

# Design Of 11 GHz Ku-Band Amplifier

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**Abstract** - Amplification is one of the most basic and prevalent RF/Microwave circuit functions. This paper describes the design of an 11 GHz PHEMT ATF-36077 microwave amplifier. The amplifier is manually designed using conventional technique, Smith chart was used to do a matching of the input and output of the amplifier. A completed design of the amplifier was optimised using Hewlett-Packard Advanced Design System (HP-ADS) software. The layout generated by the software was used to fabricate the amplifier. Performance analysis of the amplifier has been carried out and comparison between simulated and measured results has been done. Microwave amplifier normally integrated in the Low Noise Block (LNB) and connected to the indoor equipment using coaxial cable. The DC power supply is fed to the down-converter block using the same cable and typically 12 Volt. Microwave amplifier normally needed the negative power supply for biasing the Gate of the PHEMT. This paper will also describe the simplest and the cheapest design of the DC to DC converter using well known 555 timer IC. This converter was used to generate negative power supply to bias the PHEMT.

**Index Term** – Ku-Band, Microwave, Amplifier, LNB

## I. INTRODUCTION

The amplifier discriminates the relatively weak microwave signal received by the antenna from background noise, amplifies it to a reasonable working level. The first stage of the amplifier is typically the primary device that drives the noise figure and the second and the next stage provide required gain at reasonable noise figure. A high electron-mobility transistor (HEMT) have exhibited lower noise figure and higher gain at microwave frequencies up to 70 GHz [3]. The Hewlett Packard ATF-36077 PHEMT capable of noise figures of 0.5 dB at 12 GHz. It has very low noise resistance, reducing the sensitivity of noise performance to variations in input impedance match, makes this device the ideal choice for use in first stage of extremely low noise cascades [1].

However, the second and the third stage also designed using the same device.

## II. THEORY

The design method presented here is based on the manufacturer S-parameters of the device given in the technical data sheet. The transistor can be modeled by the block diagram as shown in Fig. 1 to represents the S parameters.

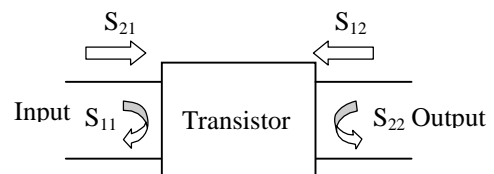


Fig. 1: The transistor S parameters.

$S_{11}$  represents the reflection coefficient at port 1 when port 2 is matched.

$S_{21}$  represents the transmission coefficient at port 1 when port 2 is matched.

$S_{12}$  represents the reflection coefficient at port 2 when port 1 is matched.

$S_{22}$  represents the transmission coefficient at port 2 when port 1 is matched.

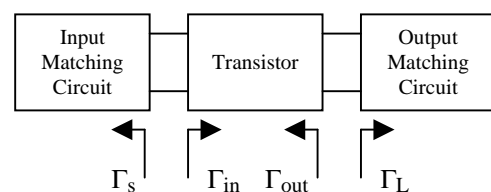


Fig. 2: The general microwave transistor amplifier block diagram.

A single stage microwave transistor amplifier circuit can be modeled by the block diagram of Fig. 2, where a matching network is used on both sides of the

transistor [3,4]. The reflection coefficients on the input and output sides of the transistor are defined as [3] – [4].

$$\Gamma_{in} = S_{11} + \left( \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \right) \quad (1)$$

$$\Gamma_{out} = \left( S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} \right) \quad (2)$$

Stability is an important factor in designing microwave amplifier. The amplifiers tend to oscillate if not stable. The stability factor of the transistor is defined as [3] – [4].

