DE LORENZO

Engineering Training Solutions

DL 2594N

MICROWAVE TRAINER

USER MANUAL

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Preface

The microwave radio communications network plays a very important role in current times. Higher frequency signals travel across the ionosphere, but experience distortion, which decreases with frequency. Microwave signals, well above the ionospheric cut-off, are hardly affected at all, at sufficiently small power levels. For these reasons, microwaves are utilized for satellite communications and space transmissions. The innovative technologies are used to make an advanced telecommunication system as a major trend asks for it. To answer the increasingly diversified needs for training in this wide telecommunication system management, a few important training programs have been developed.

The DL 2594N trainer has been designed to start with a few related concepts providing in-depth coverage of the basic topics related to the propagation of the microwave electromagnetic field through rectangular metal guides, as well as the interaction between the microwave field and various conductive or dielectric environments.

The set of experiments then builds on the knowledge gained by the student through these basic courses to provide training in more advanced topics such as electromagnetic field, microwave propagation through wave guides, the conditions in which the phenomena of stationary wave, reflected wave, resonance and attenuation occur along the propagation direction.

The destination of the designed trainer

1. The DL 2594N trainer is dedicated, first of all, to the people with some electromagnetism and telecommunications background who want to understand the use of the devices and of the telecommunication technologies in ultra-high frequencies.

2. Secondly, it can be used also as a trainer by people with basic technical knowledge, if they understand the main physical phenomena that occur in the propagation of the electromagnetic field of microwave when it is directed by metal wave guides.

3. The DL 2594N trainer exemplifies step by step, in a logical sequence, the role of each component used in the electronic circuits in the microwave field, as well as the role of the measuring apparatuses used in the quantitative evaluation of the main physical magnitudes and in the study of the propagation of the microwave electromagnetic field, through the elements that make up the microwave installations.

4. With the provided documentation, the user is able to continue or to develop new applications of the trainer.

5. As it can be seen, by having in the laboratory such complex experiments, teachers, instructors, or any other people involved in education and training can design their own teaching plan in different fields of education - from the basics of the microwave propagation study up to the telecommunication technologies in ultra-high frequencies.

About This Manual

Safety considerations

Safety symbols that may be used in this manual and printed on the equipment are listed and explained in the Safety Symbols table next to this paragraph.

Safety procedures related to the tasks that you will be asked to perform are indicated near each laboratory experiments.

Make sure that you have all the basic notions about how to handle and assemble each of the components in the kit, as well as the physical protection measures at accidental exposures to the electromagnetic field of microwave. You should never perform a task, if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Prerequisite

As a prerequisite to this trainer, you should have read and understood the sections:

- that show each component in the kit used to study the microwave field,
- the microwave signal source;
- the power meter;
- the frequency selective amplifier;
- the DL 2594PS Power sensor.

You are expected to have a basic knowledge about electrical measurements.

Systems of units & Standards

Units are expressed using the International System of Units (SI).

To the Instructor

You will find in this manual all the elements included in the experimental chapters together with the guidance to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions for helping you to guide the students through their learning process.

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1. Composition, Operation & Maintenance.

This first theoretical part conveys a basic knowledge on the physics of microwaves.

Microwaves are generated by a microwave signal source (DL 2594N device) and their propagation in conjunction with rectangular waveguides (DL 2594.1 to DL 2594.14) is examined in detail.

- Characteristics of the electromagnetic waves
- Crystal detector
- Recording a current-voltage characteristic
- Transmission line theory and line variables
- Wave propagation in waveguides
- Standing waves, short-circuits, reflection and matching
- Standing-wave ratio
- Power reduction and thermal load
- Measuring waveforms in waveguides with the aid of a slotted line
- TE, TM and hybrid waveguides
- Waveguide dimensions and operating frequency
- Dielectrics in a waveguide

Prerequisites for working successfully through this first theoretical part include:

- Knowledge of DC and AC technology
- Knowledge of DC and AC technology
- Fundamentals of transmission line theory: equivalent circuit diagram for an electrical transmission line and quantities per unit length
- Physics of wave propagation
- Understanding of complex numbers expressed using "j"

1. The training kit DL 2594N Waveguide Experiment System.

The microwave radio communications network plays a very important role at present times. The EM propagation within the ionosphere is similar to that in a waveguide. Signals at frequencies lower than 10-40 MHz (cutoff frequency) are partially or totally reflected. This property is used to realize multiple reflection links at short waves. Higher frequency signals travel across the ionosphere, but experience distortion, which decreases with frequency. Microwave signals, well above the ionospheric cut-off, are hardly affected at all, at sufficiently small power levels. For these reasons, microwaves are utilized for satellite communications and space transmissions. Communication links (both terrestrial and with orbiting satellites) with high capacities are thus possible. The various atmospheric components (oxygen, nitrogen, water vapor, carbon dioxide) and the many elements in suspension (water droplets, ice crystals, dust, and smoke) do not significantly affect signals having frequencies smaller than about 10 GHz. Higher frequency signals, however, experience several unwanted effects: absorption, depolarization and scintillation. The effective reflection area (radar cross-section, scattering cross-section) of an object depends in a very sensitive manner on the ratio of the object's size to the wavelength. When the reflecting element is much smaller than the wavelength, the reflection becomes vanishingly small.

The superior characteristics of a microwave system come from the fact that the microwave frequencies have highly directional propagation properties which are similar to those of light. Also, the high degree of noise immunity of the microwave frequencies in the atmosphere makes the microwave communication the top choice in long distance communications.

The DL 2594N waveguide experiment system kit for training, a very effective learning tool on the properties of microwave frequencies, offers a variety of experiments centered around the key components involved in the microwave frequency oscillation, transmission through antenna, and reception at the receiver

Basic components included in DL 2594N waveguide experiment system:

1. Microwave signal source	11. Directional Coupler
2. Variable Attenuator	12. Magic-Tee (or Hybrid-Tee)
3. Fixed Attenuator	13. Waveguide Straight Section
4. Slotted Line	14. Shorting Plate
5. Frequency Meter	15. Matched Termination
6. Crystal Detector	16. Power sensor
7. Crystal Detector	17. Reflector
8. Slide Screw Tuner	18. Power meter
9. Horn Antenna (2 pieces)	19. Frequency selective amplifier (SWR meter)
10. Coaxial adapter (2 pieces)	20. BNC cable with two sockets (2 pieces)

Attention !

1) Screw the nuts carefully without using force !!!

2) Insert the connectors in the correct position so that the control key matches; do not force the coupling because you risk damaging the pin connector.

3) Buttons and switch levers will be easy to operate without force.

4) The rotary knobs of the potentiometers will be twisted slightly without force.

5) Using other types of connection cables, other than those in the DL 2594N measurement devices, is not recommended.

6) It is strictly forbidden to accidentally spill liquids or store heavy objects on the DL 2594N devices and/or components !

2. Technical Descriptions of the Components used in DL 2594N

2.1. Microwave signal source

2.1.1. Summary

The DL 2594N is a new generation of microwave signal generator, based on digital controlled phase locked loop, with high frequency stability and low phase noise. It has two signal output modes, continuous wave mode and amplitude shift keying mode. A built-in 400Hz~4KHz square wave modulation signal is available for the setting by users. The output frequency range from S band to Ku band can be chosen by customers.

The DL 2594N microwave signal generator uses an LCD display. It has characteristics like: rapid response, clear display. With the front panel, the user can manually control the signal frequency, the power settings and other instructions; its superior performance can meet the requirements of radar, communications, radio and television broadcasting and other communication fields. It can also fully meet the experiment demand of a 3cm waveguide system.

2.1.2. Technical Indicators

Index	Parameters (typical)
Frequency Range	8-12GHz
Frequency Stability	1ppm
Frequency step	1MHz
Power Range	-10dBm~+10dBm
Power Accuracy	±2dB
Power Step	1dB
Phase Noise	≤-70dBc/Hz@10kHz
Spurious Power	≤-20dBc(harmonic stray)
Modulation	Inner square wave 400Hz~4KHz (1Hz step)
Temperature Range	0 ~ 40°C
Storage Temperature	-40 ~ 70°C
Power Consumption	50W
Size and Shape	330×260×105mm
Weight	About 5kg

2.1.3. Operating Mode

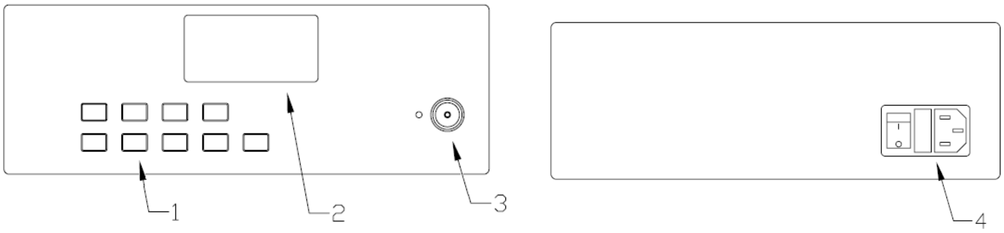
This device can operate in two distinct ways:

a. continuous wave output mode - in the continuous wave output mode, the signal source output is sent out directly without carrier signal modulation;

b. amplitude shift keying output mode - in the amplitude keying output mode, the signal source output is modulated by a carrier set by the user. The modulation frequency can be set in this mode through the panel.

2.1.4. Control Description and Function Introduction

Description (Figure)



Function

The panel.	Function
(1) Keyboard	Used to set the output signal frequency, power, mode of operation, the RF output status information.
(2) LCD	Used to display output signal frequency, power, mode of operation, the RF output status information.
(3) RF Output	Microwave signal output 8-12GHz through a N connector, when the light emitting diode beside the connector is on, the RF output signal is sending out. It is controlled by the RF output key in the keyboard.
(4) Power Plug Fuse Power Switch	AC 110 ~ 220V, 50Hz/60 Hz; 250V/1A For power on/off the signal generator.

KeyBoard	Function
[FREQ]	This key is to set the output signal frequency; press this button to enter the frequency setting mode.
[AMP]	This key is to set the output power, press this button to enter the power setting mode.
[MODE]	This key is for setting the signal output mode: 1, continuous wave mode; 2, amplitude shift keying mode, the amplitude keying mode can set the frequency of the modulating signal.
[▲ ▼ ◀ ▶]	The direction key to select and change the parameters step by step.
[RF]	To enable or disable the output RF signal.

User guide

Precautions and warnings

(1) Before using this equipment, you should carefully read the instructions and operations in the user manual;

(2) The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components in this instrument;

(3) The instrument can be more stable after 5 minutes of preheating after initialization.

Operating instructions

(1) **Power on the instrument**: connect the power cable (110 ~ 220 V, AC), turn on the power switch, the instrument enters into the initialization process. When the initialization is completed, it enters into the working state.

(2) **Key function instructions**: The front panel has 9 keys, [FREQ], [AMP], [MODE], [ ], **[▲ ▼ ◄ ►]**, [RF].

A - Output signal frequency setting

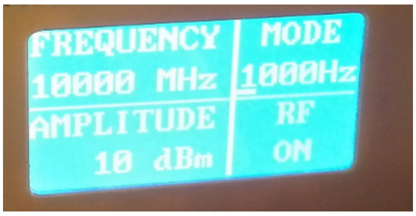
When you need to set the output frequency, press the [FREQ] key to enter into the frequency setting mode and then through the **[▲ ▼ ◄ ►]** four selection button to set the required frequency. **[◄ ►]** two keys are applied to choose the current bit of frequency, **[▲ ▼]** keys are applied to increase or decrease the current number of current bit.

B - Output power setting

When you need to set the output power, press the [AMP] key to enter into the frequency setting mode and then through the **[▲ ▼ ◄ ►]** four keys to set the required power; the power range is from -10 dB to 10 dB, the minimum step is 1 dB.

C - Model selection and carrier frequency setting

The RF output model of the generator has two kinds: 1, continuous wave output mode, the LCD upper right part displays “CW”; 2, amplitude shift keying output, the LCD upper right part displays the carrier frequency;



the output mode can be changed by the [MODE] key. When in the amplitude keying output mode, through the [▲ ▼ ◀ ▶] keys you set the required carrier frequency.

D - RF output control

Press [RF], the output RF output signal can be enabled or disabled by pressing the [RF] key.

E - [ ] is reserved for future functions.

2.1.5. Packing list

List First page, Total 1		
Model	Unit	Quantity
DL2594N RF Signal Generator	set	1
Accessories	Unit	Quantity
Power cable	Piece	1
Fuse	Piece	1
User’s Guide	Piece	1

2.2. Power Meter

2.2.1. Overview

The power meter is a microwave power measurement instrument to measure continuous wave's power. The instrument is composed of digital LED display, keypad, signal input connector, instrument panel, power supply socket (back panel), a debug interface (back panel) and a separated power sensor. The power meter sensor is made of a microwave diode and the corresponding transducer circuit.

