Semester S1

Basics of Active and Non-Linear Electronics

PRACTICAL WORK

PW1:

SCALAR NETWORK ANALYSIS TO MEASURE POWER CHARACTERISTICS OF A FET

OUTLINE

SCALAR NETWORK ANALYSIS TO MEASURE POWER CHARACTERISTICS OF A FET

I OBJECTIVE

First of all, it is necessary to familiarize yourself with some typical microwave instrumentation devices (microwave source, scalar network analyser, microwave reflectometer).

It is also very important to master the biasing techniques of microwave active components (AsGa FET).

Finally, the main objective of this PW is to study the main static characteristics of a FET amplifier, namely:

- - Output Power : P_{out}
- - Added Power: P_{add}
- - The Power Added Efficiency: PAE.

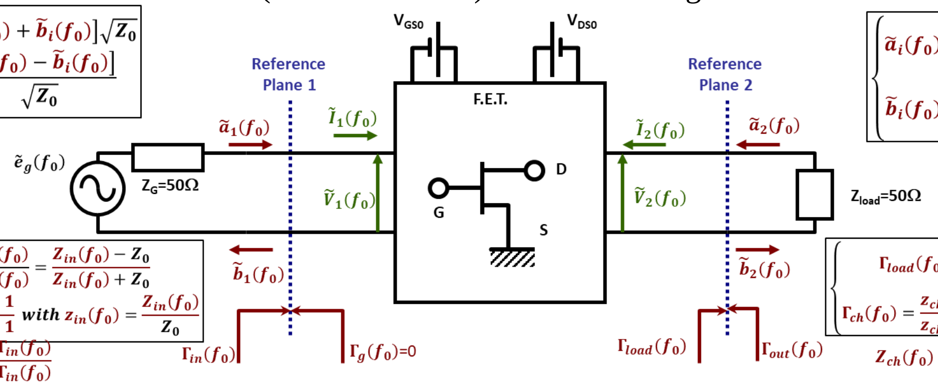
II THEORETICAL REMINDERS.

II.1 BASIC PARAMETERS.

Let us first consider a FET (common source) connected to a generator and a 50 Ω load:

$$\begin{cases} \tilde{V}_i(f_0) = [\tilde{a}_i(f_0) + \tilde{b}_i(f_0)]\sqrt{Z_0} \\ \tilde{I}_i(f_0) = \dfrac{[\tilde{a}_i(f_0) - \tilde{b}_i(f_0)]}{\sqrt{Z_0}} \end{cases}$$

$$\begin{cases} \tilde{a}_i(f_0)_{(\sqrt{W})} = \dfrac{[\tilde{V}_i(f_0) + Z_0\tilde{I}_i(f_0)]}{2\sqrt{Z_0}} \\ \tilde{b}_i(f_0)_{(\sqrt{W})} = \dfrac{[\tilde{V}_i(f_0) - Z_0\tilde{I}_i(f_0)]}{2\sqrt{Z_0}} \end{cases}$$



$$\begin{cases} \Gamma_{in}(f_0) = \dfrac{\tilde{b}_1(f_0)}{\tilde{a}_1(f_0)} = \dfrac{Z_{in}(f_0) - Z_0}{Z_{in}(f_0) + Z_0} \\ \Gamma_{in}(f_0) = \dfrac{z_{in}(f_0) - 1}{z_{in}(f_0) + 1} \ \boldsymbol{with}\ z_{in}(f_0) = \dfrac{Z_{in}(f_0)}{Z_0} \end{cases}$$

$$Z_{in}(f_0) = Z_0\frac{1 + \Gamma_{in}(f_0)}{1 - \Gamma_{in}(f_0)}$$

$$\begin{cases} \Gamma_{load}(f_0) = \dfrac{\tilde{a}_2(f_0)}{\tilde{b}_2(f_0)} = \dfrac{Z_{load}(f_0) - Z_0}{Z_{load}(f_0) + Z_0} \\ \Gamma_{ch}(f_0) = \dfrac{z_{ch}(f_0) - 1}{z_{ch}(f_0) + 1} \ \boldsymbol{with}\ z_{ch}(f_0) = \dfrac{Z_{ch}(f_0)}{Z_0} \end{cases}$$