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

where:

$$D = S_{11}S_{22} - S_{12}S_{21}$$

The transistor is unconditional stable if  $K$  is greater than 1 and conditional stable if  $K$  is less than 1. In order to determine the conditionally stable region, the stability circle can be drawn on the Smith chart. This easily can be done using Z-Match software from Number One Systems Ltd. company. The region inside the stability circle is the unstable region. Achieving the associated gain of which the device is capable is difficult since the device is not inherently stable at the desired operating frequency. The maximum gain of an unconditionally stable transistor is defined as the following [4].

$$G_{ma} = \left| \frac{S_{21}}{S_{12}} \right| \left( k - \sqrt{k^2 - 1} \right) \quad (4)$$

For a potentially unstable device, we can only compute the maximum stable gain, which is the highest physically realizable gain possible after the device is stabilized to  $K = 1$ . Thus, equation [4] can be simplified as follows [2] – [5].

$$G_{ms} = \left| \frac{S_{21}}{S_{12}} \right| \quad (5)$$

For further investigation, the gain of a PHEMT is best graphically displayed on a Smith chart, it is called a gain circle. The radius of a gain circle can be calculated using the following equation

$$R_g = \sqrt{\frac{(1 - 2k|S_{12}S_{21}|g_p) + (|S_{12}||S_{21}|^2 g_p^2)}{1 + g_p(|S_{22}|^2 - |D|^2)}} \quad (6)$$

The center of the gain circle

$$C_g = \frac{g_p(S_{22} - D\overline{S_{11}})}{1 + g_p(|S_{22}|^2 - |D|^2)} \quad (7)$$

where

$$g_p = \left( \frac{G_A}{|S_{21}|^2} \right)$$

As explained earlier, the noise figure of the first stage amplifier will determine the system noise figure. In order to ensure the amplifier will operate at a lowest possible noise figure the device is capable, the input of the device must be matched to the noise reflection coefficient. The noise reflection coefficient can be determined using the noise circle. The center of the noise circle can be calculated as follows [6].

$$C_i = \frac{\Gamma_{opt}}{1 + N_i} \quad (8)$$

The radius of the noise circle is

$$R_{ni} = \frac{\sqrt{N_i^2 + N_i(1 - |\Gamma_{opt}|^2)}}{1 + N_i} \quad (9)$$

Where:

$$N_i = \frac{[(F_r - F_{min})|1 + \Gamma_{opt}|^2]}{4r_n}$$

$F_r$  is a required noise figure

$F_{min}$  is a minimum noise figure of the device

$\Gamma_{opt}$  is a noise reflection coefficient

$r_n = R_n/Z_o$  is a noise resistance

The required noise reflection coefficient must be selected anywhere inside the circle to ensure that the required noise figure is not exceeded.

### III. DESIGN

The design proceeds with determination of the stability condition of the device. The S-Parameter of the ATF-36077 PHEMT are shown in Table 1. Using equation [3] and the data from Table 1, the stability factor ( $K$ ) of the device at 11 GHz calculated to be 0.835. This device is unstable at this frequency. For matching purposes, the unstable region can be avoided by drawing the noise figure circle, gain circle and stability circle in the same Smith chart as shown in Fig. 3. Those circles were drawn using Z-Match software.

A. First Stage Amplifier

The input of the first stage amplifier is matched to the noise reflection coefficient. The noise reflection coefficient namely  $\Gamma_{in}$  was selected to be  $0.53\angle 139.02^\circ$ . Open-circuit single stub matching was realized using Smith chart to match the above  $\Gamma_{in}$  to  $50\Omega$  microstrip line. As shown in figure 4,  $\Gamma_{in}$  was located on the Smith chart and the SWR circle has been drawn.  $Y_{in}$  is located by drawing a straight line from  $\Gamma_{in}$  to opposite side of the SWR circle passing through a center point of a Smith chart. A point of a straight-line crossing SWR circle is a  $Y_{in}$ . Moving from this point along SWR circle to the unity circle determined the length of  $50\Omega$  line of the matching network from the gate of the PHEMT to the stub position. The length of the line is  $0.024\lambda_g$ . However, the line was too short to be realised using microstrip. We should add  $0.5\lambda_g$  to overcome the problem. At this point,  $Y_{in} = 1-j1.25$ . A stub of  $j1.25$  is needed to cancelled out an imaginary part of the above  $Y_{in}$ . The length of the stub can be determined by moving from  $0\Omega$  point to  $j1.25$  towards generator. The length is found to be  $0.142\lambda_g$ .