Caution:

1) *Meter sensor maximum power input is 100mW. Over 100mW, the signal input will cause damage to the power sensor and the power meter.*
2) *The Power Meter should be well ground connected before working, otherwise it will damage the power sensor.*
3) *A mis-operation damage is not warranty granted.*

2.2.2. Technical Specifications

Index	**Parameters (typical)**
Frequency Range:	8.2-12.4 GHz
Work Range:	1mW~100mW
Accuracy:	±10% error
Voltage Standing Wave Ratio:	S≤1.5
Max Average Power:	1 min excess power test
Power benchmark:	50MHz 1.00mW±1.5%
Noise Drifting:	In a min (±0.1mW)
Display Mode:	W, mW, dBm and dB
Power Supply:	220V 50Hz 20W
Size:	220mm (w) x 155mm (h) x 290 (d)
Weight:	About 3 kg

2.2.3. Introduction

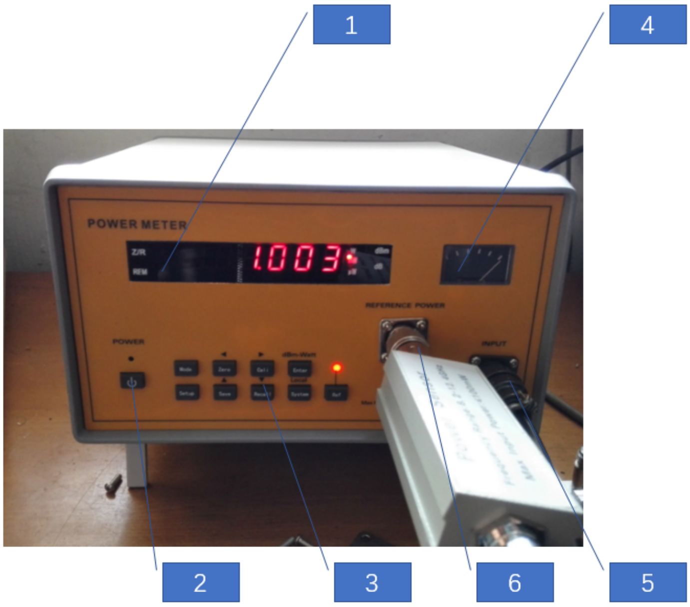


Figure 1. Front panel of power meter

1- LED Display

It displays the meter measured value.

2- Power Switch

When the power cable connects the power meter, the lights turns to red; it means that the power meter is in standby mode. When you press the power switch button, the indicator light turns to green, the instrument is now in working mode. When you press the button again, the power meter returns to the standby mode.

3- Keyboard

The keyboard includes 9 keys: mode, zero, cali, setup, save, recall, system, enter and Ref. For their operation, see the panel operating instructions.

4- Meter

It reflects the trend of the digital display.

5- Sensor Input connector

The input signal should be connected here through the power sensor.

6- Reference Power Output

It sends out a reference signal.

2.2.4. Working Principle

Principle Block Diagram (See Figure 2)

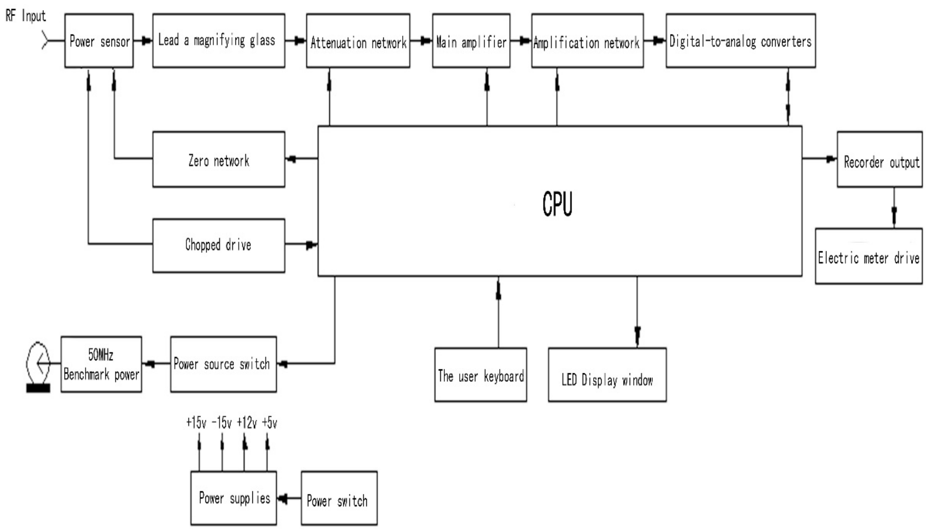


Figure 2. Power Meter Principle Block Diagram

Circuit principle

Power sensing circuit

The power meter sensing circuit is composed of a chopper and a linear correction circuit. The chopper is a series chopper composed of highly sensitive, low noise MOS-FET. Its role is to change the DC signal input through the power sensor into an equivalent AC signal, which makes the post-stage amplifier circuit easier to handle. The linear correction circuit is carried out by the spreadsheet storing the sensor parameters and processed by the CPU.

Preamplifier

The preamplifier is a hybrid amplifier consisting of a high gain transistor and a high impedance, low barrier operational amplifier. The amplifier has an AC gain of about 600 times, which utilizes the low noise of the transistor and the high gain of the op amp.

Attenuation Network and Main Amplifier

The attenuation network consists of analog switches and resistors and is controlled by the central processor. It determines the conversion of the range. The main amplifier is mainly composed of a programmable gain amplifier, which can be adjusted under the control of the central processor to the appropriate gain.

Amplification Network and A/D Converter

The amplifying network is composed of high impedance, low barrier operational amplifiers. These operational amplifiers consist of X1, X10 and X100 amplifying networks and generate three signal with different ranges. Three signals are sent simultaneously into the multi-channel, high-speed analog-to-digital converter, the central processor reads the corresponding data according to the different range.

Zero Set Network

The zero set network is composed of digital-to-analog converters and corresponding devices. When the instrument is in the zero set operation, the central processing unit reads data from the analog-to-digital converter and then sends out a negative signal through the digital-analog converter to eliminate the zero offset error to achieve zero input.

Chopping Driver

The chopping driver is to amplify the current of 220Hz signal sending to chopper.

Recorder Output Circuit

Not available.

CPU

The central processor is a high performance 8-bit microprocessor. It controls the whole instrument operation.

Panel circuit

The panel circuit is composed of LED display window and user keyboard. It is the main tool for manual manipulation of human-machine interface.

2.2.5. Use

Attention !

1) *Before using this instrument, user should carefully read the instructions of the instrument and be familiar with the method of operation.*

2) *In order to ensure a long service life of the instrument, user should choose clean, dry and ventilated indoor space to use and storage it.*

3) *The supply voltage should not exceed 220V ± 22V, otherwise the instrument performance is not guaranteed.*

4) *The instrument generally can be used a few minutes later after the boot process is finished. If the power meter is applied to very precision testing, warm it up at least 30 minutes after the boot process.*

5) *Before testing, the power meter should be set to zero with no signal input. Then, connect the input to the reference 1mW / 50MHz signal output from the panel with the power sensor and perform the calibration operations.*

6) *For precision testing, the power meter should be setup according to the frequency of the input signal (refer to 5.2).*

Panel operation

1. Power on

   When the power cord (AC220V) is plugged in, the indicator light is on with red color; the indicator is on the top of the power button, indicating that it is powered on, but in standby mode. When the power button is pressed, the indicator turns to the green color. The instrument is in working mode.

2. The keys operation

   On the front panel, there are a total of 10 keys. Power key, Mode key, Setup key, Zero/◀ (Zero), calibration/▶ (Cal) and save/▲ key (Save), recall/▼ (Recall), Enter/dBm-Watt key (Enter), the System/local key (System) and benchmarks key (Ref). The benchmark key (Ref) and a pilot light together manage the 50 MHz / 1 mW reference source. The Ref key enables or disables the benchmark signal output. Below is the usage description of the other 8 buttons.

3. Mode

   There are two modes to display the instrument. Power (Watt or dBm) measurement mode and self-reference (RES) measurement mode (i.e., dB mode). You can switch between the two modes by pressing the Mode key.

   In the power measurement mode, you can press the Enter key to switch the Watt or dBm display value.

   When the RES reference mode is selected, the logarithmic form 10lg (Xn / X0) is displayed as the first measured value. In this way, the reference value can be refreshed by pressing the Enter key.

4. Setup

The instrument sets the measured frequency and offset by the Setup key so that the measured signal is correctly reflected during the measurement.

Frequency setting: when you press the Setup key, the LED display shows "FR-XX". It indicates that the frequency setting mode has been entered. The frequency setting range is 0 ~ 12, 0 means 50MHz, others are in GHz as unit. The frequency value can be changed by pressing the Save/▲ key and the Recall/▼ key.

Offset setting: press the Setup key again in the frequency setting mode to display "RO-XXX". The setting is in the Offset setting state. The setting range is 0-99.9, with dB unit. Change the number position by pressing Cali/► (cali) key. Change the value of the current number position by pressing Save/ ▲ (Rec) and Recall/▼ (Recall) key.

Zero/◄ key (Zero) and Cali/► key (Cali)

In order to ensure the accuracy of the data, the instrument often needs to set zero and calibration operation in the measurement process.

Press Zero/◄, the LED displays ”Zero” and the instrument is in waiting mode. Then, press the Enter key to confirm the instrument's setting zero operation. The setting zero operation takes a few seconds, then the instrument returns to the measurement state. If you press the Zero/◄ key (Zero) to keep the instrument in the waiting mode, press the Zero key again to return to the measurement state.

Press Cali/► key, the LED displays “Cal” and the instrument is waiting mode. Press the Enter key to confirm the calibration operation of the instrument. The calibration operation takes a few seconds and then the instrument returns to the measurement state. If you press the Cali/► key (Cali) to keep the instrument in the waiting state, press the key again to return the instrument to the measurement state.

After pressing the Cali/▶ key (Cali), the instrument will automatically open the 50MHz reference source to avoid invalid operation. In order to make the calibration operation more accurate, it is recommended that the reference source be turned on and preheated for 15 minutes by pressing the reference key (Ref) before entering the calibration operation.

Save/▲ key (Save) and Recall/▼ key (Recall)

The instrument can save nine points (1-9) for the user. This allows users to save several deterministic measurement methods and setup data so that it can be easily recalled whenever needed, instead of doing a series complex setting operation every time.

When the Save/▲ button is pressed, 'Save' appears on the display window and the instrument is waiting. Press the Save/▲ key until 'Save N' (N = 1-9) appears. The N number can be changed by pressing the Save/▲ and the Recall/▼ key. When done, press the Enter key and the instrument will save the current measurement and setting status in the storage point N and will be recalled by Recall N in future use. When the 'Save' is displayed on the display window, you can also press Enter to exit the storage operation and return to the measurement state.

When Recall is displayed, 'Recall' appears on the display window and the instrument is waiting. Press the Recall/▼ key until "Recall N" (N = 1-9) appears. The N number can be changed by pressing the Save/▲ and the Recall/▼ key. When done, press the Enter key to recall the saved point N configuration and set the configuration as the current configuration. When the 'Recall' display is displayed on the display window, you can also press the Enter key to exit the recall operation and return to the measurement state.

Enter key

The Enter key (Enter) is a mixed function key. In the set mode, the pressing action is a confirmation action. In the set zero or calibration, it also plays confirmation; In the save or recall mode, it ends the operation process. In power measurement, the pressing action changes the display mode from Watt to dBm cyclically. In Ref way, it plays as a refresh.

System/local key (System)

Not avaliable.

Ref key

This key enables or disables the output of the 1mW benchmark signal. The status of the indicator above this key indicates the output status.

2.2.6. Repair and maintenance

Troubleshooting

Index	***Fault phenomenon***	*The fault may be*	***Troubleshooting methods***
1	*Can't boot (no lighting of power indicator)*	*Fuse broken*	*Change the fuse*
		Power connection is not good	*Check the power supply of the input*
2	*Can't boot (power indicator light green light not bright)*	*The front panel power button damaged*	*Replace the power switch key*
		The front panel electrical connection is not good	*Check the connection, if necessary change the connection cable*

3	*LED display window malfunction (dark display)*	*LED Screen damaged*	*Change LED Screen*
		The front panel electrical connection is not good	*Check the connection, if necessary change the connection cable*
4	*Display E Err*	*Invalid set Zero operation*	*When in set Zero operation, the power sensor should not be connected to any power source (signal)*
5	*Display C Err*	*Invalid calibration operation*	*The power sensor is not connected to the 1mW reference source that comes with the instrument, or the type of power sensor on the instrument does not match the type of probe being used*
6	*Display Over*	*Measurement value overflow*	*Reduce the signal power to the appropriate amount*
7	*Doesn't work properly*	*Sensor Failure*	*Replacement sensor*
		Keyboard fault	*Change the keyboard*
		Power fault	*Check the power supply, replace the damaged components*
		Main control board failure	*Change the main control board*

8	*No benchmark power output or output power exceed the rated tolerance*	*50MHz Benchmark power source stop vibration*	*Replace the damaged components*
		Output power exceeds the rated tolerance	*Recalibrate the benchmark power, in room temperature it should be adjusted to 1mW±0.5%*

Instrument maintenance

1) The instrument should be regularly checked and repaired.
2) The instrument should be covered when not in use, stored in a dry room.
3) When the instrument is operated, do not press the control keys with excessive force, this will cause damage.

2.3. Variable Attenuator

A variable attenuator provides an attenuation by varying the degree of insertion of a matched resistive strip into a waveguide. The variable attenuator is used to control a power level, or to isolate a source from a load. Remarks: the scale is not in dB, the attenuation is only indicative and can be measured by the power sensor.