$$Z_{ch}(f_0) = Z_0\frac{1 + \Gamma_{ch}(f_0)}{1 - \Gamma_{ch}(f_0)}$$

$$\left.\begin{array}{l} \overline{P_{inc}(f_0)}_{(mW)} = \frac{1}{2}|\tilde{a}_1(f_0)|^2 \\ \overline{P_{ref}(f_0)}_{(mW)} = \frac{1}{2}|\tilde{b}_1(f_0)|^2 \end{array}\right\} \begin{array}{l} \overline{P_{in}(f_0)} = \overline{P_{inc}(f_0)} + \overline{P_{ref}(f_0)} = \frac{1}{2}|\tilde{a}_1(f_0)|^2 - \frac{1}{2}|\tilde{b}_1(f_0)|^2 \\ \overline{P_{in}(f_0)} = \frac{1}{2}|\tilde{a}_1(f_0)|^2\left(1 - \dfrac{|\tilde{b}_1(f_0)|^2}{|\tilde{a}_1(f_0)|^2}\right) \\ \boxed{\overline{P_{in}(f_0)} = \overline{P_{inc}(f_0)}(1 - |\Gamma_{in}(f_0)|^2)} \end{array}$$

$$\overline{P_{out}(f_0)}_{(mW)} = \frac{1}{2}|\tilde{b}_2(f_0)|^2 \text{ if } |\tilde{a}_2(f_0)| = 0$$

$$\overline{P_{DC}}_{(mW)} = \left|V_{GS0(V)}I_{GS0(A)}\right| + \left|V_{DS0(V)}I_{DS0(A)}\right|$$

$$\left.\begin{array}{l} \overline{P_{add}(f_0)}_{(mW)} = \overline{P_{out}(f_0)}_{(mW)} - \overline{P_{in}(f_0)}_{(mW)} \\ \boxed{G_p(f_0) = \dfrac{\overline{P_{out}(f_0)}_{(mW)}}{\overline{P_{in}(f_0)}_{(mW)}}} \\ G_p(f_0)_{(dB)} = \overline{P_{out}(f_0)}_{(dBm)} - \overline{P_{in}(f_0)}_{(dBm)} \end{array}\right\}$$

$$\boxed{PAE_{(\%)} = 100\frac{\overline{P_{add}(f_0)}_{(mW)}}{\overline{P_{DC}}_{(mW)}}}$$

Let us take this device as a "black box".

At a given working frequency f_o and for 1 bias point (V_{GSO}; V_{DSO}), 4 incident and reflected power waves are generally defined. $\tilde{a}_1(f_0)$, $\tilde{a}_2(f_0)$, $\tilde{b}_1(f_0)$ and $\tilde{b}_2(f_0)$.

In linear operating mode, the scattering matrix [S] is defined as:

$$[\tilde{b}(f_0)]=[S][\tilde{a}(f_0)] \quad (1)$$

II.2 Some Reminders concerning the power units

- International System of Units: Watt (W) ⇨ 1W = 1 J/s

- Units used in the microwave Domain :

Décibel (dBW) : $\boxed{A_{(dBW)} = 10\times\log_{10}\left(\frac{P_{(W)}}{P_{ref(W)}}\right)}$ $P_{ref(W)} = 1W$

Some key figures:

Ratio $\frac{P_{(W)}}{P_{ref(W)}}$	Decibel	Ratio $\frac{P_{(W)}}{P_{ref(W)}}$	Decibel
1	0	1000	30
2	3	2000	33
4	6	0.5	-3
10	10	0.1	-10
100	20	0.01	-20

Some Rules:

- $\times 2$ en linéaire ⇔ +3 dB
- $\div 2$ en linéaire ⇔ –3 dB
- $\times 10$ en lin. ⇔ +10 dB
- $\div 10$ en lin. ⇔ –10 dB

- Other Units used in the microwave Domain :

le dBm : $\boxed{A_{(dBm)} = 10\times\log_{10}\left(\frac{P_{(W)}}{P_{ref(W)}}\right)}$ $P_{ref(W)} = 1mW$

$$A_{(dBm)} = 10\log_{10}\left(\frac{P_{(W)}}{1}\times\frac{1}{1mW}\right) = 10\log_{10}\left(\frac{P_{(W)}}{1}\right) + 10\log_{10}\left(\frac{1}{1mW}\right)$$

$$A_{(dBm)} = A_{(dB)} + 10\log_{10}\left(\frac{1}{1}\times 10^3\right) = A_{(dB)} + 30\log_{10}\left(\frac{10}{1}\right)$$

$$\Rightarrow \boxed{A_{(dBm)} = A_{(dBW)} + 30dB}$$

Ratio $\frac{P_{(W)}}{P_{ref(W)}}$	dBm	Ratio $\frac{P_{(W)}}{P_{ref(W)}}$	dBm
1	30	0.5	27
2	33	0.1	20
4	36	0.01	10
10	40	0.001	0
100	50	0.002	3

- $\times 2$ en lin. ⇔ +3 dBm
- $\div 2$ en lin. ⇔ –3 dBm
- $\times 10$ en lin. ⇔ +10 dBm
- $\div 10$ en lin. ⇔ –10 dBm

III TEST BENCH

At low frequencies (up to few hundreds MHz), a probe is applied at any point in a circuit to measure the voltage and current at that point. This technique cannot be used to characterize a circuit operating at frequencies above 1 GHz without disrupting signal propagation in that circuit and, therefore, the operation of the circuit itself.

