Experiment 1

SLOTTED LINE MEASUREMENT.

Experiment 1

Objective:

- Familiarization with the waveguide bench.
- Measurement of standing wave distribution on a slotted line with short-circuit and open-circuit terminations.
- Measurement of guide wavelength λ_g and the frequency *f*.
- Plot of dispersion diagram (ω-β plot).
- Finding the internal broadside dimension, *a* of the waveguide.
- Measurement of VSWR of a load.

Theory:

Cavity wavemeter:

A calibrated cavity frequency meter (wavemeter) is used in the microwave bench for frequency measurement. The cavity frequency meter consists of a high-Q cylindrical cavity resonator whose effective length may be varied by a movable short-circuit plunger. Resonant frequency of the cavity is determined by its dimensions and the permittivity of the dielectric inside the cavity. The position of the plunger is indicated on a dial. Scale of the dial is calibrated in terms of frequency. The cavity is so designed that it resonates in a particular mode only in the desired frequency range. The cavity is coupled to the waveguide by an iris. The resonant cavity behaves as a narrowband bandstop filter. Power propagation through the waveguide is interrupted when the frequency of electromagnetic wave flowing down the guide matches with the resonant frequency of the cavity and a dip is obtained in the VSWR meter. Be sure to detune the wavemeter after frequency measurement to avoid amplitude fluctuations that may occur when the wavemeter is set to the operating frequency.

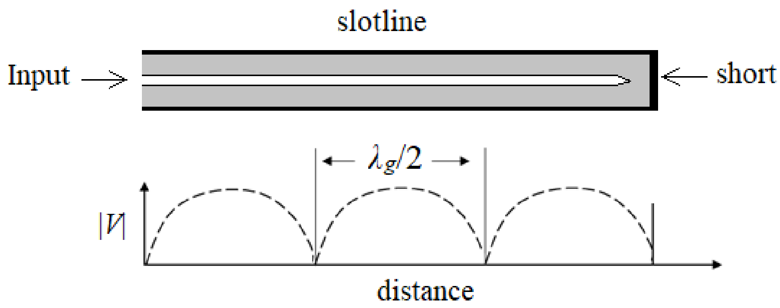


Fig.1 Standing wave distribution inside a waveguide with short-circuit termination.

Standing wave distribution:

If a transmission lines is terminated with an impedance not equal to its characteristic impedance, the termination is said to be 'not matched' to the line. Electromagnetic waves traveling down the line are partially or wholly reflected from the termination. Total reflection occurs when the terminal impedance is not dissipative, i.e. a short, open or reactive termination. Standing waves are the result of two wave trains of equal wavelength incident and reflected along the line in opposite directions (Fig. 1).

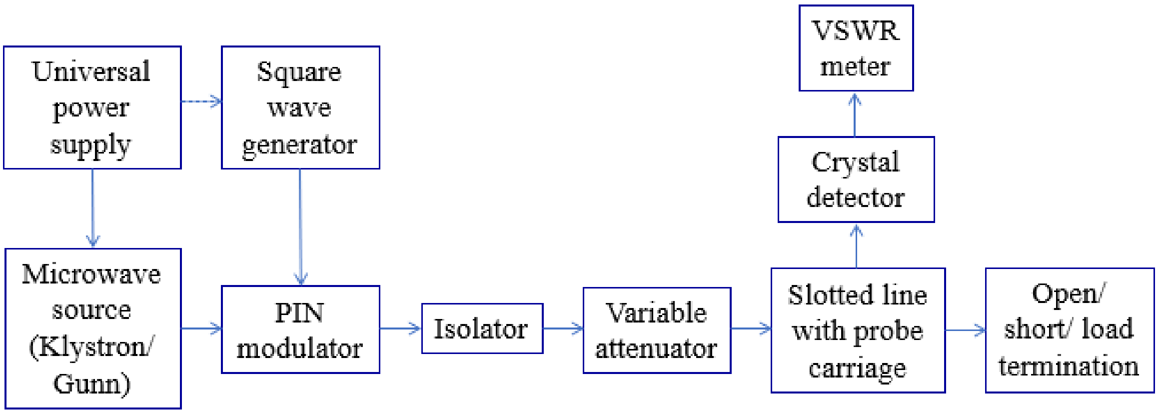


Fig. 2 Test bench set up to measure standing wave distribution.

Slotted line with probe carriage:

A block diagram of the experimental set up is shown in Fig. 2. The source may be a square wave modulated Klystron or a Gunn oscillator. The slotted line probe carriage carries a coaxial electric probe to sample the electric field inside the slotted line. The voltage induced in this probe is approximately proportional to the electric field inside the waveguide. A general rule in slotted line measurements is to use minimum penetration of the sampling probe. The power picked up by the probe causes a distortion in the standing wave pattern. The effect on the pattern is greater as the probe penetration is increased. This can be explained by considering the probe as an admittance shunting the line. Therefore, the effect is maximum at the position of V_{max}. The probe induced voltage is applied to the crystal detector (Schottky barrier junction) having square law response. The crustal sits inside the tunable coaxial tube. The crystal output corresponding to the modulation frequency (generally 1 kHz) is fed to a VSWR meter.

VSWR meter:

A VSWR meter is a narrowband high gain linear amplifier, usually tuned at a frequency of 1 kHz. Typical sensitivity is 0.2 μV at 200 Ω (in some cases 200 kΩ) input impedance for full scale deflection. The reading is proportional to incident power. Since the crystal has a square law characteristic only for small powers, the amplifier should be set at almost full gain so that as small a power as possible gives full scale reading on the meter. This can easily be checked by decreasing the power level with the attenuator and verifying that the power reading (in dB) indicated on the SWR meter drops by the same amount. If it does not, reduce the received power level by reducing the penetration depth of the probe. Alternatively, the power level can be reduced at the source. But it is usually best to work with a minimum probe depth, and maximum source power to maintain a good signal to noise ratio.

The VSWR meter can be used to measure a standing wave ratio as a direct reading or as a decibel reading to be converted to SWR. VSWR measurement steps are given below.

- Peak the VSWR meter (i.e. move needle to right) by adjusting the modulation frequency of the signal source, if adjustable.
- Peak the reading by tuning the probe detector (impedance tuning by length of the coaxial tube).
- Peak the VSWR meter by moving the probe along the slotted line.
- Adjust GAIN and VERNIER of VSWR meter and/or output power from signal source to obtain a SWR reading of exactly 1.0.