2.3.1. Specification and performance

Technical specifications

Index	Parameters (typical)
Input:	SWR <1.2
Attenuation data at start location:	<0.5dB
Maximum Attenuation:	≥30dB
Accuracy:	±%5 (±0.5dB)

2.4. Slotted Line

In measuring the standing waves inside a waveguide, a slotted line is used to probe the amplitude and the phase of the standing wave pattern.

Obtaining the standing wave pattern information allows us to determine the wavelength, the standing wave ratio and the impedance of the transmission line.

As the name implicates, a slotted line has a slot along the centre line of the broad side of the wall.

An assembly consisting of a probe and a crystal detector is designed to slide along the open slot and, as it does, the probe samples the field in the waveguide, while the crystal detector provides a rectified signal.

The depth of the probe into the waveguide is adjustable and the strength of the detected signal is proportional to the depth.

The user should be aware of an optimized depth in use of a slotted line since a too shallow depth would make the detected signal too weak and a too deep depth would substantially reduce the main signal power in the waveguide and may even cause field distortion.

2.4.1. Specification and performance

Technical specifications

Index	Parameters (typical)
Combination Voltage Standing-wave ratio:	≤ 1.03
Probe Insert Waveguide Depth:	1.5mm
Probe Distance:	95mm
Waveguide Specification:	BJ100 (Size: 22.86mm X 10.16mm)
Flange Specification:	FBP-100

2.5. Frequency Meter

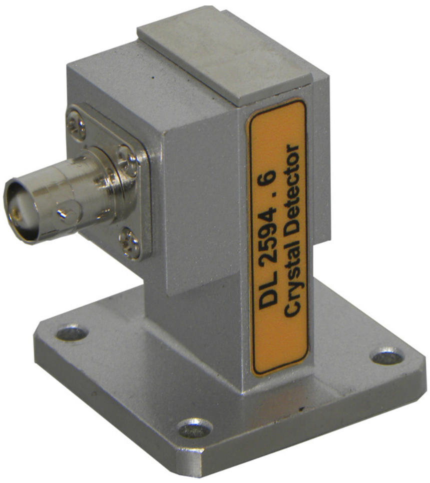
The basic working principle of the frequency meter in DL 2594N comes from the high Q resonant characteristic of the resonant cavity which is attached to a waveguide. The microwave signal in the waveguide is coupled to the resonant cavity through a small slot between the cavity and the waveguide. The effective size of the cavity, and thus the resonant frequency of the cavity, is variable by moving in and out an adjustable plunger which has a calibrated dial knob assembly. When the resonant frequency of the cavity is equal to the frequency of the waveguide, there is a maximum energy transfer from the waveguide to the cavity. This condition is indicated by a large power drop on the power meter which is connected to the waveguide. The actual frequency is obtained by reading the calibrated dial.

2.5.1. Specification and performance

Technical parameter

Index	Parameters (typical)
Frequency Meter Accuracy:	≤0.3%

2.6. Crystal Detector



The crystal detector is located inside the waveguide walls which is joined to a coaxial connector. The crystal detector is basically a diode assembly which responds to the electromagnetic field inside the waveguide. The diode assembly consists of a small thin piece of silicon, a thin tungsten wire and a case. One side of the silicon is directly connected to the case and the other side is connected to the tip of the tungsten wire. The diode action is due to the different properties of silicon and tungsten; silicon has a few surplus electrons, but there are many free electrons in tungsten. Therefore, when a voltage is applied across the diode in such a direction as to force electrons to leave silicon and enter tungsten, a very small current results. In contrast, when the direction of the voltage is reversed, a large current flows from tungsten into silicon. This is how the diode can be used for detection of the microwave energy.

The diode is a fragile device; it can be easily damaged from an excessive voltage.

The characteristic of a crystal detector (or the relationship between the output voltage and current to the input voltage) is such that the device follows a square law within a certain range of input power. The square law characteristic means that the output voltage is proportional to the square of the input voltage. It can also be said that the output voltage is directly proportional to the input power.

2.6.1. Specification and performance

Technical parameters

Index	Parameters (typical)
Frequency range:	8.2~12.4 GHz
Input:	SWR <1.05
Detecting sensitivity:	> 1.5mV/µw

2.7. Matched Termination

The matched terminator is essentially a matched load to a microwave transmission line. As the standing waves occur due to impedance mismatches in the system, the matched termination is used to minimize the SWR in a system.

2.7.1. Specification and performance

Technical parameters

Index	Parameters (typical)
Frequency range:	8.2~12.4 GHz
Input:	SWR <1.05
Detecting sensitivity:	> 1.5mV/µw

2.8. Slide Screw Tuner

The primary use of the slide screw tuner is to match loads, detectors, or antennas to the characteristic impedance of the waveguide. The mechanical structure of a slide screw tuner consists of a probe mounted on a carriage which slides along a narrow and long slot on the feeding waveguide. When the adjusting micrometer is turned, the depth of the probe varies. The combination of the depth and the position of the probe causes a reflection in the waveguide at a specific amplitude and phase.

Relation between probe's depth and micrometer's scale [unit: mm]

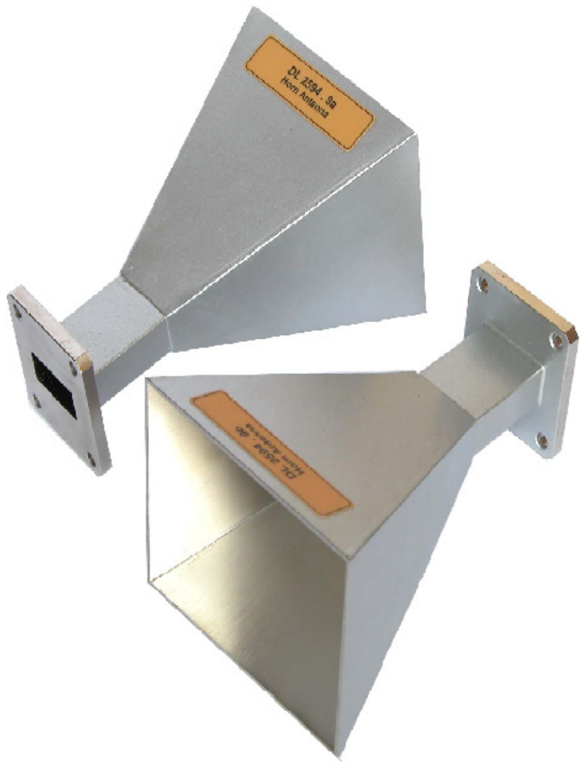
micrometer's scale	3	5	7	9
probe's depth	7	5	3	1

2.8.1. Specifications and performance

Technical parameters

Index	Parameters (typical)
Frequency range:	8.2~12.4 GHz
SWR adjust range:	20~1.05
Slide Moving Distance:	≤ 40mm

2.9. Horn Antenna



Horn Antenna size and gain:

- $A = (3\ \lambda_0\ L_h)^{1/2}$
- $B = (3\ \lambda_0\ L_c)^{1/2}$
- $G = 8.1 + 10 \log (AB/\lambda_0^2)$

A, B is the size of the Horn Antenna E, H.

L_h is the distance between the wave guide E's center to A.

L_c is the distance between the wave guide H's center to B.

2.9.1. Specification and performance

Technical parameters

Index	Parameters (typical)
Frequency range:	8.2~12.4 GHz
Input	SWR ≤ 1.5
Antenna gain	G ≥ 15dB

2.10. Coaxial Adapter

It provides a match between a waveguide and a 50 ohm coaxial line. The power flow can be in either direction. However, the SWR in the adapter should be kept less than 1.2.

2.10.1. Specification and performance

Technical parameter

Index	Parameter (typical)
Input	SWR < 1.5

2.11. Fixed Attenuator

The purpose of the fixed attenuator used in DL 2594N is to provide a fixed attenuation of 6 dB. The attenuation is obtained by the insertion of a thin conducting absorber into a straight portion of a standard waveguide.

2.11.1. Specification and performance

Technical parameters

Index	Parameters (typical)
Frequency range:	8.2~12.4 GHz
Input	SWR ≤ 1.15
Attenuation value:	a) 20±5dB b) 6±1dB

2.12. Directional Coupler

The directional coupler, which allows a directional coupling of energy in the waveguide, is basically a sampling device of the microwave signal.

A directional coupler consists of two waveguides combined together and coupled by holes at the joining section of the two. Directional couplers are very popular in microwave systems where measurements of incident and reflected power are needed to determine the Standing Wave Ratio or SWR.

The directivity, which is a figure of merit of a directional coupler, is a measure of how well the power can be coupled in the desired direction in the neighbouring waveguide.

Usually, one end of the neighbouring waveguide contains a matched load which absorbs the energy headed towards an undesired direction.

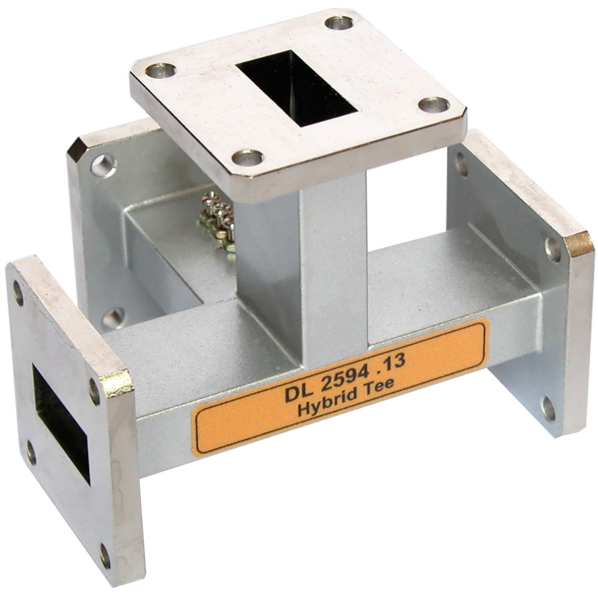
The directional coupler used in DL 2594N has a coupling factor of 10dB (±3dB) and a directivity of 40dB.

2.12.1. Specification and performance

Technical parameters

Index	Parameters (typical)
Frequency range:	8.2~12.4 GHz
Input	SWR ≤ 1.25
Coupling coefficient	C=22±2dB
Directivity	D ≥ 15dB
Insertion loss	L ≤ 1dB

2.13. Magic-Tee (or Hybrid-Tee)



A magic-Tee is a four port device which is basically a microwave version of a hybrid coil of the type commonly used in telephone repeater circuits.

It has the properties that, when properly terminated in external impedances, the power incident on any arm splits equally between the two adjacent arms, but there is no power coupled to the opposite arm.

The magic-Tee is an essential device in balanced mixers, automatic frequency control circuits and impedance measurement circuits.

2.13.1. Specification and performance

Technical parameters

Index	Parameters (typical)
Frequency range:	f = 8.2~12.4 GHz
Input	SWR (every terminal)≤ 1.25
Isolated depth:	≥ 30dB
Asymmetry (power distributes to two terminals)	≤ 0.5dB

2.14. Waveguide Straight Section

A six inch straight section of waveguide used in measurements of the wavelength and the phase velocity inside a waveguide.

2.14.1. Specifications and performance

Technical parameters

Index	Parameters (typical)
Frequency range:	f = 8.2~12.4 GHz
Input	SWR ≤ 1.15

2.15. Shorting Plate

When measuring the wavelength inside of a waveguide, a shorting plate is used to create a short (zero impedance) at the open end of a wave guide.

2.15.1. Specifications and performance

Technical parameters

Index	Parameters (typical)
Route	≥35mm
Input :	SWR > 50

2.16. Frequency Selective Amplifier (SWR meter)

2.16.1. Overview

The frequency selective amplifier is a precision measuring amplifier capable of detecting weak signals. With signal generator and slot lines, it can be applied to measure standing wave ratios (SWR). This instrument is an indispensable device in microwave measurement systems.

2.16.2. Specifications and performance

Technical specifications

Index	Parameters (typical)
Work Frequency:	1000Hz Adjustable range ≤40Hz
Transmission bands:	16Hz~40Hz continuously adjustable
Sensitivity:	With resistance of 200KΩ, meter being full scale, 16HZ passband, sensitivity will be not less than 50 microvolts
Scale:	0~1000mV • Decibel:~10db • standing-wave-ratio (SWR): 1~4,3~10 • nonlinear error: <5% full scale
Amplifier range:	• 0~60db, every 10db±0.5db step • 0~5db±0.2db • 0~5db continuous adjustable
Input Resist:	200KΩ
Power:	AC~200V, 50Hz, 20W
Size:	99mm (H) x 220mm (W) x 250mm
Weight:	about 3Kg

Working conditions

Ambient Temperature:	0~40°C
Relative Humidity:	≤80%
Pressure:	1atm
Avoid strong magnetic fields and high mechanical vibrations.	