Thus, since conventional measurement of the voltage and current parameters of microwave circuits is not possible, other parameters such as incident and reflected power waves are used.

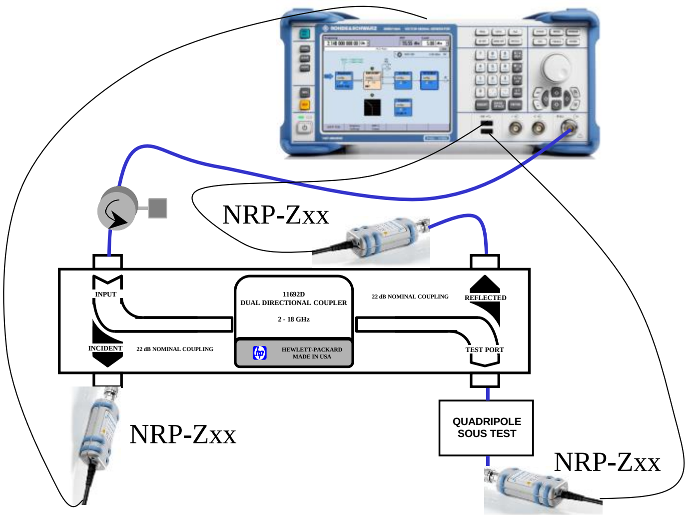
More precisely in this PW, we will measure two types of parameters:

- ☑ the absolute powers of these waves expressed in mW or dBm (milliwatts or dB milliwatts). (Absolute units).
- ☑ The power ratios of two waves expressed in decibels (dB): (Relative unit).

These measurements of power waves and wave ratio must be carried out without disturbing the device to be characterized. This is done by taking a fraction of the incident and reflected power waves along the transmission line connecting a generator to the device under consideration. The device that allows part of the incident and reflected waves to be simultaneously sampled along a line is called a reflectometer (or bidirectional coupler).

III.1 TEST BENCH PRESENTATION

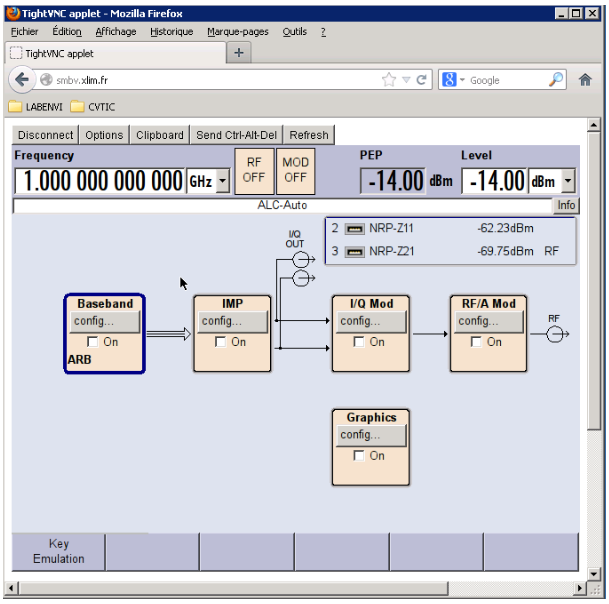
The test bench is the following one :



The coupler separates incident and reflected powers, the parts of which are taken to characterize the component to be measured.

The NRP-Zxx power probes detect the power level (use of fast diodes) and are connected directly to the SMBV100A on the USB ports: 2 at the front and one at the back. The power display is done directly on the SMBV 100A and is displayed directly in dBm or mW.

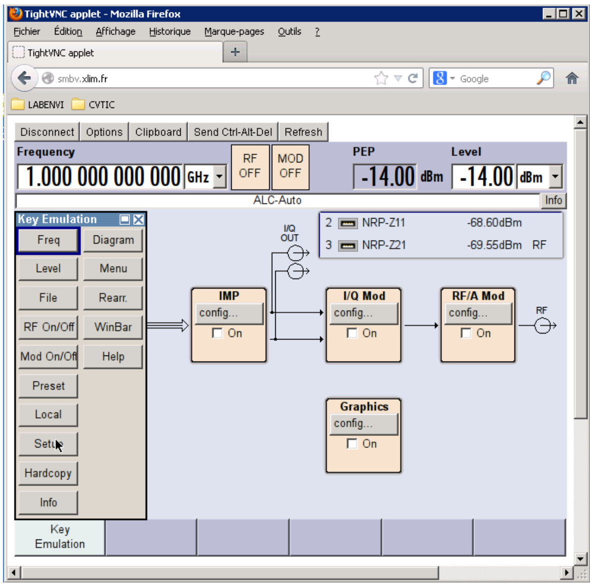
To view the front panel and work directly on the SMBV, use the application server and in a web client (firefox or ie), access the front panel by typing the URL given on the instrument. You are obtaining then the following front panel:

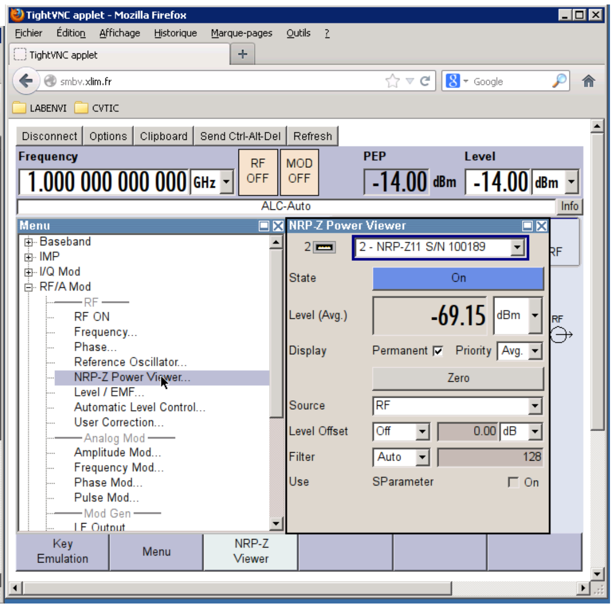


Locating correctly the probes, you will be able to fill the excel table given in your platform.

(Replace xx in NRP-Zxx with the values corresponding to your test bench).

To access the third probe, a right click on the mouse allows you to access a menu in which you must click on "setup" as follows:

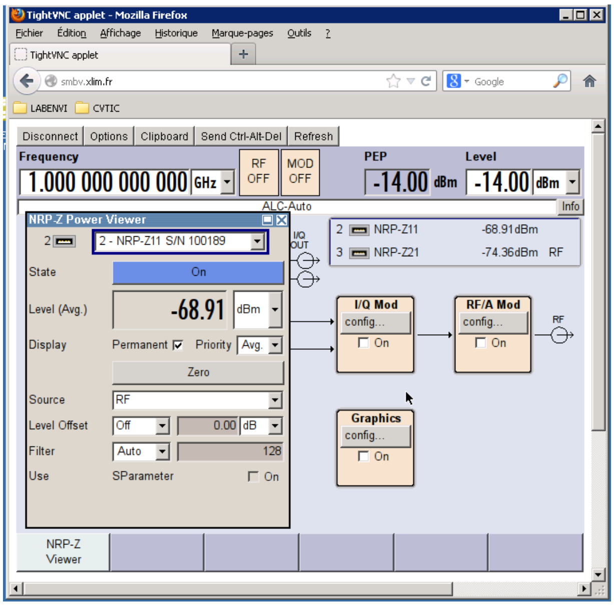




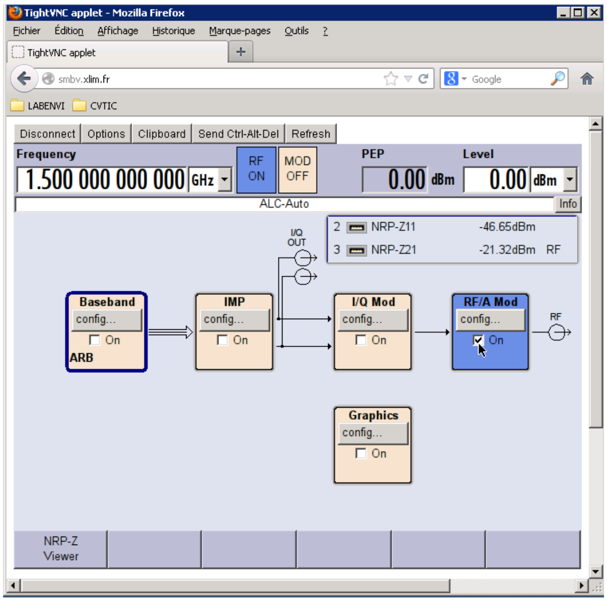
Then select the "RF/A Mod" menu and the NRP-Z Power viewer submenu.

Identify your three power probes and then complete the previous excel file to associate it with the measurement of the desired power waves.