Using equation (2), output reflection coefficient namely  $\Gamma_{out}$  was calculated to be  $0.46\angle -158.3^\circ$ . However, for maximum power transfer, the output of the PHEMT must be matched to the conjugate of the output reflection coefficient. Thus, we have a load reflection coefficient ( $\Gamma_L$ ) is  $0.46\angle 158.3^\circ$ . A similar procedure can be used to determine the output matching network. A microstrip line from the drain of the PHEMT to the stub position was found to be  $0.058\lambda_g$ . The line is too short, so that we need to add  $0.5\lambda_g$  to make it easier to fabricate. The stub length was found to be  $0.129\lambda_g$ .

B. Second Stage Amplifier

Second stage and third stage amplifier normally used to scale the overall gain of the low noise block to the required gain level. In this paper, the third stage amplifier is a duplicated of a second stage amplifier.

From equation (5), maximum stable gain of the PHEMT is calculated to be 16.2 dB. Using Z-match software, a 16.2dB gain circle has been drawn on a same Smith chart together with a noise figure circle and stability circle as shown in Fig. 3. In order to get the highest possible gain can be achieved by the device, the load reflection coefficient must be selected exactly on the gain circle line. The region nearest to the stability circle must be avoided. For the reason, if there is a slight variation of a load impedance, it will drastically effect the amplifier gain. The load reflection coefficient ( $\Gamma_L$ ) for a second stage amplifier was chosen to be  $0.52\angle 154.66^\circ$ . For maximum power transfer output of a second stage amplifier was conjugately matched. The length of a microstrip line

from the drain of the PHEMT to the stub position is  $(0.048+0.5)\lambda_g$ .

Using equation (1), input reflection coefficient ( $\Gamma_{in}$ ) of the PHEMT was calculated to be  $0.83\angle -164.98^\circ$ . For maximum power transfer, the input of the second stage amplifier must be conjugately matched. As shown in Figure 2, the conjugate of  $\Gamma_L$  is  $\Gamma_s$ . Thus we have  $\Gamma_s$  to be  $0.83\angle 164.98^\circ$ . The input matching network was designed using similar procedure as before and the length of a microstrip line from a gate of PHEMT to the stub position is  $(0.5+0.026)\lambda_g$ . The length of a stub is  $0.198\lambda_g$ .

C. Microstrip Line Length And Width In Millimeter.

The width of a  $50\Omega$  microstrip transmission line can be estimated using (5)

$$Z_0 = \left( \frac{120\pi}{\sqrt{\epsilon_{eff}}} \right) \times \frac{1}{\left[ \frac{w}{h} + 1.393 + 0.667 \ln \left( \frac{w}{h} + 1.4444 \right) \right]}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ \left( 1 + \frac{12h}{w} \right)^{-\frac{1}{2}} \right] \tag{10}$$

where

- $\epsilon_r$  is the relative dielectric constant of the substrate.
- $w$  is the width of the transmission line.
- $h$  is the substrate thickness.

Microwave laminate of dielectric constant 2.5 and thickness of 0.7878 mm was used in the design. Using equation (10), the width of the  $50\Omega$  transmission line was found to be 2.25 mm and  $\epsilon_{eff}$  is 2.079. The wavelength on the microstrip line is given by

$$\lambda_g = \frac{C}{f\sqrt{\epsilon_{eff}}} \tag{11}$$

$$= \frac{3 \times 10^8 \text{ m/s}}{(11 \times 10^9 \text{ Hz})(\sqrt{2.079})}$$

$$= 18.92 \text{ mm}$$

where

- $C$  is a speed of light  $3 \times 10^8 \text{ m/s}$
- $f$  is a design frequency

The microstrip line measured in wavelength is now can be converted to the millimeter.