- Move the probe along the line to a voltage minimum (needle moves to left). Do not retune probe or detector once set to 1.0.
- Choose an appropriate scale. For example, if the needle is to the left of 3.2 (out-of-scale) on the 1 to 4 SWR scale, change the RANGE switch to the next 10 dB position above the initial setting. The SWR is then indicated directly on the 3.2 to 10 dB scale. For a reading between 1 and 1.3 on the 1 to 4 SWR scale, change the EXPAND switch to 0.0. This SWR segment is then expanded to full scale and the reading is taken from the 1 to 1.3 dB scale.

Frequency and wavelength:

The distance between successive minima of a standing wave pattern determines the half wavelength $\lambda_g/2$ on the line. For the TE_{10} mode, the guide wavelength λ_g is related to the free space wavelength λ_0 by

$$\lambda_g = \frac{\lambda_o}{\left[1-\left(\frac{\lambda_o}{2a}\right)^2\right]^{1/2}}, \qquad (1)$$

which can be expressed as

$$\frac{1}{\lambda_g^2} = \frac{1}{\lambda_0^2} - \frac{1}{4a^2}, \qquad (2)$$

and the frequency f is

$$f = \frac{c\left(\lambda_g^2 + 4a^2\right)^{1/2}}{2a\,\lambda_g}, \qquad (3)$$

where a is the larger internal dimension of the guide and c is the velocity of light in free space. For a lossless line the phase constant β is

$$\beta = \frac{2\pi}{\lambda_g}. \qquad (4)$$

High VSWR by double minimum method:

The voltage standing wave ratio of a transmission line terminated in a load is defined as

$$VSWR = \frac{V_{\max}}{V_{\min}}, \qquad (5)$$

where V_{max} and V_{min} are the voltage magnitude at the maxima and minima of voltage standing wave distribution. When the VSWR is high (≥5), the standing wave pattern will have a high maxima and low minima. Since the square law characteristics of a crystal detector is limited to low microwave power, an error is introduced if V_{max} is measured directly. This difficulty can be avoided by using the 'double minimum method' in which measurements are taken on the standing wave pattern near the voltage minimum. The procedure consists of first finding the value of voltage minima. Next two positions about the position of V_{max} are found at which the output voltage is twice the V_{min} value. If the detector response follows square law, VSWR is given by

$$VSWR = \left[1 + \frac{1}{\sin^2\left(\frac{\pi d}{\lambda_g}\right)} \right]^{1/2}, \qquad (6)$$

where λ_g is the guide wavelength and d is the distance between the two points where the voltage is $2V_{min}$.

Apparatus:

1. Klystron/Gunn power supply.
2. Klystron Mount (2K25 Reflex klystron) or Gunn mount.
3. Isolator.
4. Cavity wavemeter.
5. Variable attenuator.
6. Waveguide Slotted Section with carriage and untuned probe.
7. Two waveguide-to-coaxial adaptors.
8. One detector mount.
9. One shorting plate.

Procedure:

1. Set up the test bench along with the other instruments as shown in Fig. 2 with short-circuit termination.
2. Before switching on any instrument familiarize yourself with the operation of each unit and consult instruction manuals, wherever necessary.
3. Set the controls of the power supply for rated electrode voltage of the Klystron/ Gunn.
4. Switch on all the instruments and wait for about 20 minutes before recording any data.
5. Adjust the square wave modulation amplitude so that the detector output is maximum.
6. Tune the probe for maximum sensitivity by adjusting the tuning plunger on the slotted line.
7. Tune the wavemeter until a maximum fall in the square wave output amplitude is obtained. Note down the frequency reading.
8. Switch the probe output of the slotted line to the pre-amplifier, slide the probe carriage along the slotted line and accurately locate the positions of minima on the scale of the slotted line. The minima are best located by finding the positions corresponding to equal but small power levels on either side of the desired minima. The average of the two positions represents the positions of the true minimum. Since the distance between adjacent minima is equivalent to half the guide wavelength, the value of λ_g is directly obtained.
9. Find the value of λ_g from slotted line and f from the cavity wavemeter for each setting of the mechanical tuner of the Klystron/ Gunn (8-10 readings over a wide frequency range).
10. In a table compare calculated λ_g from (1), measured λ_g, calculated f by (3), measured f by the wavemeter.

11. Repeat the above steps for open-circuit termination.
12. Plot β/k_0 vs. f, where $k_0 = 2\pi/\lambda_0$.
13. Plot $1/\lambda_g^2$ vs. $1/\lambda^2$ (= f^2/c^2) and hence find the value of a. Compare the value of thus obtained with the actual value of 0.900” ± 0.002” for the WR-90 waveguide.

Measurement of high VSWR:

1. Connect the load to the end of the slotted line.
2. Locate a position of V_{min} on the slotted line. Adjust the VSWR meter gain to some reference value say, 3 dB.
3. Move the probe along the slotted line on either side of V_{max} so that the reading is 3 dB below the reference i.e. 0 dB. Record the probe positions and obtain the distance between the two positions. Determine the VSWR using equation (6).

Sample questions:

- If the excitation of the waveguide is changed to TE_{mn} mode, can we continue with this set up?
- Why is the guide wavelength always greater than the free-space wavelength?
- What is the cut-off wavelength for the TE_{10} mode of WR-90 guide?
- Show that only TE_{10} mode would propagate in WR-90 guide in the frequency range 8.20 GHz to 12.4 GHz.
- How would you assure yourself that RF power leakage is negligible?
- What is the effect of the probe depth?
- Why is the 10 dB attenuator inserted in the generator side of slotted line?
- Why the slot is cut in the centre of the waveguide not off-centre?
- Why detector is required to have a square law response?
- Why the Klystron/Gunn source is square wave modulated?

REFERENCES:

1. E.L. Ginzton, *Microwave Measurement*.
2. D. M. Pozar and E. J. Knapp, *Microwave Engineering Laboratory Notebook*, 2004.

Experiment 2

CHARACTERISTICS OF GUNN DIODE

Experiment 2

Objective:

- Study the effect of bias variation on diode current and frequency.
- The effect of mechanical tuning on oscillator output power.
- Measurement of pushing figure.