Close the "setup" and "key emulation" menus and present your front panel as follows:



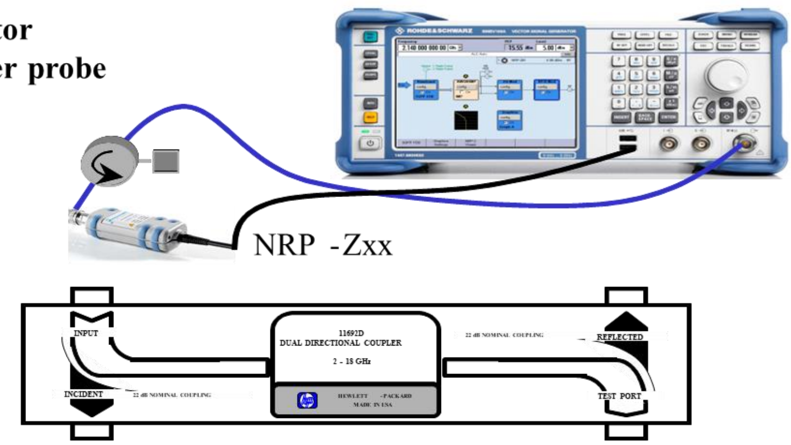
Adjust the RF level to 0 dBM and the frequency to 1.5 GHz and turn the RF ON as follows:



III.1.1 First Measurement: Power level at the input plane of the reflectometer.

Carry out the following assembly:

Disconnect the isolator
And Connect 1 power probe

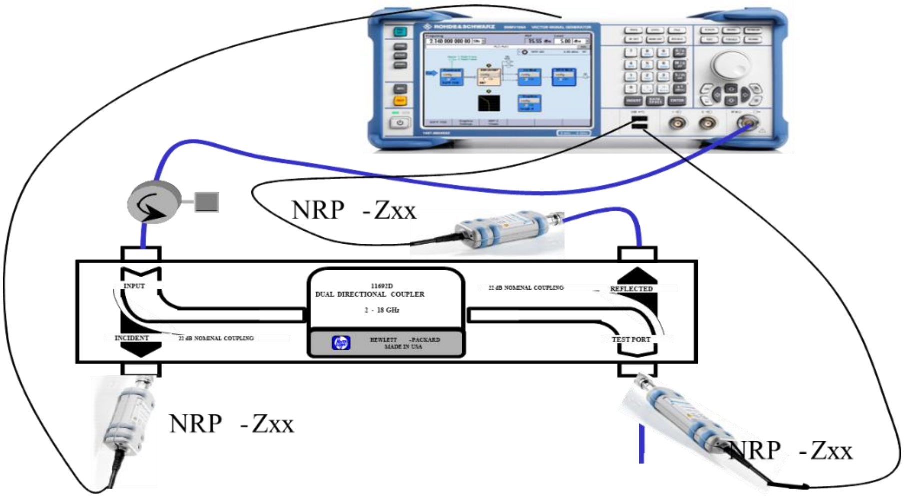


Fill the sheet “1.Delta Pgene” of the excel file given in your platform.

What can you calculate then about the coupler alone?

III.1.1 Second Measurement: Charcateristics of the reflectometer.

Carry out the following assembly:



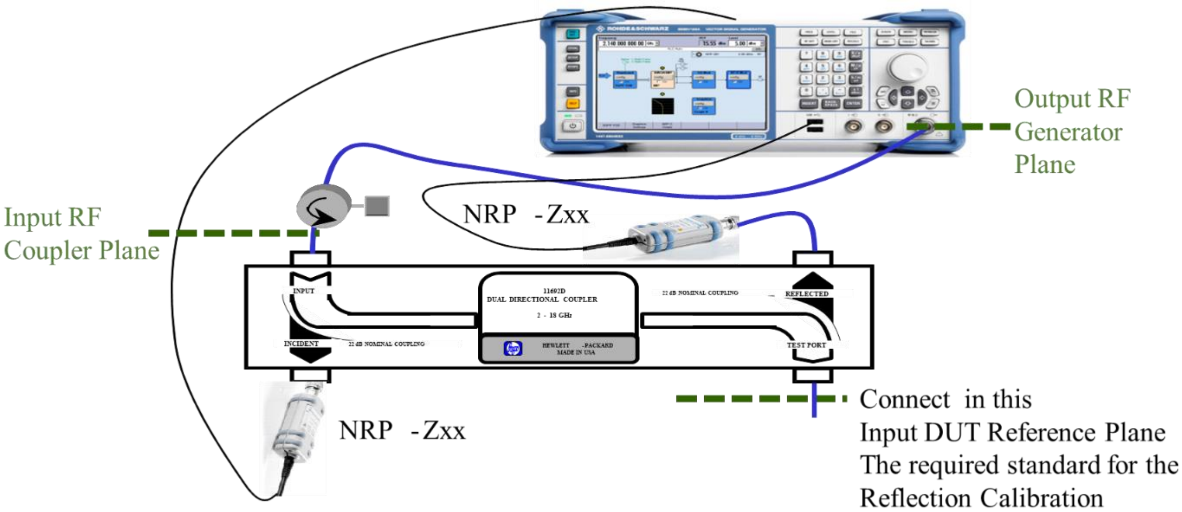
Fill the sheet “2.Caract Coupler” of the excel file given in your platform.