*D. Biasing*

Dual-supply biasing is a recommended method to bias the PHEMT. The source of the PHEMT should be grounded and the plated through hole to connect the source to the ground plane should be directly under the source base. This is to minimise the parasitic components added to the circuit. The required drain and gate voltage were set according to the specification given in the manufacturer data sheet. The drain voltage is 1.5 V and the current is 10mA. The gate voltage is – 0.2 V.

The low noise block normally located at the out-door front-end is connected to the in-door portion via coaxial cable. The 12 V supply also fed to the active circuit of the low noise block through the same cable. As explained earlier, PHEMT needs dual-supply biasing. Thus, we need the negative supply to bias the gate of the PHEMT. The voltage converter is only the choice to overcome the problem.

In this design, the simplest and the cheapest voltage converter was used to induce the negative voltage. As shown in Fig. 4, the voltage converter consist of a 555 timer IC operated as an oscillator to produce AC voltage. This AC voltage is rectify by the negative rectifier and a negative voltage was generated. The Zener diode was used for over voltage protection and a voltage divider were used to scale down the negative voltage to the required operating voltage.

IV. RESULT

The complete circuit of the 11 GHz amplifier was optimised using HP-ADS software. The optimisation result is shown in Fig. 5. The gain of the amplifier is found to be approximately 41 dB at 11 GHz. The noise figure of the amplifier was found to be less than 1.2 dB at 10.9 GHz and gradually decreases to 0.9 dB at 11.3 GHz. The amplifier was fabricated and tested using network analyser. The photograph of the amplifier is shown in Fig. 6. The gain of the amplifier was found to be 27.9 dB at 11 GHz. The noise figure of the amplifier was not measured.

V. CONCLUSION

The 11 GHz amplifier has been designed successfully. However, predicted gain was not as physically tested gain. This is due to the unpredicted parasitic components and fabrication tolerances. In order to increase the amplifier gain, another stage of the amplifier can be cascaded using a similar configuration of a second stage amplifier.

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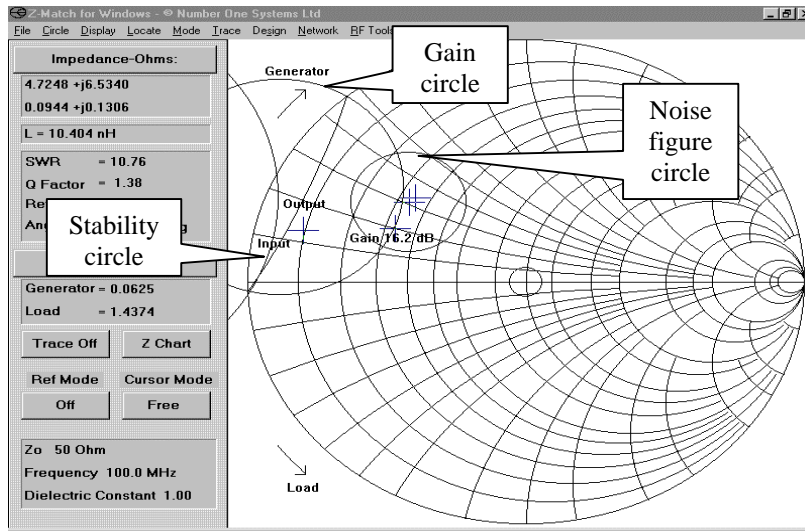


Fig. 3: Stability, constant gain and noise figure circle.