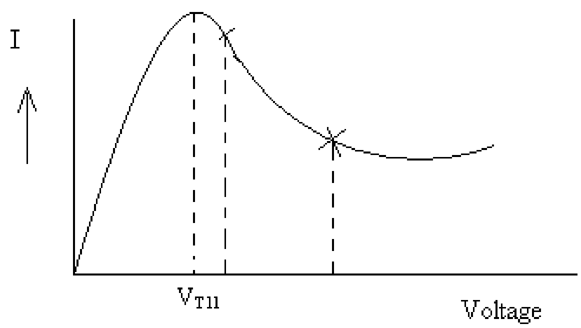


Fig1. Voltage-current characteristic of a Gunn diode.

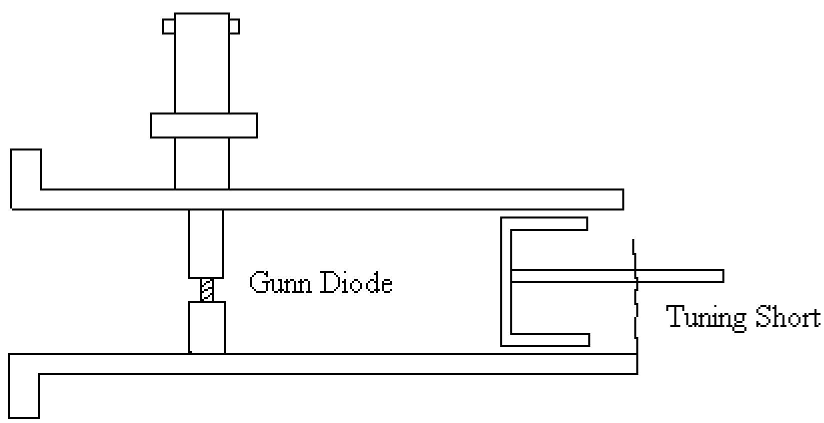


Fig 2. A tunable Gunn oscillator.

Theory:

Gunn diode:

Gunn diode is an example of a transferred electron device (TED). In the Gunn diode, two regions are heavily *n*-doped on each terminal. A thin layer of lightly *n*-doped material in the middle called the active region. It therefore does not conduct in only one direction and cannot rectify alternating current like a conventional diode with a *pn* junction. Its largest use is in electronic oscillators to generate microwave signal. The working principle is based on the "Gunn effect" discovered in 1962 by physicist J. B. Gunn. Some group III-V semiconductor materials like GaAs behaves as a normal semiconductor material at low electric field but shows negative resistance at high electric field (hot electron). Negative resistance is a special property of the Gunn diode in which an increase in voltage across the device's terminals results in a decrease in current. Unlike a positive resistance that consumes power from current passing through it, a negative resistance produces power, amplifying it.

GaAs has two conduction bands, known as lower and upper valleys. Electrons in the lower valley have high mobility, small effective mass, and low density of state. When a voltage is applied to the device, the electrical gradient is largest across the thin middle layer. If the voltage is increased, the current through the layer first increases, but eventually, at higher field, more electrons are transferred to the upper valley increasing its resistivity and causing the current to fall. The conductive property of the middle layer is altered. Thus, a Gunn diode has a region of negative differential mobility which results in different slope in its current-voltage characteristic curve as shown in Fig. 1. This negative resistance property allows it to amplify, functioning as a radio frequency amplifier, or to become unstable and oscillate when it is biased with a DC voltage.

The negative differential mobility gives rise to a space charge instability and is responsible for the formation of high field domains in Gunn devices when a suitable DC voltage is applied across the diode. High field domains originate near the cathode and drift across the sample towards the anode. The transit time of these ‘domains’ determines the periodicity of the external current waveform when the circuit is resistive. When the diode is placed in a resonant circuit, various modes of operation are possible depending upon the relationship between transit time frequency and the frequency of the resonant circuit.

Gun diode oscillator used in the laboratory employs a device mounted in the waveguide. The schematic of an X-band waveguide oscillator is shown in Fig. 2. In this oscillator, the cavity consists of a waveguide section with a movable short circuit at one end and the diode at the other end. The movable short can be continuously moved by turning the tuning knob and thus changing the oscillation frequency.

Procedure:

1. Set up the experiment as shown in Fig. 3 with the attenuator at maximum attenuation.
2. Connect the power supply to Gunn oscillator.
3. Connect the bolometer and the laptop.
4. Turn on the power supply with its main switch.

Voltage versus current characteristic:

i) Measure the diode current as a function of bias voltage. Do not exceed 9 volts.
ii) Plot bias voltage V and diode current I.
iii) Determine the threshold voltage V_{th} and the corresponding maximum current.

Frequency tuning:

1. Bias the Gunn oscillator at 9 volts.
2. Tune the Gunn oscillator frequency to approximately 9 GHz by tuning the tuning knob. Measure the frequency and power output.
3. Tune the Gunn oscillator at various frequencies and measure the corresponding output power (8-10 readings over a wide frequency band).
4. Note down the screw reading for each frequency point.
5. Plot power output versus frequency.

Pushing Figure:

Pushing figure is a measure of frequency sensitivity against variation in voltage for an electronically tuned oscillator. It is defined as the incremental change in frequency with the increasing voltage. Its unit is MHz/Volt. Pushing figure may be either positive or negative.

Tune the Gunn oscillator frequency to approximately 10 GHz. Note down the frequency. Adjust the bias at 8 V. Now vary the bias by about 0.5V and measure the frequency again. Determine the pushing figure.

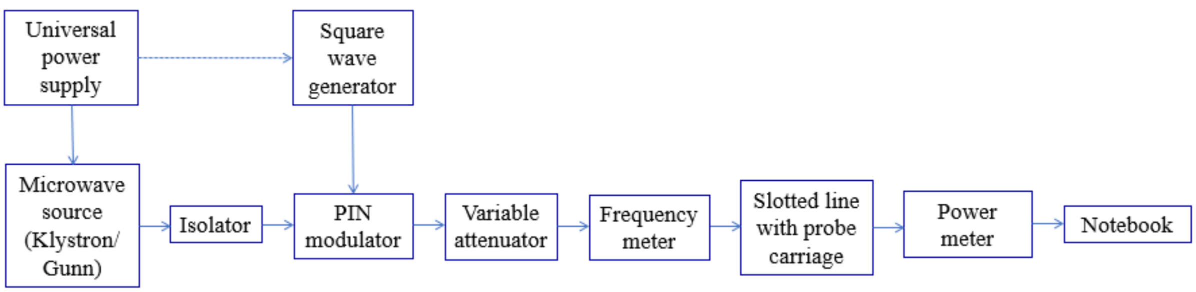


Fig. 3 Measurement set-up.