What are the characteristics of the coupler? Comments.

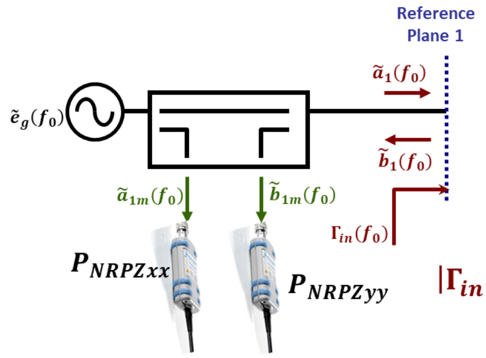
III.2 REFLECTION CALIBRATION.

With this calibration, we want to determine the reflection coefficient at the input of the device under test $|\boldsymbol{\Gamma}_{in}(\boldsymbol{f}_0)|$.

Carry out the following assembly:



The explanation of the reflection calibration is as follows:



$$\begin{cases} \frac{1}{2}|\tilde{a}_{1m}(f_0)|^2 = C_{inc}(f_0)\frac{1}{2}|\tilde{a}_1(f_0)|^2 \text{ with } C_{inc}(f_0) \text{ the incident coupling of the coupler} \\ \frac{1}{2}|\tilde{b}_{1m}(f_0)|^2 = C_{ref}(f_0)\frac{1}{2}|\tilde{b}_1(f_0)|^2 \text{ with } C_{ref}(f_0) \text{ the incident coupling of the coupler} \end{cases}$$

$$|\Gamma_{in}(f_0)|^2 = \frac{\frac{1}{2}|\tilde{b}_1(f_0)|^2}{\frac{1}{2}|\tilde{a}_1(f_0)|^2} = ???$$

$$|\Gamma_{in\_meas}(f_0)|^2 = \frac{\frac{1}{2}|\tilde{b}_{1m}(f_0)|^2}{\frac{1}{2}|\tilde{a}_{1m}(f_0)|^2} = \frac{\frac{1}{2}C_{inc}(f_0)|\tilde{b}_1(f_0)|^2}{\frac{1}{2}C_{ref}(f_0)|\tilde{a}_1(f_0)|^2} = \underset{??}{\mathrm{K}}\,|\Gamma_{in}(f_0)|^2$$

Coefficient we would like to determine

1°) <u>Réflexion Calibration</u>: To determine K => Use of a reference standard connected in Reference Plane 1
A short circuit is chosen to be sure to have a known value of:

$$|\Gamma_{in\_meas}(f_0)|^2 = \mathrm{K}|\Gamma_{in}(f_0)|^2 \Rightarrow |\Gamma_{in\_meas}(f_0)|^2 = \mathrm{K} \times 1 \Rightarrow \mathrm{K} = |\Gamma_{in_{meas}}(f_0)|^2 = \frac{P_{NRPZyy}}{P_{NRPZxx}}$$

2°) <u>Measure</u> : The Device Under Test can be know connected in Reference Plane 1:

$$|\Gamma_{in\_meas}(f_0)|^2 = \mathrm{K}|\Gamma_{in}(f_0)|^2 \Leftrightarrow |\Gamma_{in}(f_0)|^2 = \frac{|\Gamma_{in\_meas}(f_0)|^2}{\mathrm{K}} = \frac{\frac{P_{NRPZxx}}{P_{NRPZyy}}}{\mathrm{K}}$$

Fill the sheet "3.Cal reflexion" of the excel file given in your platform.

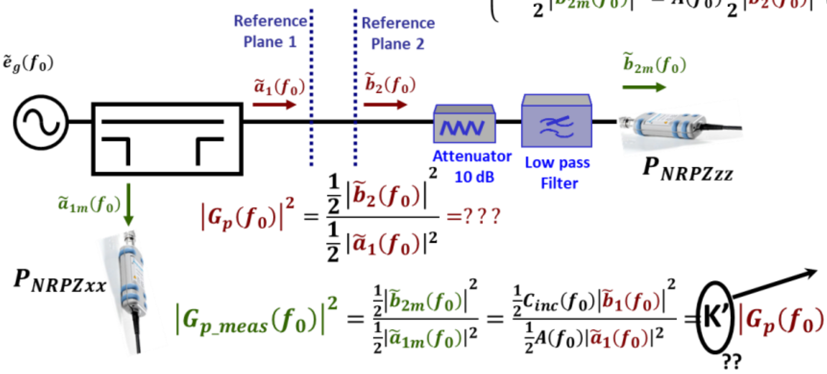
Measure the SWR of the unknown device provided by the teacher.