2.16.3. Panel of the instrument

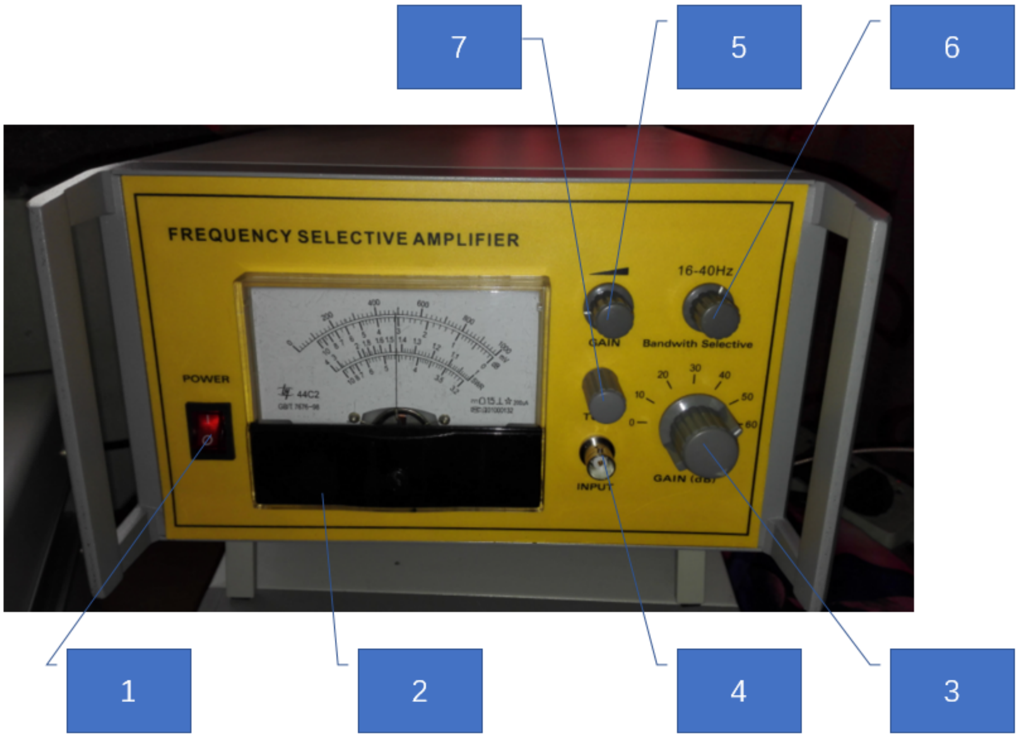


Figure 3. The front panel adjusting structure

1) The power switch with indicator: press the upper part of the power switch, the instrument is powered on and the power switch indicator is on. The instrument starts the booting process. When you press the bottom part of the power switch, the instrument power is turned off.

2) The meter: it indicates SWR, attenuation and millivolt value. The millivolt scale is 0 ~ 1000 mv. the attenuation scale is 0 ~ 10 db. The SWR has two scales: 1 ~ 4 and 3.2 ~ 10.

3) Gain selective switch: it selects the current coarse amplifier gain. The gain range is from 0 to 60 db, with a 10 db step.

4) Signal input connector: BNC connector, signal input form this connector.

5) Gain adjust knob: it selects the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With a clockwise adjustment, the gain amplifier is increased; with an anticlockwise adjustment, the gain is decreased.

6) Bandwidth adjust knob: it adjusts the bandwidth of the current measurement. The range is 16 HZ to 40 HZ continuously adjustable. With a clockwise adjustment, the bandwidth amplifier is increased; with an anticlockwise adjustment, the bandwidth is decreased.

7) Frequency tuning knob: when there is an input signal, this knob can be adjusted to get the maximum sensitivity.

2.16.4. Structure Features

The size of the frequency selection amplifier is: 220mm *99mm *250mm (b *d * h). The structure of the instrument uses frame type profile materials forming a frame type chassis. The connection and composition of the chassis facilitate maintenance and production. The preamplifier section uses an electrically shielded structure to reduce the interference of stray electromagnetic fields. The rear panel of the instrument is the input socket for the power supply.

Preparation:

2) Power off the instrument, observe the meter. If the needle is not at the zero position, adjust the header of the mechanical zero screw on the bottom part of the meter panel, to force the needle to return to zero.

3) Adjust the Gain Adjust Knob in the middle position.

4) Adjust the Frequency Tuning Knob in the middle position.

5) After power on, it is better to keep the instrument powered on for 10 to 30 minutes and then to start the measurement.

Instrument use:

1) Connect the input signal to the "signal input connector".

2) According to the measured signal amplitude, choose a suitable "gain selective switch". The suitable position means to make the needle of the meter at 2/3 of the full scale. 0 db means no amplifier.

3) When the gain is well adjusted, the sensitivity of the meter can now meet the measurement requirements and the user can choose a wider pass band by adjusting the band width knob; this instrument could have more stable performance.

4) "Gain control knob" and "Gain select switch" combined together to amplify the input signal amplitude to a certain position. This position is a relative observing benchmark for measurement.

5) Before testing the waveguide component, the user can adjust the “frequency tuning knob” to tune the frequency of the input signal and the instrument strobe frequency to the best condition. The best condition means that the needle reaches the maximum position of the signal.

6) Measurement of the standing wave ratio (SWR): according to the common measurement of the standing wave ratio, the standing wave ratio of the measured load can be read out directly on the meter scale of 1 to 4 on the meter. When the SWR reading is greater than 3.2, the "Gain Selective Switch" could be turned one gear clockwise and the user can read the standing wave ratio on the scale 3.2 to 10.

2.16.5. Maintenance and repair

When the needle of the meter exceeds the full scale, adjust the “Gain selective switch” anticlockwise gear by gear to make the needle to return to the scale range. If the " Gain selective switch " is reduced to 0db, the needle is still out of full scale and the user should stop testing to find the problems. Otherwise, the meter may be damaged after a long time out of full scale.

2.16.6. Notes

This product necessary accessories (already included in the instrument):

1) Power cable 1
2) Fuse
3) Technical instruction manual

Storage and transportation.

In order to guarantee a long service life of the equipment, the user should choose a clean, dry and ventilated indoor space for use and storage.

2. Installation of the DL 2594N Trainer

1. DL 2594N description and layout

Before starting the experiments, we recommend you to understand the role of the hardware components of the trainer and how they are arranged and handled.

Care For Use

1. In order to improve the measuring reliability, the connection of each microwave component should be made correctly and should follow these rules:

   - The central rectangle of the waveguide should be kept in a line and the edge should be matched.

   - Two flanges should be tightly jointed with four screws and nuts so that the microwave does not leak.

2. The components of this experiment set should not be used for any other experimental purpose.

3. No drop or shock should be applied to any component.

4. Keep away from humidity or heat.

5. You should avoid to use it in a dusty area and the system should be kept in its storage case after use.

6. Check whether any substance is attached to the entry/exit of the waveguide before the assembly for the experiment circuit construction of components and remove the substance, if existing.

7. While the oscillator is oscillating, the internal part of the oscillator must not be observed through the output part. Since the oscillator used in this experiment unit has a relatively small power, ***the output is not dangerous to other body parts, but eyes can be permanently damaged***.

Arranging the equipment and devices

The components of the DL 2594N trainer are grouped by function and arranged according to some criteria:

1. ***Safety*** is the critical reason for the experimental setup - moving parts have to be protected, accidental exposure to radiation from the microwave electromagnetic field has to be avoided.
   - cables are divided in two:
     - *signal cables* - they are used to connect the device named Frequency selective amplifier (SWR meter) with the device named Crystal Detector.
     - *power cables* - they have a standard color - black. They also have specific connectors.

2. From the ***maintenance*** point of view:
   - the routes of the connections must be established in the simplest way, with minimum crossed paths;
   - the grounding cable (when it is necessary) and connectors must be visible, uncovered, and always available for checking.

3. ***Handling*** is another issue - the most used parts are located in a way that allows fast and easy control;

4. When it is possible, we consider that INPUTS are located in the left side of the devices, and the OUTPUTS are located at their right side.

2. Hardware layout and description

From the hardware point of view, the DL 2594N trainer kit is divided in:

1. Measuring devices and microwave electromagnetic field generator – it has been described in the upper paragraph.

2. The DL 2594N kit devices used in the laboratory experiments (such as bolts and nuts).

3. Cables for connecting the measuring devices and the microwave generator (microwave signal source) with the elements that make up the laboratory experiments.

4. The stand base elements. They are used to ensure that the waveguide assembly remains mechanically stable on the working surfaces. All waveguide components are designed with a thread on their underside to facilitate mounting on the stand base.

Note

The pictures and notifications that will be shown next are only for guidance.

2.1. The Way to Use the Component with IN/OUT Directions

Among the 15 kinds of microwave components within the DL 2594N, the input and output of wave course is classified as in the following.

- Slide Screw Tuner
- Slotted Line

The above two kinds hold the sliding location of 0 ~ 40. Since the flange with "0" on this adjustment scale becomes input and the flange with "40" becomes output, the connection should be made correctly according to the experiment and route.

The following picture shows a connection example of the Slotted Line.

Experimental module for measuring the influence of the measuring probe on the microwave field propagation characteristics at a given frequency.

The design of the experimental module has the architecture in the next figure:

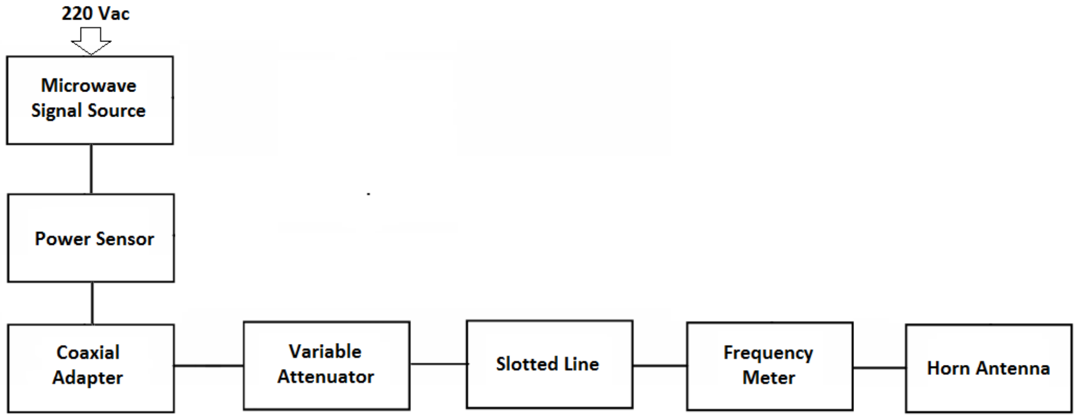


Figure 1. Experimental module for measuring the influence of the measuring probe on the microwave field propagation characteristics at a given frequency

The main idea for designing this laboratory experiment: to create a laboratory experiment in which to highlight the disturbing influences of a metal body introduced into the microwave electromagnetic field propagation environment.

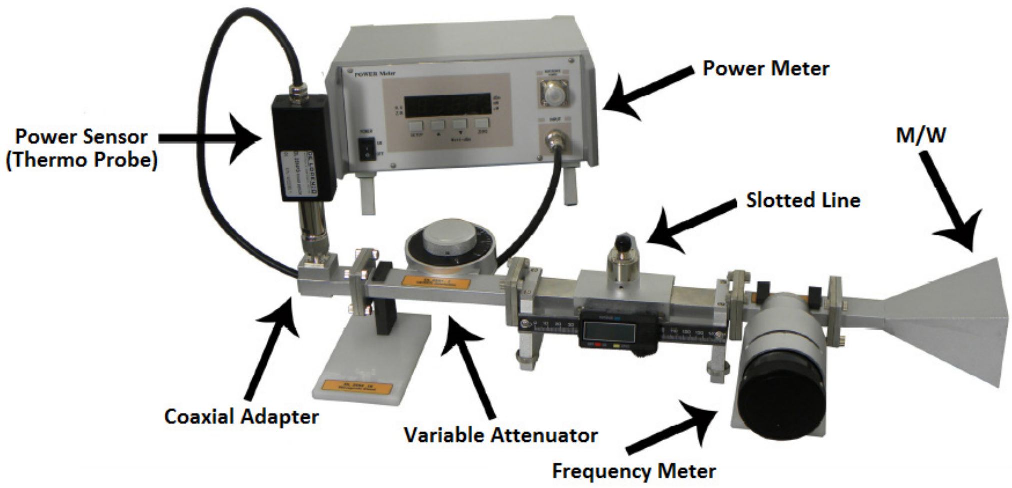


Figure 2.1. The experimental installation for highlighting the disturbing influences of a metal body introduced into the microwave electromagnetic field propagation environment.

Compare the two figures and understand the role of each component.

The position of the metal body (the probe into the Slotted Line) and the depth of its penetration into the microwave electromagnetic field propagation space through the waveguide is adjusted manually by the user of the experiment.

Both the level of attenuation and the position and depth of the probe are of major importance in assessing the electromagnetic field disturbances that a metal body introduces into the microwave space.

2.2. The Way to Use the Component with Directions

Among the microwave components, there are components that have a pre-set connection direction. These components are not transmitted in a certain direction and send the wave only to a specific direction.

These components are:
- Directional Coupler
- Magic-Tee (also called as Hybrid Tee)

The following picture is an example of using a directional coupler and the arrows indicate the possible wave directions.