Table 1: PHEMT ATF-36077 S-Parameter

Common Source, $Z_0 = 50 \Omega$ , $V_{DS} = 1.5 \text{ V}$ , $I_D = 10 \text{ mA}$								
Frequency (GHz)	$S_{11}$		$S_{21}$		$S_{12}$		$S_{22}$	
	Mag	Ang	Mag	Ang	Mag	Ang	Mag	Ang
11	0.66	-159	3.473	25	0.083	-13	0.4	-129

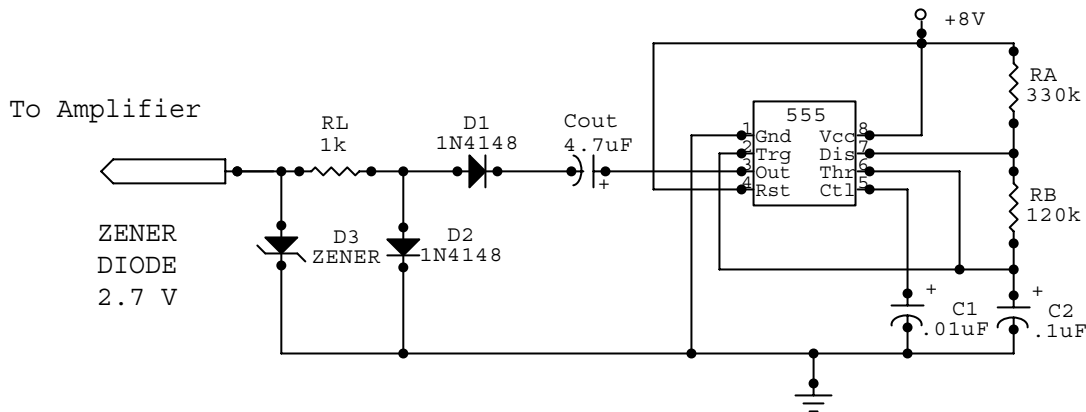


Fig. 4: DC to DC Converter Schematic Diagram

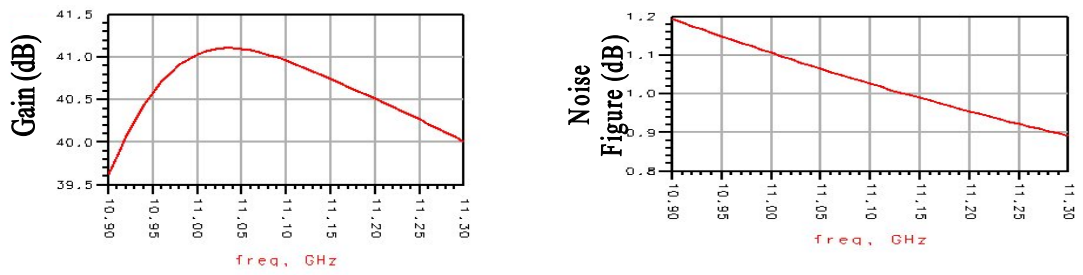


Fig.5 The optimization results

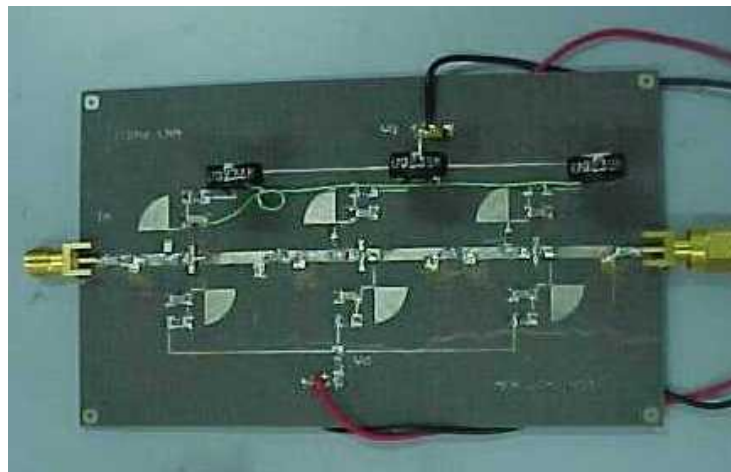


Fig.6 Photograph of the amplifier.