Experiment 3

CHARACTYERISTICS OF AN ANTENNA

Experiment 3

Objective:

- To study input impedance matching of an antenna.
- To study the radiation characteristics of an antenna.

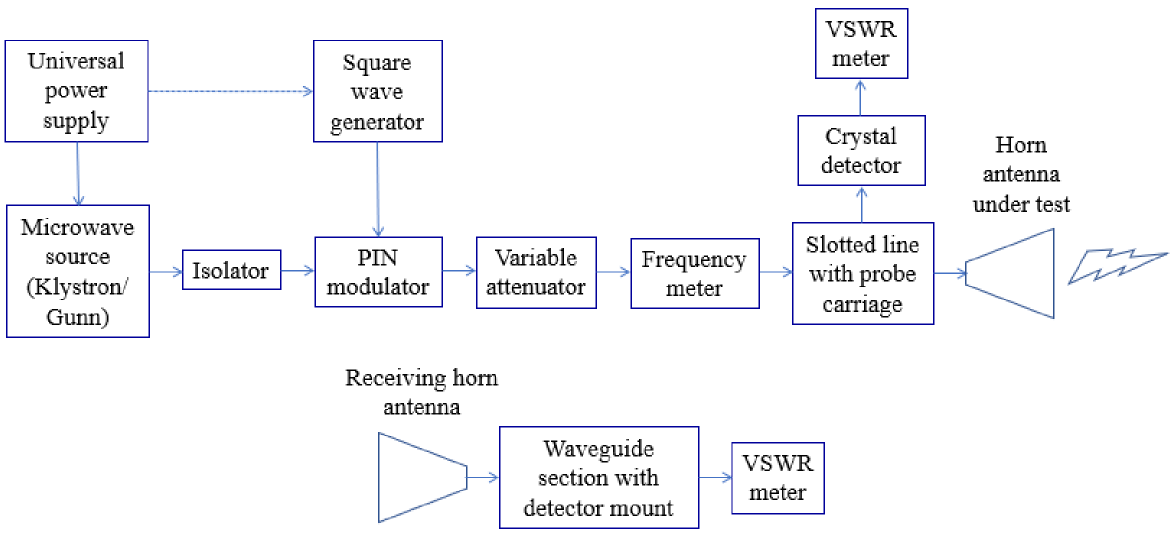


Fig. 1 Measurement set-up for the horn antenna.

Theory: Refer to page number 1-4 in the simulation study.

Procedure: (horn antenna)

Input impedance matching:

1. Set up the experiment as shown in Fig. 1.
2. Connect the power supply to Klystron.
3. Adjust the Klystron repeller voltage for maximum reading in the VSWR meter.
4. Adjust the square wave modulation amplitude so that the detector output is maximum.
5. Tune the probe for maximum sensitivity by adjusting the tuning plunger on the slotted line.
6. Tune the wavemeter until a maximum fall in the square wave output amplitude is obtained. Note down the frequency reading.
7. Off-tune the wavemeter. Determine the VSWR of the antenna (see experiment 1).
8. Change the Klystron frequency by the tuning screw and repeat steps 3-7 for 8-10 frequency reading.
9. Convert VSWR to reflection coefficient (dB) and plot it versus frequency.

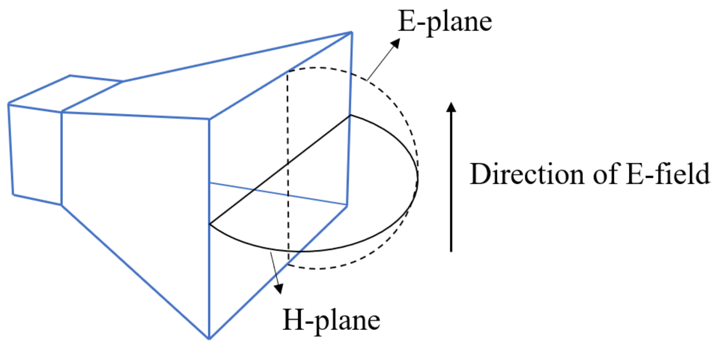


Fig. 2 E- and H-planes of the horn antenna under test.

Radiation pattern:

1. Align the receiving horn at 0^o direction. Both the antenna under test and the receiving horn should be in the same polarization, say H-plane.
2. Set the Klystron at the mid-band frequency, say 10 GHz.
3. Follow steps 3-6 for maximum reading in the VSWR meter with the attenuator at maximum attenuation (at least 30 dB).
4. Connect the VSWR meter to the receiving horn antenna.
5. Tune the screw connected at the detector mount of the receiving antenna for maximum reading in VSWR meter.
6. Move the receiving horn to the right in 5° steps up to at least 70°. Note down the power reading for each step. (Received power is maximum at 0^o direction. Use the corresponding VSWR meter reading as the reference. Now decrease attenuation to obtain the same reading for the new position of receiving horn. Thus, change in attenuation provides the change in received power in dB).
7. Plot relative received power versus angle.
8. Next, use 90^o twist for both the antennas and repeat the same for E-plane.
9. From the plots, determine 3 dB beamwidths at the two planes.

Boresight gain:

1. Align the receiving horn at 0^o direction.
2. Change the Klystron frequency by the tuning screw and repeat steps 3-7 in the first section.
3. Measure the relative received power at 8-10 frequency points.
4. Plot relative gain versus frequency.
5. Expression for approximate gain is

$$G = \frac{4\pi r}{\lambda_0}\sqrt{\frac{P_r}{P_t}} \text{ dB.}$$

Experiment 4

Objective:

- To study the D.C. characteristics of a Schottky barrier junction.
- To study a detector based on Schottky barrier diode.