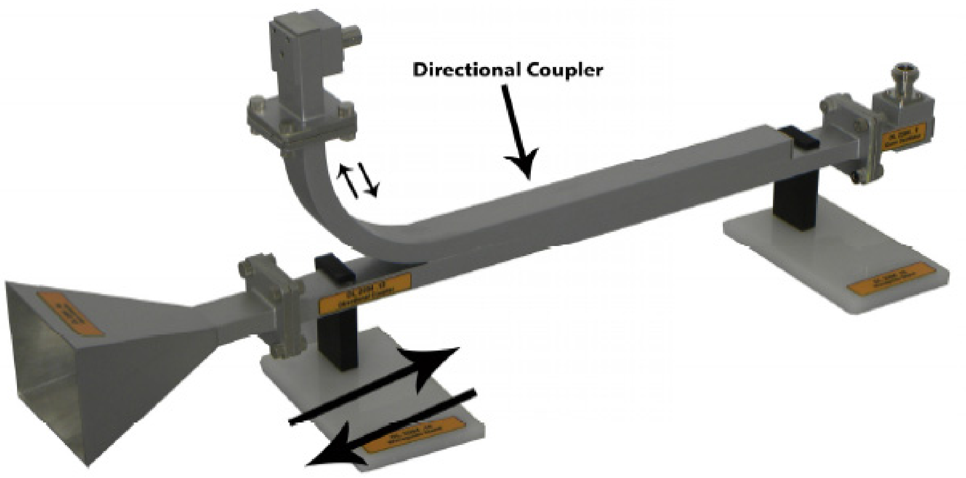
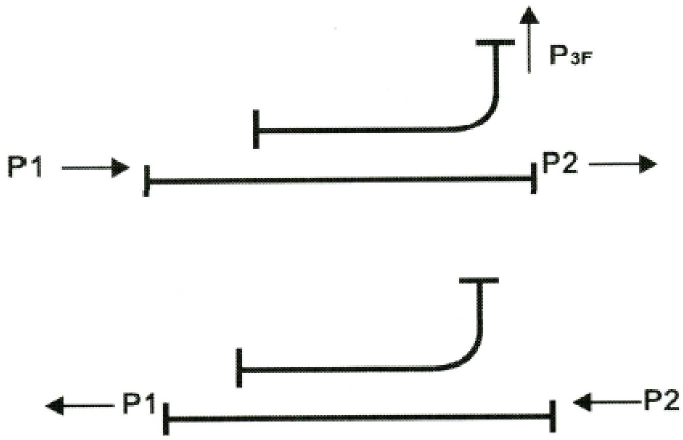


Figure 2.2. The example of using a directional coupler and the arrows indicate the possible wave directions.



The directional coupler of the upper part of the picture shows that in the case that the wave enters to P_1, the same P_1 wave is transmitted to P_2 and P_3. However, the lower part of the picture shows an opposite case in which the wave enters through P_2. Although this wave is transmitted to P_1 from P_2, it is not transmitted to P_3.
If we use these characteristics, an M/W antenna can be made for transmission and reception and the reflection wave in the waveguide circuit can be detected.
Experiment-9 (EXT.-9) provides the detailed information about Magic-Tee component. Refer to Experiment-9.

2.3. The Way to Use the Power Meter

The DL 2594N Microwave Trainer provides the M/W Power Meter Model DL 2594PM. The following picture shows an example of using the Power Meter and the Power Sensor.

The Power meter and the Power sensor must be connected together based on their identification number.

Figure 2.3. DL 2594 PM04 (Power meter) - DL 2594 PM04.1 (Power Sensor)

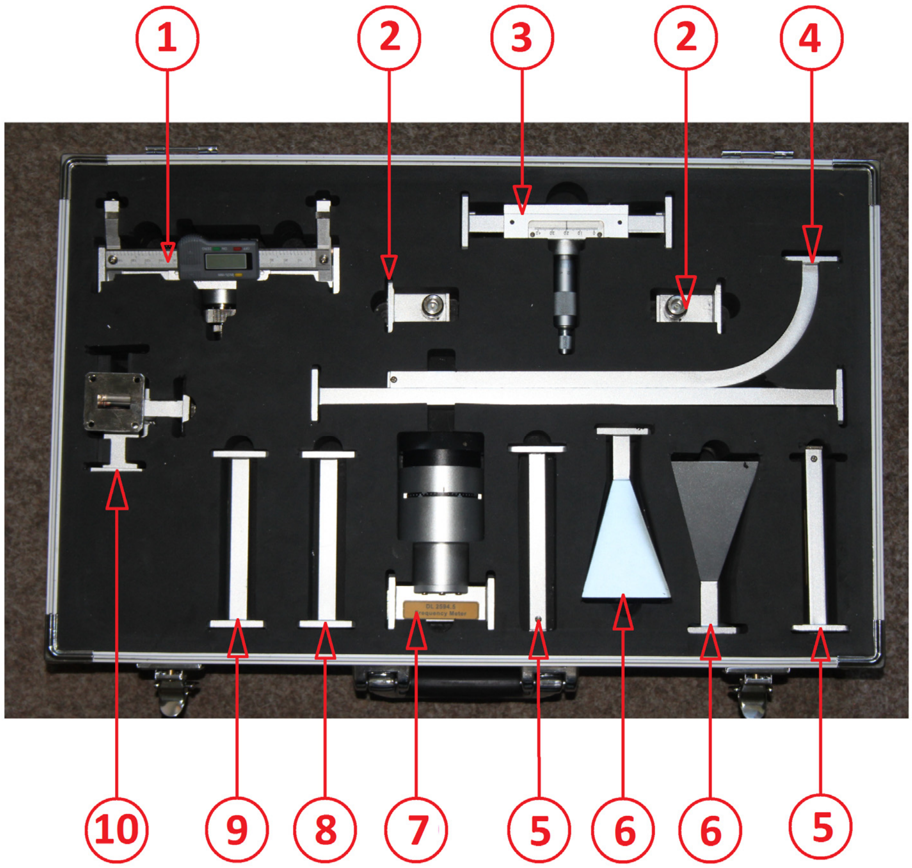
Note

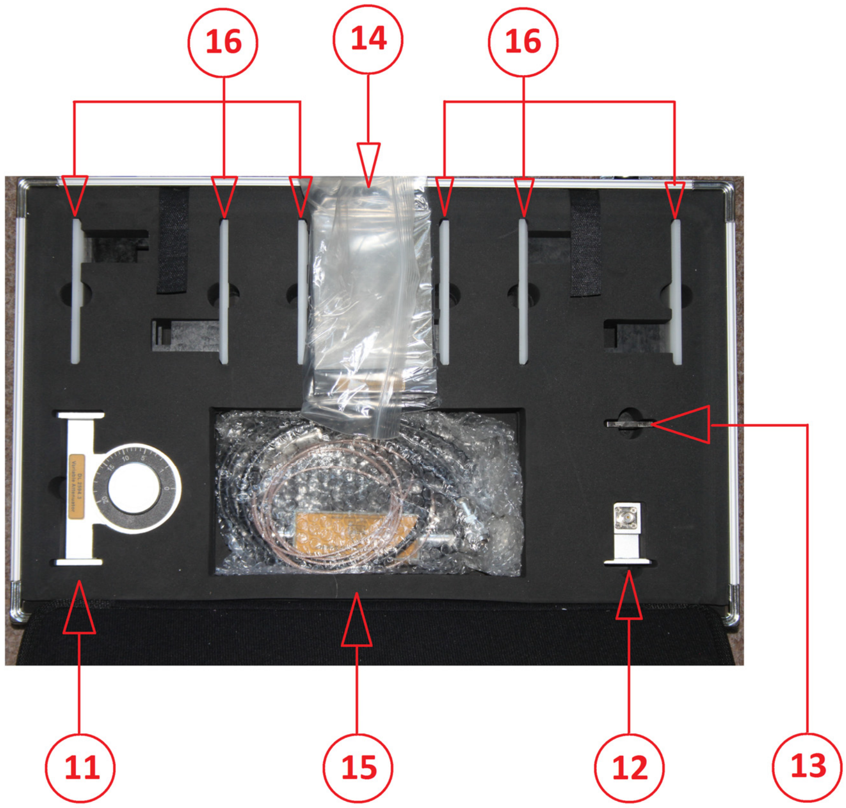
The DL 2594N Power Meter measures up to 100 mW through a power sensor. If the RF power over 100 mW is directly measured without attenuation, the M/W, even if the measures are accurate in the range 8.2 GHz – 12.4 GHz, may be damaged.

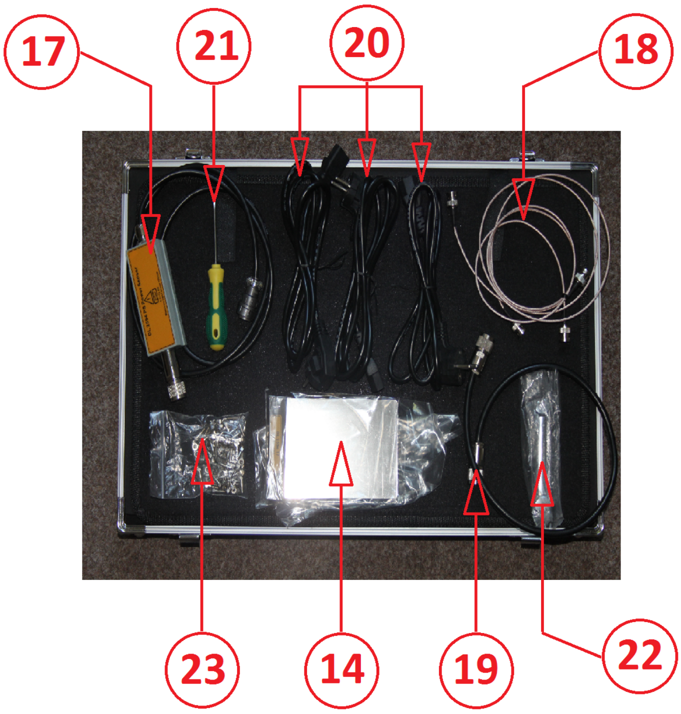
The DL 2594PM holds the frequency measurement range of 8.2 GHz ~12.4 GHz and the power range is 1mW~100mW. Therefore, when initially measuring, measure by setting the 10mW range and gradually select a lower range according to the indication sensitivity of the meter; in order to have an accurate measurement, it is suggested that the instrument is warmed up for 30 minutes at the ambient temperature between +15° C and +30° C.

2.4. The DL 2594N trainer kit content

The DL 2594N trainer kit contains the following 26 parts:







1. Slotted Line	14. Reflector
2. Coaxial Adapter	15. Cables, Power sensor
3. Slide Screw Tuner	16. Stand base
4. Directional Coupler	17. Power sensor
5. Matched Termination (2 pieces)	18. BNC cable with two sockets (2 pieces)
6. Horn Antenna (2 pieces)	19. Cable for coaxial adapter
7. Frequency Meter	20. Cable for 220 V c.a.
8. Waveguide Straight Section	21. Screwdriver
9. Fixed Attenuator	22. Wrench
10. Hybrid-Tee	23. Bag with bolts and nuts
11. Variable Attenuator	24. Microwave signal source
12. Crystal Detector	25. Power meter
13. Shorting Plate	26. Frequency selective amplifier (SWR meter)

Each connection is made one after the other. Each cable is connected at both ends, then go to the next connection. Do not leave any free ends, even temporary, for a short time.

When you finish connecting one cable with both ends, ensure it against accidental disconnection.

The position of the cables (routes) should be as clear as possible.

Before assembly, make sure that you have all the parts, otherwise ask the supplier DE LORENZO.

2.5. Technical specifications and features

The next sketch shows some guidance sizes [m].

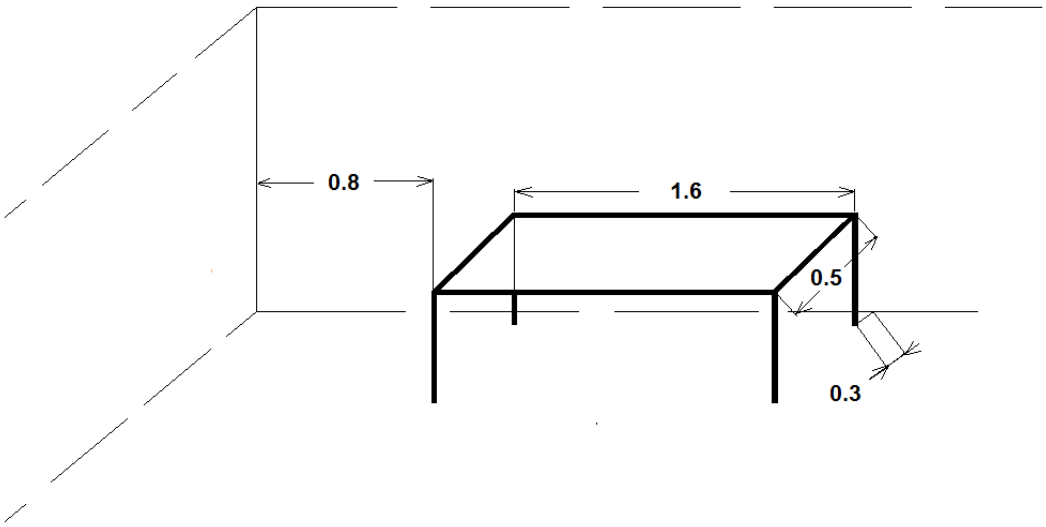


Figure 2.4. The guidance arrangement of the main supports (table) that are used for the DL 2594N Trainer kit.

