear S-Parameter model

V. Power Gains

The amplification properties of the two-port can be achieved by comparingthe power Pin going into the two-port to the power P_L coming out of the two-port networkand going into the load.Three most widely used definitions for the power gain of two-port network are thetransducer power gain G_T, the available power gain G_A, and the power gain G_P are defined as follows:

Power gain = $G_P = P_L/P_{in}$ is the ratio of the power dissipated in the load Z_L to the power delivered to the input of the two-port network.

$$G_P = \frac{|s_{21}|^2 \left(1-|\Gamma_L|^2\right)}{\left(1-|\Gamma_{in}|^2\right)|1-s_{22}\Gamma_L|^2} \quad (13)$$

Available power gain = $G_A = P_{avn}/P_{avs}$ is the ratio of the power available from a two-port network to the power available from the source.

$$G_A = \frac{|s_{21}|^2 \left(1-|\Gamma_S|^2\right)}{\left(1-|\Gamma_{out}|^2\right)|1-s_{11}\Gamma_S|^2} \quad (14)$$

Transducer power gain = $G_T = P_L/P_{avs}$ is the ratio of the power delivered to a load to the power available from the source.

$$G_T = \frac{|s_{21}|^2 \left(1-|\Gamma_L|^2\right)\left(1-|\Gamma_S|^2\right)}{|1-\Gamma_{in}\Gamma_S|^2 |1-S_{22}\Gamma_L|^2} \quad (15)$$

The necessary and the sufficient conditionor simultaneous matching is $K \geq 1$, where K is the Rollett stability factor. It canbe shown that the $\mathbf{G_{MAG}}$ can be expressed as:

$$G_{MAG} = \frac{|s_{21}|}{|s_{12}|}\left(k-\sqrt{k^2-1}\right) \quad (16)$$

The maximum stable gain ($\mathbf{G_{MSG}}$) is the maximum value G_{MAG} can have, which isachievable when K = 1:

$$G_{MSG} = \frac{|s_{21}|}{|s_{12}|} \quad (17)$$

VI. Conclusion

This paper represents the design steps to be followed for thedesign of the power amplifier which has been designed using the linearS-Parameter model. The accuracy of this model is dependenton the accuracy of the model parameters, which in tumdepends on the device characterization process. Initially the device is unstable which is made stable using series resistor with gate terminal.After stabilization of device,using the complex conjugate matching, the input and output matching networks are designed to meet the gain,input return loss and output return loss requirements. The gain,input and output return losses are as per the requirements.

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