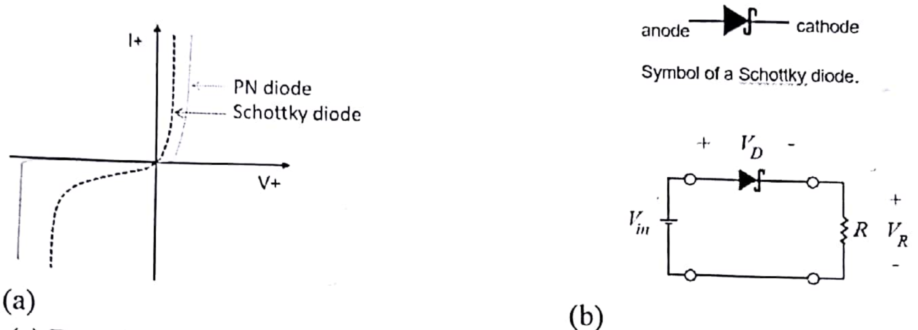


Fig. 1 (a) D.C. characteristics of a Schottky diode, and (b) the circuit used to obtain the D.C. characteristics.

Theory:

A Schottky diode is a special diode using the Schottky barrier due to the junction of a metal and a semiconductor. The junction has no space-charge region. Therefore, offers very low capacitance. It also has low forward voltage. The Schottky diodes are popularly used to design fast switches, microwave power detector, mixer, and multiplier at high microwave to terahertz frequencies. The principle of diode detection relies on rectifying the signal (AC component) through a diode and generating voltage as DC component. The detection makes use of the non-linear characteristic of the Schottky diode. So, a bias circuit may not be necessary. Then, it is called a zero bias detector. Fig. 1(a) shows typical response of a Schottky diode. Fig. 1(b) shows the circuit to obtain the D.C. characteristics. Current in the reverse bias condition is several orders higher than a conventional *pn*-junction diode. However, the forward voltage is much smaller, which makes it suitable to detect low microwave signal.

Fig. 2(a) shows a zero bias detector circuit. It does not require any D.C. power supply for its operation. When a microwave signal is applied to its input, a D.C. voltage is generated at the output. The voltage varies with the input power. Fig. 2(b) shows response of a detector circuit. The detector behaves as square law device i.e. output voltage proportional to the square of input voltage for small input power. A key parameter for a diode detector is the slope of the transfer curve, which is called sensitivity of the detector γ, generally expressed in mV/μW. In the square law region, γ is usually constant when plotted against P_{in} (dBm). The sensitivity γ can be controlled by external bias current. It is also a function of temperature.

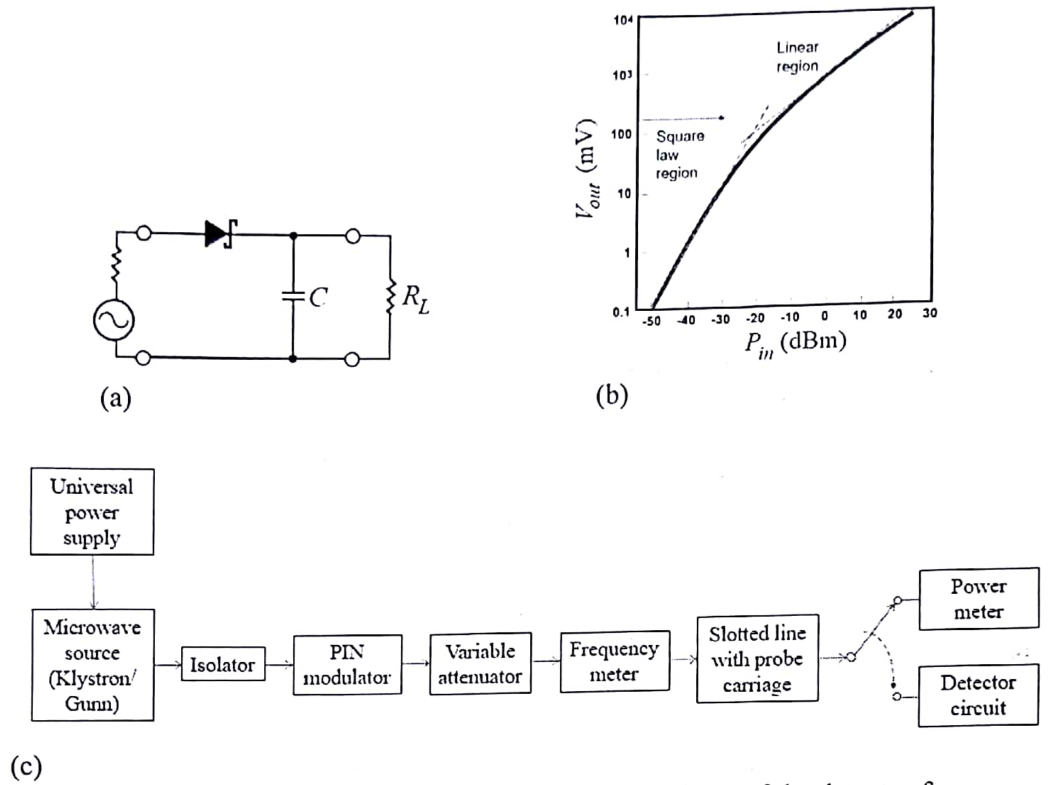


Fig. 2 (a) A simplified detector circuit, (b) output voltage of the detector for a continuous-wave input signal, (c) measurement set up to calibrate the detector.

Procedure:

D.C. characteristics:

1. Note down the maximum voltage and current rating of the diode.
2. Connect a variable D.C. voltage source as shown in Fig. 1(b).
3. Obtain both the forward and reverse bias characteristics as shown in Fig. 1(a).

Detector calibration:

1. Set up the measurement set up as shown in Fig. 2(c). Here, the PIN modulation is not required.
2. Connect the power meter and adjust the source frequency to the specified frequency of the detector circuit.
3. Note down the power reading shown by the power meter. Now replace the power meter by the detector circuit.
4. Vary the input power level by the calibrated attenuator and repeat the above step for 10-12 readings over -30 dBm to +10 dBm input power.
5. Obtain a plot as shown in Fig. 2(b).
6. Calculate and plot the diode sensitivity vs. P_{in} (dBm).