As you can see in this figure, we recommend you to install the components of each experiment on the table, with some space for handling (0.8 m on the left side).

At the back, between the frame and the wall there is space, according to local regulation for cables and wiring handling. We leave around 0.3m space.

Consult the local regulations for safety and electrical equipment handling in public institutions or educational centers in order to accommodate our recommendations to the regulations.

The main consumers are:

- Power Meter: 20 W
- Microwave Signal Source: 50 W
- Frequency Selective Amplifier (SWR meter): 20 W

The main power supply should be adapted to these consumptions.

In order to accommodate the electricity distribution for electrical devices, a few electric specifications should be taken into consideration:

- the main sockets are adapted usually to the local regulations;
- the main voltage level is also adapted to the local network.

According to the local regulations (national), before connecting the power supply to the trainer, check for the correct groundings.

The grounding cable (for Microwave Signal Source) should be visible, accessible for handling and securely connected to the general grounding network.

3. Operation

In order to operate any experiment on the trainer, some steps should be completed:

- Carefully remove, without moving suddenly and without forcing them from their chambers, the components you need to carry out the experiment.
- Connect the components together using screws and nuts in the order in which they appear in the symbols in the figure associated to the experiment.
- Remove the measuring devices and the Microwave Signal Source from the boxes in which they were stored and place them carefully on the table.
- Choose the cables you need for the experiment, and connect the measuring devices with the components as described in the symbol figure.
- Connect the Microwave Signal Source using the dedicated cable to the Coaxial Adapter component.
- Make sure that the connections are secure and that there is no possibility that they will unravel.
- Connect the microwave measuring devices and vMicrowave Signal Source to the power grid.
- Switch the Power button of the microwave measuring devices and of the Microwave Signal Source to ON.
- Perform the operations described in the manual section associated with the chosen experiment.

Each experiment has a specific procedure. Identify the *Procedure* in the manual section associated to the chosen experiment.

Do not hit the components while assembling them and do not force the connectors.

3. Theoretical section

1. Introduction. Application areas of microwaves

This first theoretical part conveys a basic knowledge on the physics of microwaves. Microwaves are generated by a microwave signal source (DL 2594N device) and their propagation in conjunction with rectangular waveguides (DL 2594.1 to DL 2594.14) is examined in detail.

- Characteristics of the electromagnetic waves
- Crystal detector
- Recording a current-voltage characteristic
- Transmission line theory and line variables
- Wave propagation in waveguides
- Standing waves, short-circuits, reflection and matching
- Standing-wave ratio
- Power reduction and thermal load
- Measuring waveforms in waveguides with the aid of a slotted line
- TE, TM and hybrid waveguides
- Waveguide dimensions and operating frequency
- Dielectrics in a waveguide

Prerequisites for successfully working through this first theoretical part include:

- Knowledge of DC and AC technology
- Fundamentals of transmission line theory: equivalent circuit diagram for an electrical transmission line and quantities per unit length
- Physics of wave propagation
- Understanding of complex numbers expressed using "j"

2. A few notions. General background

Frequency Definition: The frequency range extending from 300 MHz up to 300 GHz is generally known as microwaves. These limits are to some extent arbitrary.

Wavelength Definition: From $c = \lambda \cdot f$ (in vacuum), λ is between 1m and 1mm.

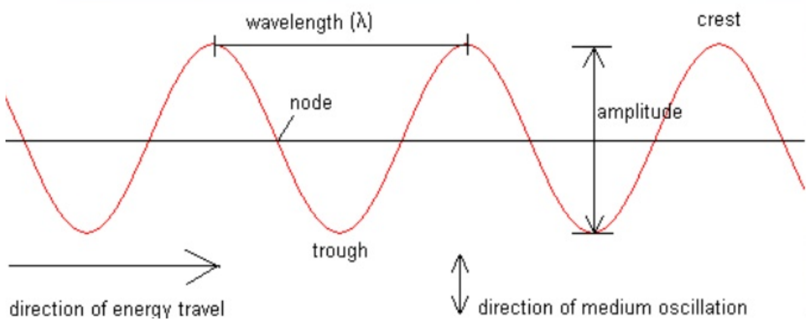


Figure 3.1. Waves main parameters

Energy of a Microwave Photon: A microwave photon has an energy in the range roughly $1.2x10^{-6}$ - $1.2x10^{-3}$ eV (calculated from energy = $h \cdot f$ where $h = 6.63x10^{-34}$ J s). Non ionization.

Order of Magnitude of the Periods: The period $T = 1/f$ is between 3ns (nanoseconds) and 3 ps (picoseconds).

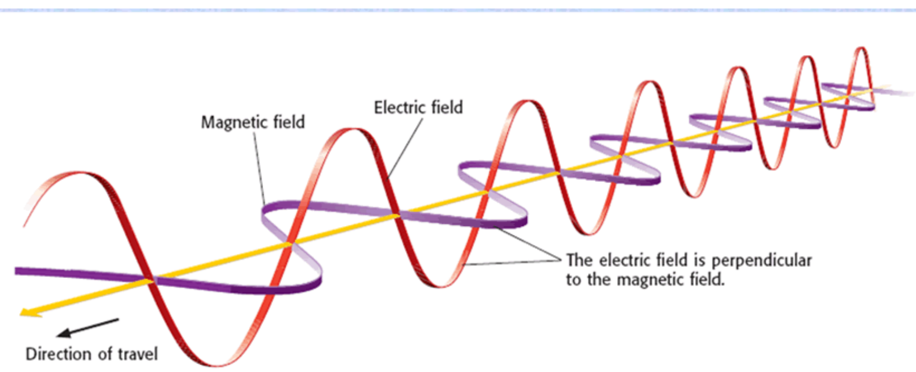


Figure 3.2. The orthogonality property of electromagnetic waves. The pattern.

Dimensional Comment: The wavelength of a microwave signal is of the same order of magnitude as the devices used to produce and transmit it. It is not possible to assume that devices are merely dimensionless points in free space as it is done in circuit theory approximations. Also, the term voltage is not defined in a unique way, since the electric field is not derived from a scalar potential. On the other hand, it is neither possible to assume that devices are too large with respect to the wavelength, as it is the case for the geometrical optics. Microwave problems must be considered in terms of electric and magnetic fields as defined in Maxwell's model.

Bandwidth: The rate of transmission of a channel being directly proportional to its bandwidth. A simple calculation shows that, over the range of 300 MHz to 300 GHz frequency range, 999 times more information can be transmitted over a specified time period than in all the lower frequency bands taken together (0 - 300 MHz). A 1% bandwidth at 600 MHz is 6 MHz (the bandwidth of one channel), while at 60 GHz a 1% bandwidth is 600 MHz (about 100 TV channels).

Directivity of Antennas: The width of the beam radiated by an antenna is directly proportional to the ratio of the wavelength to the antenna's largest dimension. When transmitting a signal from one point to another (microwave link) or when determining the origin of a reflection (radar), a narrow beamwidth is required.

Note

It is, then, necessary either to have a large size antenna, which is often not convenient for mechanical reasons, or to utilize a signal of high frequency.

Transparency of the Ionosphere: The EM propagation within the ionosphere is similar to that in a waveguide. Signal at frequencies lower than 10 - 40 MHz (cutoff frequency) are partially or totally reflected. This property is used to realize multiple reflection links at short waves. Higher frequency signals travel across the ionosphere, but experience distortion, which decreases with frequency. Microwave signals, well above the ionospheric cut-off, are hardly affected at all, at sufficiently small power levels. For these reasons, microwaves are utilized for satellite communications and space transmissions. Communication links (both terrestrial and with orbiting satellites) with high capacities are thus possible.

Partial Transparency of the Atmosphere: The various atmospheric components (oxygen, nitrogen, water vapor, carbon dioxide) and the many elements in suspension (water droplets, ice crystals, dust, and smoke) do not significantly affect signals having frequencies smaller than about 10 GHz. Higher frequency signals, however, experience several unwanted effects: absorption, depolarization and scintillation.

Reflection of Targets: The effective reflection area (radar cross-section, scattering cross-section) of an object depends in a very sensitive manner on the ratio of the object's size to the wavelength. When the reflecting element is much smaller than the wavelength, the reflection becomes vanishingly small.

1- RADAR

-Surveillance (air traffic control)

-Navigation (direction finding)

-Meteorology

2- MEDICINE

-Treatment of Diseases

-Microwave Imaging

3- SURVEYING LAND

4- HEATING

5- INDUSTRIAL QUALITY CONTROL

6- RADIO ASTRONOMY

7- NAVIGATION VIA GLOBAL POSITIONING SYSTEMS

8- REMOTE SENSING

9- POWER TRANSMISSION

3. The microwave spectrum

Microwaves occupy a portion of the EM spectrum extending from 300MHz (= 3x10^8 Hz) to 300GHz (= 3X10^{11} Hz). Some important prefixes and their multiplicative equivalents are listed below:

Prefix	Symbol	Multiplicative Value
Exa	E	10^{18}
Peta	P	10^{15}
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
kilo	k	10^{3}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

As a result of common usage developed over the past half century, the microwave spectrum has been divided into bands, each with an idendifying letter designation.

Note

All electromagnetic waves are transverse waves.

Letter Designation	Frequency Range	Wavelength Range
L- Band	1-2 GHz	30-15 *cm*
S- Band	2-4 GHz	15-7.5 *cm*
C- Band	4-8 GHz	*7.5-3.75 cm*
X- Band	8-12 GHz	3.75-2.5 *cm*
K_μ -Band	12-18 GHz	2.5-1.67 *cm*
K- Band	18-27 GHz	1.67-1.11 *cm*
K_a - Band	27-40 GHz	1.11-0.75 *cm*
U- Band	40-60 GHz	7.5-5 *mm*
V- Band	60-80 GHz	5-3.75 *mm*
W- Band	80-100 GHz	3.75-3 *mm*

4. The electromagnetic spectrum

Electromagnetic waves can be produced by both electronic circuits and heated bodies at a certain temperature.

The main characteristics of the electromagnetic waves are correlated, this correlation being seen in the following figure.

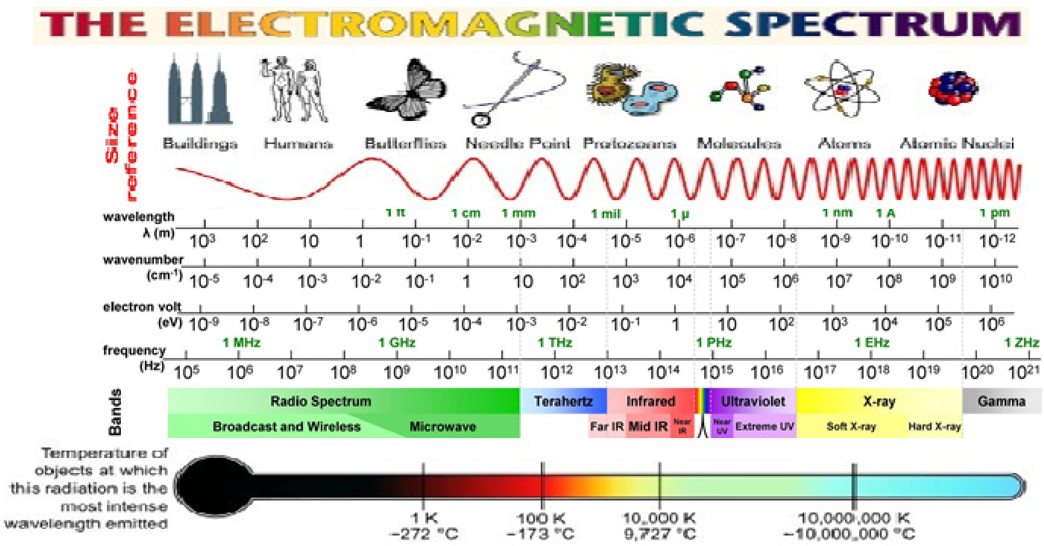


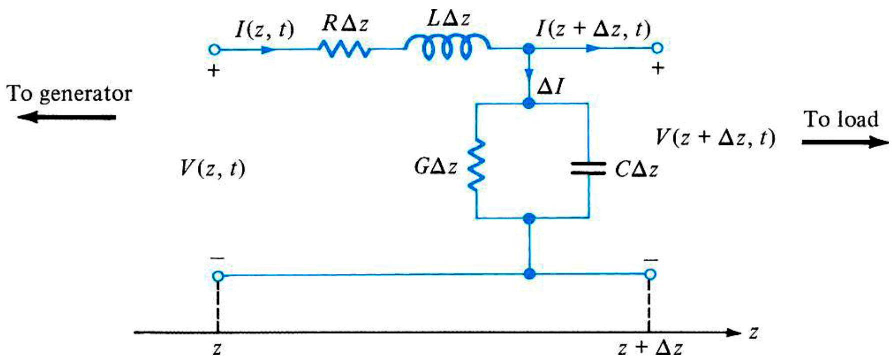
Figure 3.3. The electromagnetic spectrum

5. Transmission line (TL) theory (TEM Line)

A uniform transmission line is defined as the one whose dimensions and electrical properties are identical at all planes transverse to the direction of propagation.

5.1 Circuit Representation of TLs

A uniform TL may be modeled by the following circuit representation:



R: Series resistance per unit length of line (for both conductors (ohm/m)).