III.1 TRANSMISSION CALIBRATION.

With this calibration, we want to determine the Power Gain of the DUT (Device Under Test).

Explain the role of the Low Pass filter at the output of the device under test. Do the same with the attenuator.

$$\begin{cases} \frac{1}{2}|\tilde{a}_{1m}(f_0)|^2 = C_{inc}(f_0)\frac{1}{2}|\tilde{a}_1(f_0)|^2 \text{ with } C_{inc}(f_0) \text{ the incident coupling of the coupler} \\ \frac{1}{2}\left|\tilde{b}_{2m}(f_0)\right|^2 = A(f_0)\frac{1}{2}\left|\tilde{b}_2(f_0)\right|^2 \text{ with } A(f_0) \text{ the attenuation of the output path} \end{cases}$$



$$|G_p(f_0)|^2 = \frac{\frac{1}{2}\left|\tilde{b}_2(f_0)\right|^2}{\frac{1}{2}|\tilde{a}_1(f_0)|^2} = ???$$

$$|G_{p\_meas}(f_0)|^2 = \frac{\frac{1}{2}\left|\tilde{b}_{2m}(f_0)\right|^2}{\frac{1}{2}|\tilde{a}_{1m}(f_0)|^2} = \frac{\frac{1}{2}C_{inc}(f_0)\left|\tilde{b}_1(f_0)\right|^2}{\frac{1}{2}A(f_0)|\tilde{a}_1(f_0)|^2} = K'|G_p(f_0)|^2$$

1°) <u>Transmission Calibration</u>: To determine K » => Use of a reference standard connected between the 2 Reference Planes
A Thru (Length=0) is chosen to be sure to have a known value of:

$$|G_{p\_meas}(f_0)|^2 = K'|G_p(f_0)|^2 \Rightarrow |G_{p\_meas}(f_0)|^2 = K' \times 1 \Rightarrow K = |G_{p\_meas}(f_0)|^2 = \frac{P_{NRPZzz}}{P_{NRPZzz}}$$

2°) <u>Measure</u> : The Device Under Test can be know connected between the 2 Reference Planes :

$$|G_{p\_meas}(f_0)|^2 = K'|G_p(f_0)|^2 \Leftrightarrow |G_p(f_0)|^2 = \frac{|G_{p\_meas}(f_0)|^2}{K'} = \frac{\frac{P_{NRPZzz}}{P_{NRPZxx}}}{K'}$$

Fill the sheet “4.Cal Transmission” of the excel file given in your platform.

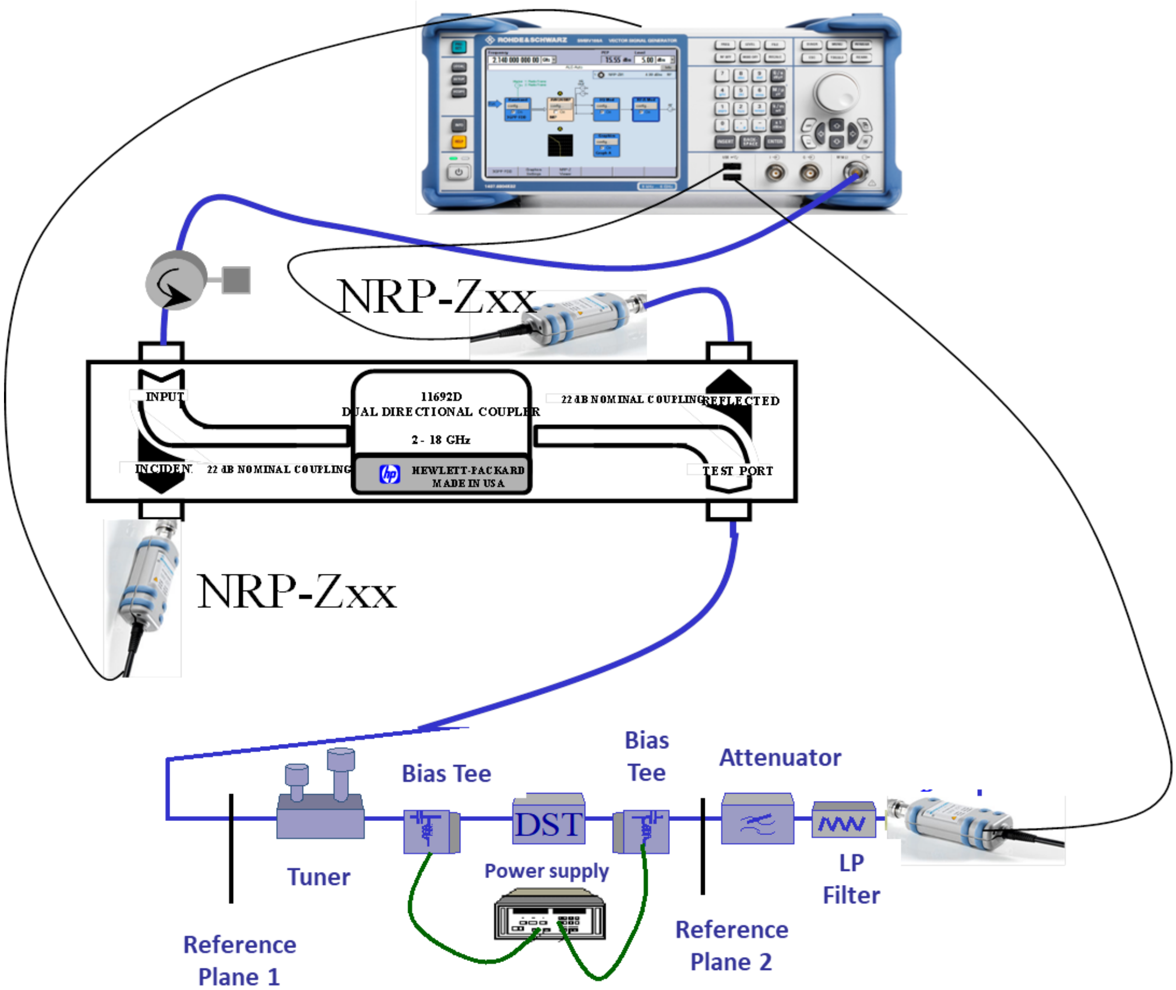
Measure the Power Gain of the unknown device provided by the teacher. Comments.