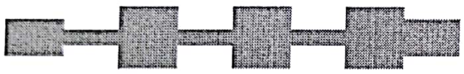
Experiment 5

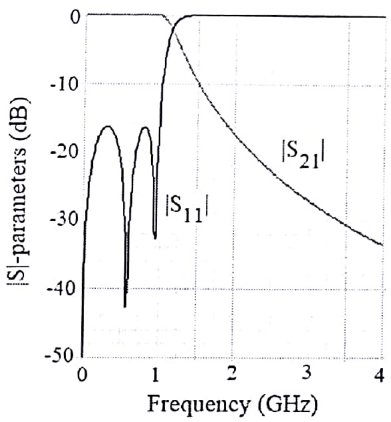
CHARACTERISTICS OF PASSIVE COMPONENTS

Experiment 5

Objective:

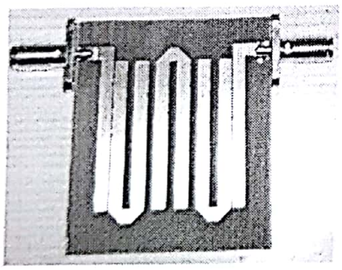
- To calibrate a vector network analyzer (VNA).
- To study the complex scattering (S) parameters of the given passive networks.

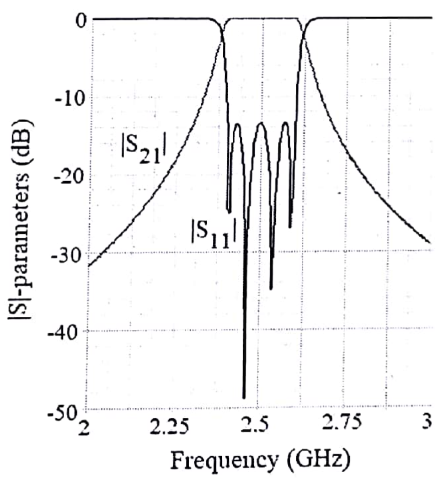




(a) (b)

Fig. 1(a) Layout of a hi-lo lowpass filter and (b) its ideal response.





(a) (b)

Fig. 2(a) Photograph of a hairpin band pass filter and (b) its ideal response.

Theory:

The complex scattering parameters of passive and active networks are measured with a vector network analyzer (VNA). A VNA has a two-channel or four-channel microwave receiver, RF source, and internal computing system to process the magnitude and phase of the transmitted and reflected waves from the network under test. The RF source is usually set to sweep over a specified bandwidth. A four-port reflectometer samples the incident, reflected, and transmitted RF waves. A switch allows the network to be driven from either port 1 or port 2. Four dual-conversion channels convert these signals to IF frequencies (in KHz or MHz), which are then detected and converted to digital form. An internal computer is used to calculate and display the magnitude and phase of the S-parameters or other quantities like SWR, return loss, group delay, impedance, etc. derived from these data. The time-domain response of the network can be obtained by calculating the inverse Fourier transform of the frequency-domain data.

An important feature of the VNA is the substantial improvement in accuracy made possible with error-correcting software. Error is caused by mismatch, imperfect directivity, loss, and variations in the frequency response of the internal components of the VNA as well as external components like cables and connectors. The calibration process determines the error terms, requires a test system consisting of a VNA, cables, and generally a test fixture, and is performed by sequentially making measurements using calibration standards. These calibration standards are one-port and two-port networks such as a 50 Ω matched load, open, short, and through with known characteristics. A full 2-port reflectivity and transmission calibration involves determination of 12 possible systematic error terms. The most common method for correcting for these involves measuring a short, open, and load standards on each of the two ports, as well as transmission between the two ports using a through. The acronym is SOLT. The test port must have the same type of connectors (N-type, 3.5 mm etc.). The SOLT calibration method is suitable for coaxial measurements, where it is possible to obtain the short, open, load and through.

Filters:

A filter is a two-port network used to control the frequency response in an RF or microwave system by providing transmission at frequencies within the passband and attenuation in the stopband of the filter. Typical frequency responses include low-pass,

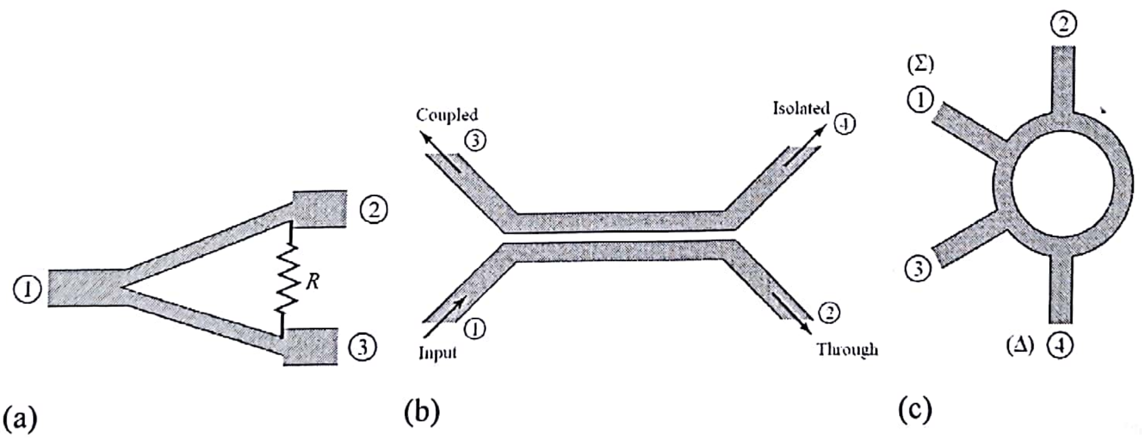
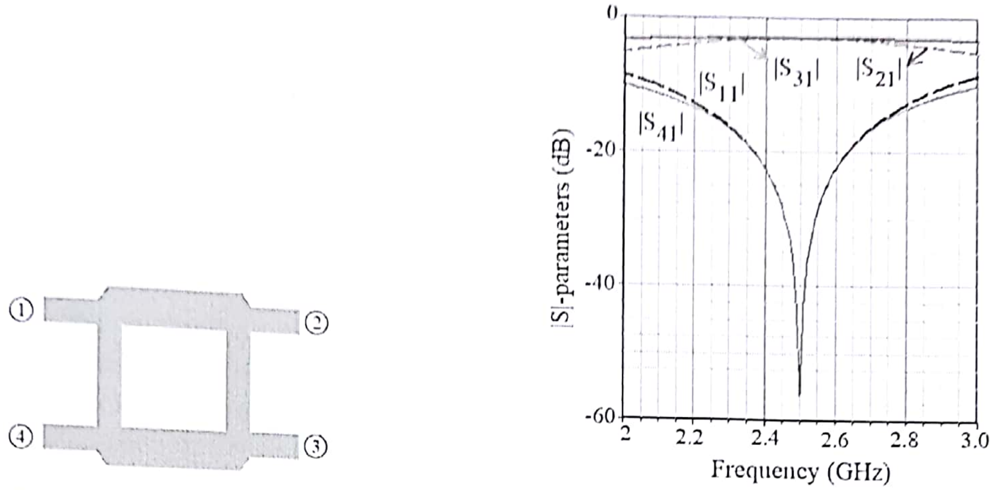


Fig. 3 Microstrip line layout of a (a) Wilkinson power divider, (b) directional coupler, and (c) 180° hybrid coupler.