L: Series inductance per unit length of line (Henry/m).

G: Shunt conductance per unit length of line (mho/m).

C: Shunt capacitance per unit length of line (Farad/m).

The line is pictured as a cascade of identical sections, each of Δz long.

Since Δz can always be chosen small compared to the operating wavelength, an individual section of line may be analyzed using ordinary AC circuit theory. In the following analysis, we let Δz→0 , so the results are valid at all frequencies (hence for any physical time variation).

Applying the Kirchhoff's voltage law to the line section gives:

$$v(z,t) = (R\,\Delta z)\,i(z,t) + (L\,\Delta z)\frac{\partial i(z,t)}{\partial t} + v(z+\Delta z,t)$$

Rearranging:

$$\frac{v(z+\Delta z,t) - v(z,t)}{\Delta z} = -R\; i(z,t) - L\frac{\partial i(z,t)}{\partial t}$$

Letting Δz→0, we get,

$$\frac{\partial v(z,t)}{\partial z} = -R\, i(z,t) - L\frac{\partial i(z,t)}{\partial t}$$

Now, applying the Kirchhoff's current law to the line section gives:

$$i(z,t) = \left(G\Delta z\right)v\left(z+\Delta z,t\right) + \left(C\Delta z\right)\frac{\partial v(z+\Delta z,t)}{\partial t} + i(z+\Delta z,t)$$

Rearranging:

$$\frac{i(z+\Delta z,t) - i(z,t)}{\Delta z} = -G\, v(z+\Delta z,t) - C\frac{\partial v(z+\Delta z,t)}{\partial t}$$

Letting Δz→0:

$$\frac{\partial i(z,t)}{\partial z} = -G\, v(z,t) - C\frac{\partial v(z,t)}{\partial t}$$

Then, the time domain TL or telegrapher equations are:

$$\frac{\partial v(z,t)}{\partial z} = -R\, i(z,t) - L\frac{\partial i(z,t)}{\partial t}$$

$$\frac{\partial i(z,t)}{\partial z} = -G\, v(z,t) - C\frac{\partial v(z,t)}{\partial t}$$

The solution of these equations, together with the electrical properties of the generator and load, allows us to determine the instantaneous voltage and current at any time t and any place z along the uniform TL.

Lossless Line: For the case of perfect conductors (R=0) and insulators (G=0), the telegrapher equations reduce to the following form:

$$\frac{\partial^2 v(z,t)}{\partial z^2} - LC\frac{\partial^2 i(z,t)}{\partial t^2} = 0$$

$$\frac{\partial^2 i(z,t)}{\partial z} - LC\frac{\partial^2 i(z,t)}{\partial t^2} = 0$$

Although real lines are never lossless, losslessness approximation for practical TLs is very useful.

6. Transmission lines with sinusoidal excitation

We will only consider the sinusoidal steady-state solutions.

Transmission-Line Equations: Under sinusoidal steady state conditions, the TL equations take the form:

$$\frac{dV(z)}{dz} = -(R + j\omega L)I(z)$$
$$\frac{dI(z)}{dz} = -(G + j\omega C)V(z)$$

Where V(z) and I(z) are voltage and current phasors. The real sinusoidal voltage and current waveforms are obtained from:

$$v(z,t) = \mathrm{Re}\left[V(z)e^{j\omega t}\right]$$
$$i(z,t) = \mathrm{Re}\left[I(z)e^{j\omega t}\right]$$

6.1 Wave Propagation on a TL

The second order differential equations for V(z) and I(z) are:

$$\frac{d^2V(z)}{dz^2} - \gamma^2 V(z) = 0$$
$$\frac{d^2I(z)}{dz^2} - \gamma^2 I(z) = 0$$

where

$$\gamma = \alpha + j\beta = \left[(R + j\omega L)(G + j\omega C)\right]^{1/2}$$

γ = complex propagation constant

α = attenuation constant (Np/m)

β = phase constant (rad/m)

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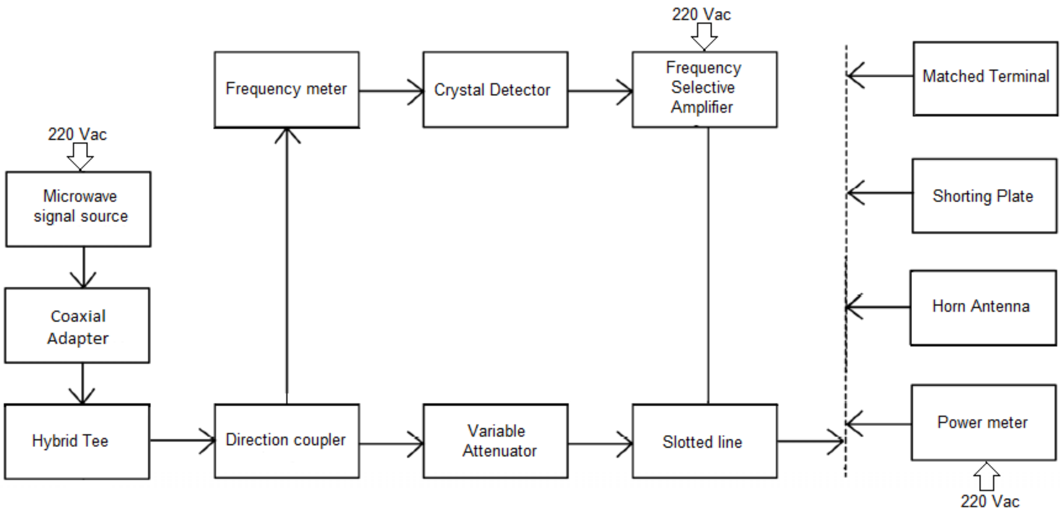
4. Experimental Section

Introduction

Microwave and light waves are both electromagnetic waves. They share the common phenomena of all waves, such as reflection, refraction, polarization, interference, and diffraction. However, as the wavelength of a microwave is about 4 orders larger than that of a visible light wave, the experimental phenomena and apparatus of the microwave are different.

DL 2594N 3cm waveguide experiment system module schematic diagram



This diagram is only informative because in the experiments that will be presented below, only some of the devices and components will be used.

Warning!

The microwave absorption is directed by the dielectric constant of the tissue.

As the speed of the electromagnetic waves is proportional to the reciprocal value of the square root of the dielectric constant, the resulting wavelength in the tissue can drop to a fraction of the wavelength in air; e.g., at 10 GHz the wavelength can drop from 3 cm to about 3.4 mm.

Because the oscillator used in this experiment unit has a relatively small power, the output is not dangerous to other body parts, but eyes can be permanently damaged!!!

Note

All the experimental works described in subchapters 4.1 to 4.10 will be made with the following device settings of the Microwave Signal Source (read on display):

Power up the Signal Source. Press the FREQ button. Adjust the microwave frequency to 10 GHz. The result is:

FREQUENCY = 10 GHz

Do not press the AMP button. The result is:

AMPLITUDE = 00 dB

Press the RF button. The result is:

RF = ON

4.1. Experiment 1: Crystal detector

Objectives

- To learn the basic theory and the operation of the crystal detector.

1. Theory

A. Crystal detector.

The crystal detector is a device capable of detecting microwave signals based on the "square law" characteristics. Point contact germanium or silicon crystal diodes are the most popular type of crystal detectors. Sometimes, a bolometer is used for microwave detection, although the device is mainly intended for microwave power measurements. A typical crystal detector circuit and associated characteristic curves of a crystal detector are presented in Figure 4.1.1 and Figure 4.1.2. The filter (input high-pass) is to separate the microwave frequencies from the DC output.

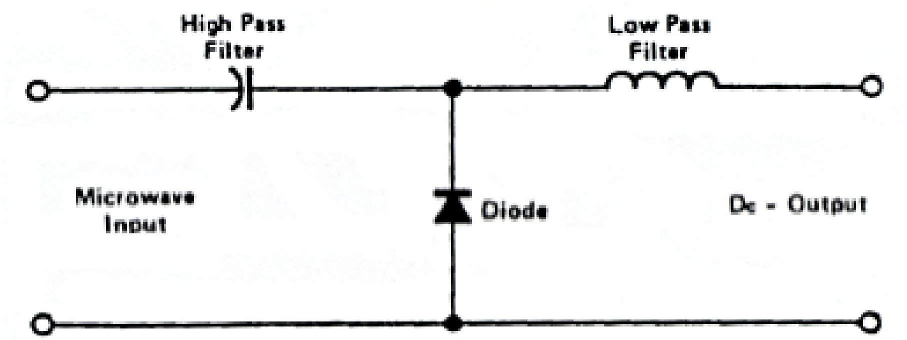


Figure 4.1.1. Typical crystal detector circuit

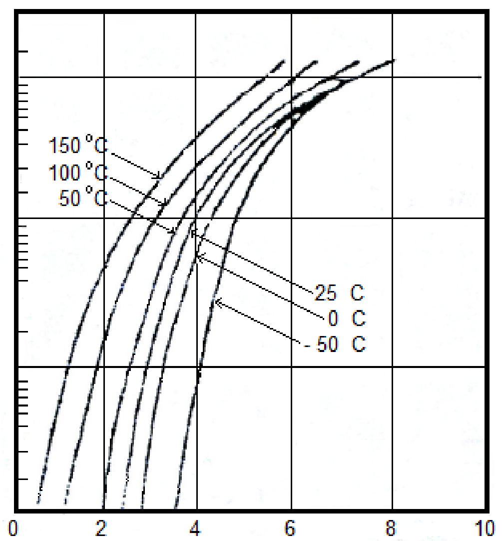


Figure 4.2. The V-I characteristics of a crystal diode. Forward Voltage

In Figure 4.1.2, we are interested in finding the relationship between the diode current and the diode voltage.

$$i = a_0 + a_1V + a_2V^2 + a_3V^3 \qquad (4.1\text{-}1)$$

Normally, the first three terms are sufficient to approximate the entire function. If the voltage is expressed as:

$V = A\cos\omega t$; where A is the amplitude and ω is equal to $2\pi f$

Substituting V into (4.1-1):

$$i = a_0 + a_1 (A\cos\omega t) + a_2 (A\cos\omega t)^2 + \dots \qquad (4.1\text{-}2)$$

Using:

$$\cos^2\omega t = 1/2(1 + \cos^2\omega t) \qquad (4.1\text{-}3)$$

$$i = a_0 + a_1 (A\cos\omega t) + (a_2A^2/2) (A\cos 2\omega t) + \dots \qquad (4.1\text{-}4)$$

Now, the characteristics of the square-law become clear. In equation (4.1-4), the DC component is contained in the $a_2A^2/2$ term.

The second harmonics is expressed as $(a_2A^2/2) (A\cos 2\omega t)$. Therefore, we can say that the current in the detector is proportional to the square of the amplitude A of the microwave voltage.

This concept is only valid up to a certain signal level. At higher signal levels, more terms may be needed in (4.1-4) and the diode is no longer considered as a square-law device.

In Figure 4.1.3, a complete equivalent circuit of a detector is presented.

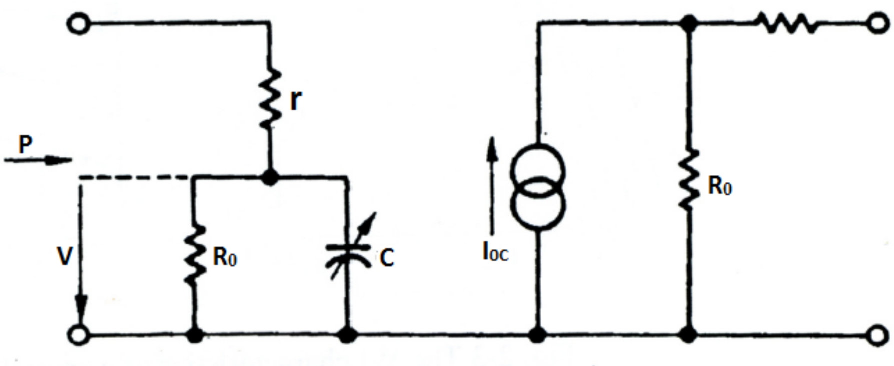


Figure 4.1.3. Equivalent circuit of a detector.

In Figure 4.1.3., R_0 and C represent the impedance of the junction and r is the body resistance of the diode. A figure of merit of a detector is the voltage and current sensitivity of the detection function which is expressed as:

$$\text{Voltage sensitivity} = \frac{\text{Open circuit voltage}}{\text{Input power}} = \frac{R_0 I_{dc}}{P_{in}} \qquad (4.1\text{-}5)$$

$$\text{Current sensitivity} = \frac{\text{Short circuit voltage}}{\text{Input power}} = \frac{R_0 /(r + R_0)}{P_{in}} \qquad (4.1\text{-}6)$$

In order to maximize the output power, it is necessary to match the microwave impedance of the diode to the characteristic impedance of the waveguide. Another reason for the impedance matching is to minimize the reflection from the detector since the measurement accuracy is affected by the reflection.

The minimum signal level a diode can detect depends on the noise in the diode. The ability of a diode to detect a signal in the presence of noise is called the tangential sensitivity (TSS) of a detector.

The ability of a diode to detect a signal in the presence of noise is called the tangential sensitivity (TSS) of a detector.