III.2 FET CHARACTERIZATION.

The microwave transistors used in this manipulation are the AsGa FLU17XM FET whose main characteristics sheet is given in the platform.

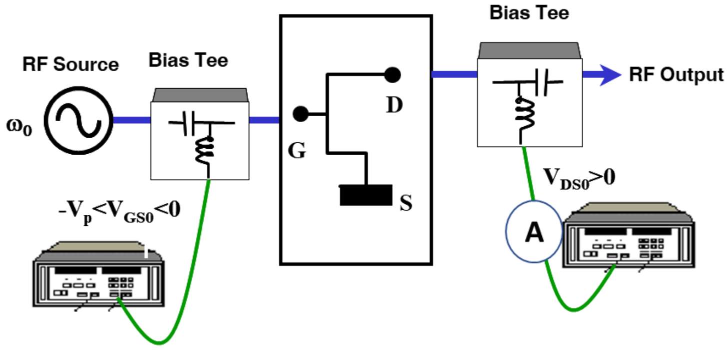
Set the microwave source to position 1 RF -OFF 1 after setting the power level to -20 dBm.

Then carry out the following assembly:



III.2.1 FET Biasing.

A classical bias scheme of a field effect transistor is as follows:



The DC Block capacitances and the DC Feed Inductances are embedded into the bias tee.

It is FUNDAMENTAL to correctly bias the transistor according to a methodology that will be described to you during the session.

The following tasks should be performed in the process:

1. Check the polarity of the power supplies: Vgs < 0 and Vds > 0
2. Common Ground to both power supplies.
3. Adjust the short circuit currents for the gate and the drain
4. - Adjust the power supply voltages before connecting them to the TEC at the values :
5. VGS0 = 0V and VDS0 = 0 V
6. - Connect the gate power supply to the TEC.
7. - Connect the drain supply to the TEC.
8. - Increase the gate voltage first to the selected value, depending on the transistor and the polarization class
9. - Increase the drain voltage secondly to the desired value.

MANDATORY !!!: Do not increase V_{DSO} when V_{GSO}=0V. The avalanche on the static characteristic at V_{GSO} =0V is sudden and irreversible.

To depolarize the transistor, perform the following tasks in order:

- Decrease V_{DS0} to 0 V and then decrease V_{GS0} to 0V.
- Disconnect the drain and fate polarizations respectively
- Switch off the power supplies.

MANDATORY: Turn off the power supplies before disconnecting the TEC...

In all cases, ask first the teacher to define and justify the limits of the potential source power variations without risk of deterioration of the FET.

III.2.2 Measurement of the Power Characteristics of the FET

Implement the measurement and plotting of the following characteristics for the class A operating mode when the transistor is unmatched.:

Pout=f(Pin) in mW

Padd=f(Pin) in mW

PAE=f(Pin) in %

Fill the sheet “5.Measure FET” of the excel file given in your platform.

At 3 dB Gain Compression, use the tuner to match the input of the transistor. How do you know that the transistor is matched? Explain.

Fill the sheet “5.Measure FET” of the excel file given in your platform for the match transistor.

Repeat the measurements for the class AB operating mode when the transistor is unmatched (tuner reinitialized) and after matching.