(a) (b)

Fig. 4(a) Microstrip line layout of a quadrature hybrid coupler and (b) its ideal response.

high-pass, bandpass, and band-reject characteristics. Filter design usually involves a rigorous network synthesis, called the insertion loss method, which provides a specified frequency response for a given application. Fig. 1 and 2 show typical lowpass and band pass filter in microstrip technology and their responses. Important parameters of a filter are bandwidth of the filter, insertion ($20 \log_{10}|S_{21}|$ dB) and return ($20 \log_{10}|S_{11}|$ dB) losses in the passband, out of band attenuation ($20 \log_{10}|S_{21}|$ dB), and group delay variation ($\tau_d = -\Delta\text{angle}(S_{21})/\Delta\omega$ ns) within the specified bandwidth. The bandwidth is usually defined by the passband over which ripple value remains constant (e.g. 0.1 dB equal ripple passband).

Power divider and couplers:

Wilkinson power divider:

Among the RF power dividers, 3 dB equal-split Wilkinson power divider is the most popular power divider. It can be made with arbitrary power division. The phase difference between the output ports of a power divider is always zero. The S-parameters of a Wilkinson power divider at the design frequency is

$$[S] = \frac{1}{2}\begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix}.$$

Coupled-line directional coupler:

Coupled-lines directional couplers are a four port device consist of input port, coupled-port, through-port and isolated port. Most of the input power is available at the through port. The phase difference between the through- and coupled-ports at the design frequency is 90°. They are assumed to operate in the TEM mode, and often implemented in planar technology like stripline, microstrip line, coplanar waveguide, or slotline structures. Coupled transmission lines can support two distinct propagating modes, called the even-mode and odd-mode. The S-parameters of an ideal directional coupler is

$$[S] = \begin{bmatrix} 0 & \alpha & j\beta & 0 \\ \alpha & 0 & 0 & j\beta \\ j\beta & 0 & 0 & \alpha \\ 0 & j\beta & \alpha & 0 \end{bmatrix}.$$

where are α and β are non-zero real numbers.

Rat-race coupler:

The 180° hybrid coupler also known as rat-race hybrid coupler is a four-port network with an 180° phase shift between the two output ports. It can also be operated so that the outputs are in phase. With reference to the 180° hybrid shown in Fig. 3, a signal applied to port 1 will be evenly split into two in-phase components at ports 2 and 3, and port 4 will be isolated. If the input is applied to port 4, it will be equally split into two components with an 180° phase difference at ports 2 and 3, and port 1 will be isolated. When operated as a combiner, with input signals applied at ports 2 and 3, the sum of the inputs will be formed at port 1, while the difference will be formed at port 4. Hence, ports 1 and 4 are referred to as the sum (sigma) and difference (delta) ports, respectively. The scattering matrix for the ideal 3 dB 180° hybrid has the following form:

$$[S] = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

Quadrature hybrid coupler:

Quadrature hybrids are 3 dB directional couplers with a 90° phase difference between the outputs of the through and coupled arms. It is also known as the branch-line coupler. Fig. 4 shows the layout of a quadrature hybrid in microstrip form and its ideal response. The S-parameters of the coupler is

$$[S] = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}.$$

Caution:

The VNA is one of the most expensive instruments. Handle with care. Note that all the connectors has a movable part. Only turn this movable parts so that there is no rotational movement of the inner conductors. When connecting the cables it should not provide any pressure on the PCB circuit. Otherwise, it can tear out the SMA connector and the microstrip layout. While handling the microstrip line based circuit, do not touch the circuit layout. Just hold the connectors.

Procedure:

VNA calibration:

1. Set the frequency scale to a suitable range, e.g. 1-3 GHz. Set the display setting to Smith chart.
2. Open calibrate full two port - SOLT.
3. Start calibration using the standard short, open, load and through.
4. After calibration, check the accuracy of calibration by connecting the through. It should show the $|S_{11}|$ as a single point at the center of the Smith chart. Change display setting to log-magnitude. Now the phase of S_{21} should be zero over the range of frequency.

Measurement of the passive devices:

1. After calibrating the VNA, connect the devices one by one.
2. Any unused port should be terminated with a matched load (50 Ω).
3. Save the measurement data (complex S-parameters) in a pen-drive.

Calculations:

Filter: Plot the insertion loss and calculate the 3 dB bandwidth of the filter. Plot return loss in the same figure. Plot the group delay τ_d and calculate the maximum delay variation within the 3 dB passband.

Couplers: Plot $|S_{11}|$, $|S_{21}|$, $|S_{31}|$, and $|S_{41}|$. Next, plot the amplitude imbalance ($|S_{21}|-|S_{31}|$) and the phase imbalance $\angle S_{21}-\angle S_{31}$. The frequency range for the plots can be set as $f_0\pm0.5$ GHz. Calculate bandwidths under the following conditions: 20 dB return loss, 20 dB isolation, ±0.5 dB amplitude imbalance, $\pm5^\circ$ phase imbalance. For the rat-race coupler, the measurement has to be repeated for the delta port i.e. plot $|S_{44}|$, $|S_{24}|$, $|S_{34}|$, $|S_{14}|$, ($|S_{24}|-|S_{34}|$), and ($\angle S_{24}-\angle S_{34}$).

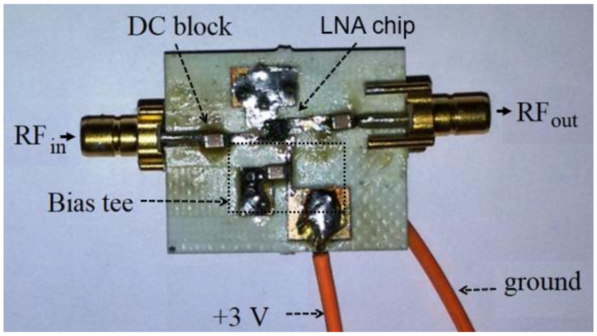
Experiment 6

CHARACTERISTICS OF A LOW-NOISE AMPLIFIER

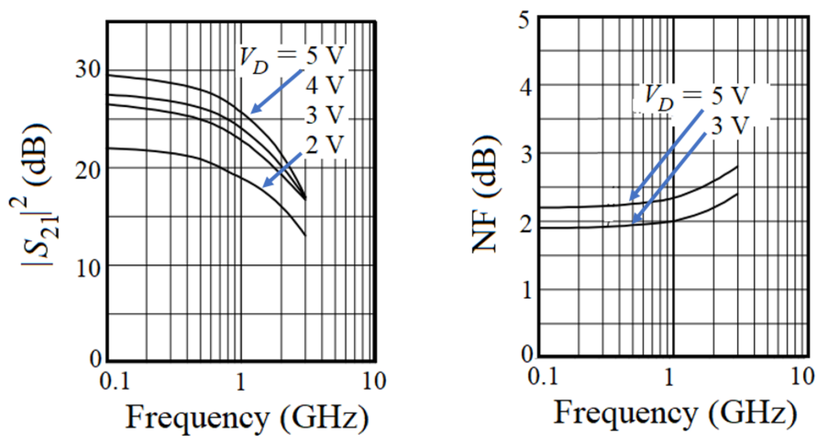
Experiment 6

Objective:

- To study the small signal S-parameters of a low-noise amplifier (LNA).
- To study the 1 dB compression point of a LNA.
- To study the noise figure of a LNA.



(a)



(b)

Fig. 1 (a) A photograph of the LNA with biasing scheme and (b) its measured characteristics.

Theory:

A LNA is a special RF amplifier that amplifies a very week signal without significantly degrading its signal-to-noise ratio (SNR). An amplifier increases the power of both the signal and the noise present at its input. LNAs are designed to minimize additional noise. It is used as the first component after antenna in a RF receiver chain. Sometimes, other conditions like gain, impedance matching are compromised for minimum noise. The design steps involves choosing an appropriate amplifier topology, and selecting low-noise biasing conditions. Fig. 1 shows a LNA and variation of its responses with the bias voltage.

Noise and Noise Figure (NF):

Noise power is a result of random processes such as the voltage generated between the terminals of a device or component due to the random motions of charges or charge carriers in the device. All components in a microwave system generate noise. Noise also enters from external source. Among different types of noise, the thermal noise due to the thermal vibration of bound charges at a temperature above absolute zero is the most basic source of noise. The noise level of a system sets the lower limit on the strength of a signal that can be detected in the presence of the noise.

The thermal noise is modeled with a Thevenin equivalent circuit consisting of a noiseless resistor R and a generator with a *rms* voltage $v_n = \sqrt{(4kTBR)}$, where $k = 1.380 \times 10^{-23}$ J/K is the Boltzmann's constant, T = the temperature in degrees kelvin (K), B = the bandwidth of the system in Hz. Then, maximum power delivered from the source to a matched load is kTB, independent of the resistance value. An antenna when connected to a LNA delivers signal as well as noise. Noise is also generated inside the LNA. Thus, input SNR of a LNA is more than the output SNR.

Noise figure (NF) and noise factor are measures of degradation of the SNR caused by a component. The noise factor is defined as the ratio of actual output noise to that which would remain if the device itself did not introduce noise, i.e.

$$\text{Noise factor } (F) = \frac{\text{Input SNR}}{\text{Output SNR}}.$$

While measuring the input SNR, the input noise is attributed to thermal noise produced at a standard noise temperature T_0 = 290 K. Noise figure is the noise factor in decibel scale i.e. $\text{Noise figure } (NF) = 10\log_{10}(F) = SNR_{in}(dB) - SNR_{out}(dB)$.

Absolute maximum rating of BGA427H6327XTSA1 (LNA chip):

- Device current I_D = 25 mA
- Device voltage V_D (+V) = 5 V (suggested operating range = 3 to 4 V)
- Total power dissipation at T_S = 120°C, P_{tot} = 150 mW.
- RF input power P_{RFin} = -10 dBm (suggestion: do not cross -15 dBm)
- Junction temperature T_j = 150°C.

Procedure:

Scattering parameters:

1. Set the VNA power level to -20 dBm (Caution: The LNA provides gain. Therefore, $|S_{21}|$ dB is positive. The VNA may be damaged if you don't set the VNA power to a low level).
2. Calibrate the VNA over 0.1-3.0 GHz.
3. Connect the LNA to VNA.
4. Switch on D.C. supply of the LNA and wait for 5 min.
5. Measure and plot the S-parameters ($|S_{11}|$, $|S_{22}|$, $|S_{21}|$, and $\angle S_{21}$).

1 dB compression points:

1. Connect the LNA input to a RF source (Signal Generator).
2. Connect the LNA output to a Spectrum Analyzer.
3. Set the signal frequency at 2.0 GHz.
4. Switch on the LNA D.C. power supply and wait for 5 min.
5. Vary the input power level over -70 dBm to -15 dBm. Note down both input and output powers for 10-15 steps and plot it. (Caution: Do not increase the input power level above -15 dBm, otherwise you will burn the device).
6. Repeat the measurement at 1.0 GHz and 3.0 GHz.

NF measurement (approximate method):

1. Fix the centre frequency of measurement as 2.0 GHz. Set the resolution bandwidth of the Spectrum Analyzer to minimum available value (e.g. 1 KHz).
2. The output of the LNA is connected to the input of the spectrum analyzer with its input terminal shorted with matched load.
3. Measure the output noise power (P_{NOFF} dBm) by using the averaging option in the Spectrum Analyzer without the D.C. bias*.
4. Now, switch on the D.C. bias and again measure the noise power (P_{NON} dBm).
5. Then, NF = P_{NON} -P_{NOFF} dB.
6. Repeat the measurement at 1.0 GHz and 3.0 GHz.
7. Calculate the theoretical noise power as below and compare it with the measured P_{NOFF}.

   $$P_{Nout} = -174 \text{ dBm/Hz} + 10\log_{10}\left(\text{B.W.}\right) + Gain.$$

   *N.B.: The averaging option may not work if the sensitivity of the spectrum analyser is not below the calculated P_{Nout}. Then, collect the measured data and obtain the averaging in MATLAB.