A graphical illustration of the concept of TSS is sketched in Figure 4.1.4.

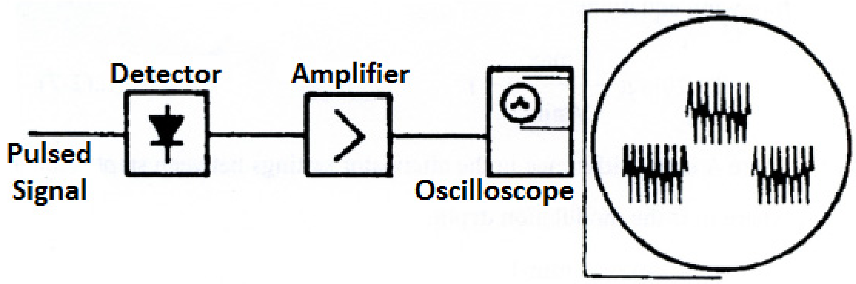


Figure 4.1.4. The TSS of a diode.

In Figure 4.1.4, a microwave signal which is pulse modulated is detected, amplified and displayed on an oscilloscope. The real meaning of TSS is there has to be a minimum microwave power level to make the pulse ride above the noise.

The TSS of a detector is very much dependent upon the bandwidth of the amplifier which follows the detector since the noise amplitude on the scope is determined by the bandwidth. One MHz bandwidth and -50dBm of TSS are typical values of a microwave detector.

B) Amplitude Modulation

In the previous section we saw that a carrier without modulation can communicate very little information. The signal can, therefore, be considered as having two parts:

1. the information signal – this is the message we need to send and could be speech, text, or pictures;
2. the carrier – this will be the method of passing the information signal from the transmitter to the receiver, usually a radio wave, microwave, light wave or electrical current.

In Amplitude Modulation (AM), as its name suggests, it is the amplitude of the carrier wave which becomes altered by the instantaneous value of the information signal. The following diagram illustrates this effect.

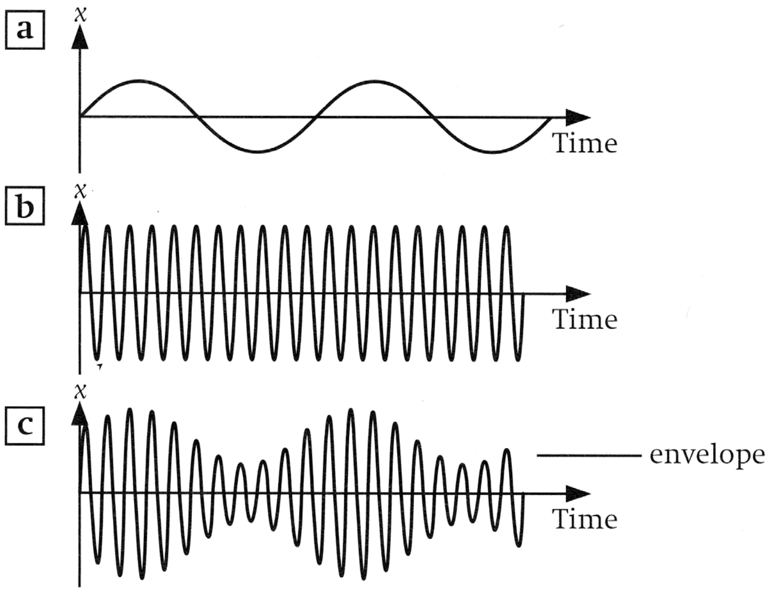


Diagram 'a' shows the information signal.

Diagram 'b' shows the unmodulated carrier signal.

Diagram 'c' shows the modulated carrier signal.

When the AM carrier wave is analysed, we find that it has three different components.

- The original carrier frequency f_c and the original amplitude A_c.
- A wave of frequency f_c-f_i, called the lower side frequency.
- A wave of frequency f_c+f_i, called the upper side frequency.

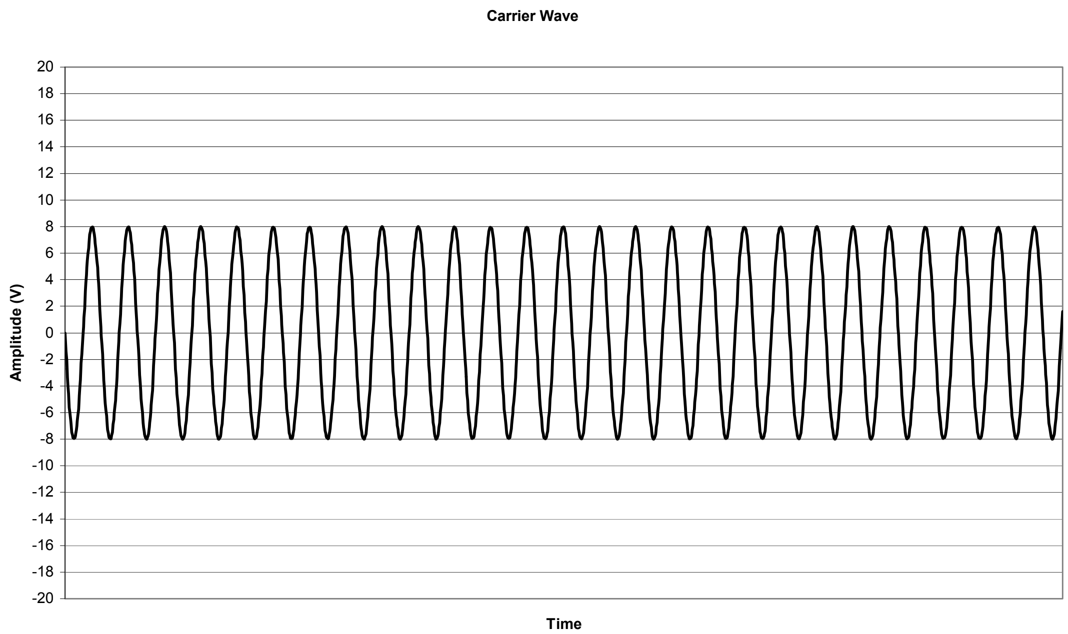
Other observations that can be made are as follows:

- The original signal frequency f_i has disappeared.
- The maximum amplitude of the AM carrier is A_c+A_i.
- The minimum amplitude of the AM carrier is A_c-A_i.
- The carrier frequency f_c must be greater than the information frequency f_i.
- The carrier amplitude A_c must be greater than the information amplitude A_i.

C) Depth of Modulation

Depth of modulation is the term given to how much the amplitude of the carrier wave is affected by the information signal. This is best illustrated by considering some examples.

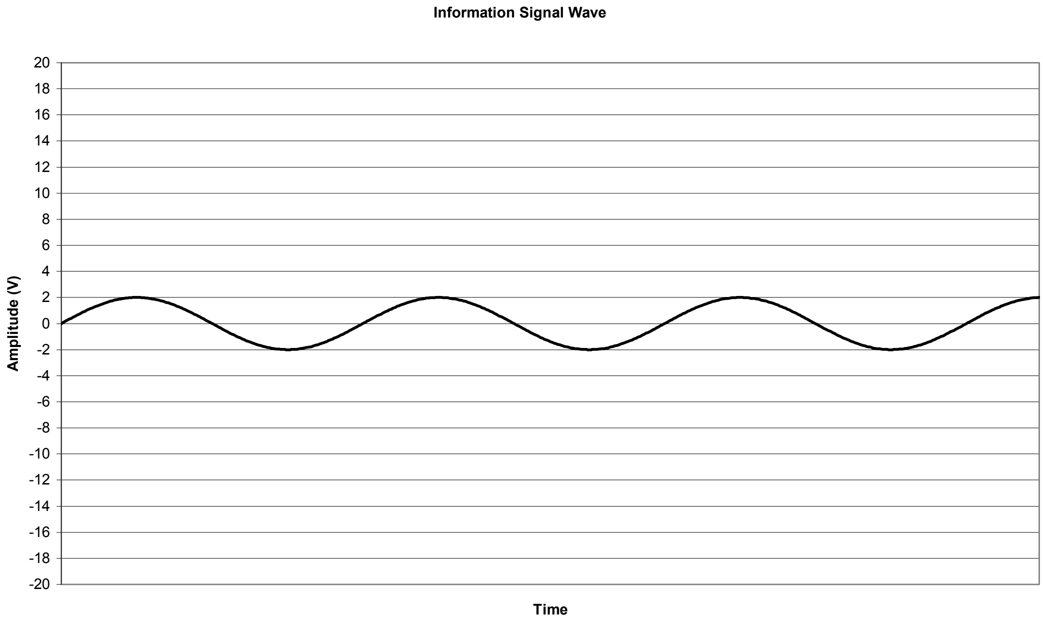
To demonstrate the effect, the same carrier signal will be used as shown in the following diagram. The amplitude of the carrier is 8V, and is of high frequency, no units have been added to the time axis as these are illustrative diagrams only.

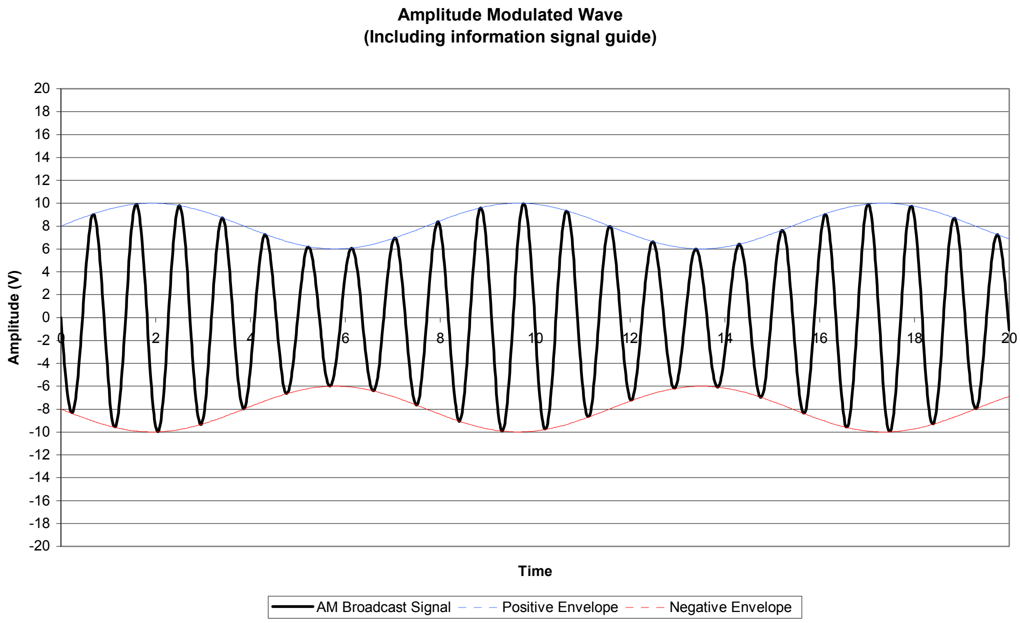


We will now add a number of different information signals of lower frequency, but with amplitudes of 2V, 4V, 6V, 8V and 10V, to see the effect on the modulated signal.

Example 1.

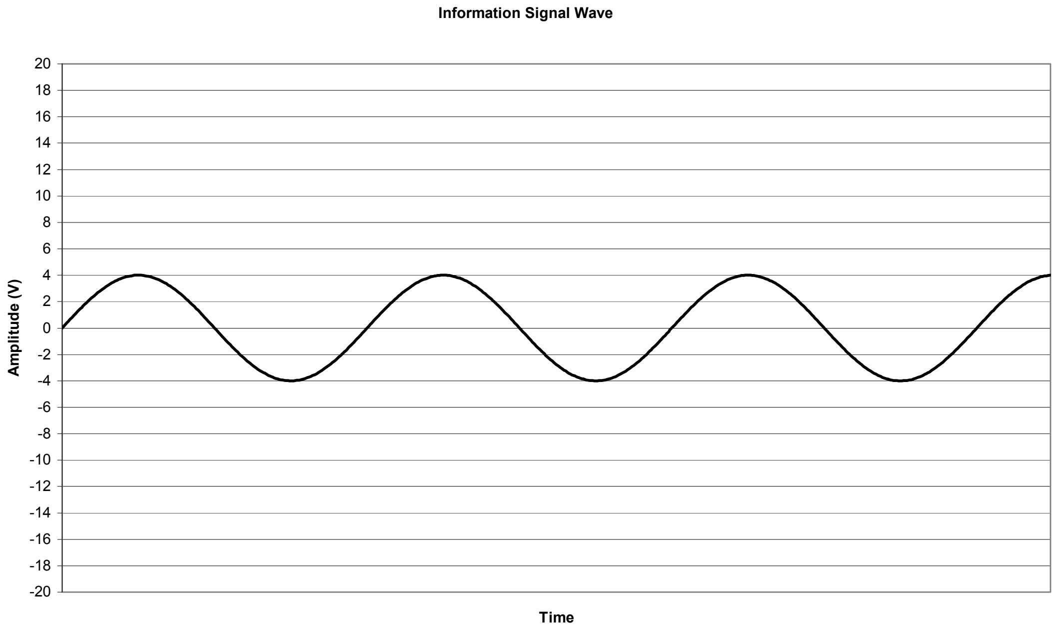
In this example, the information signal has an amplitude of 2V.

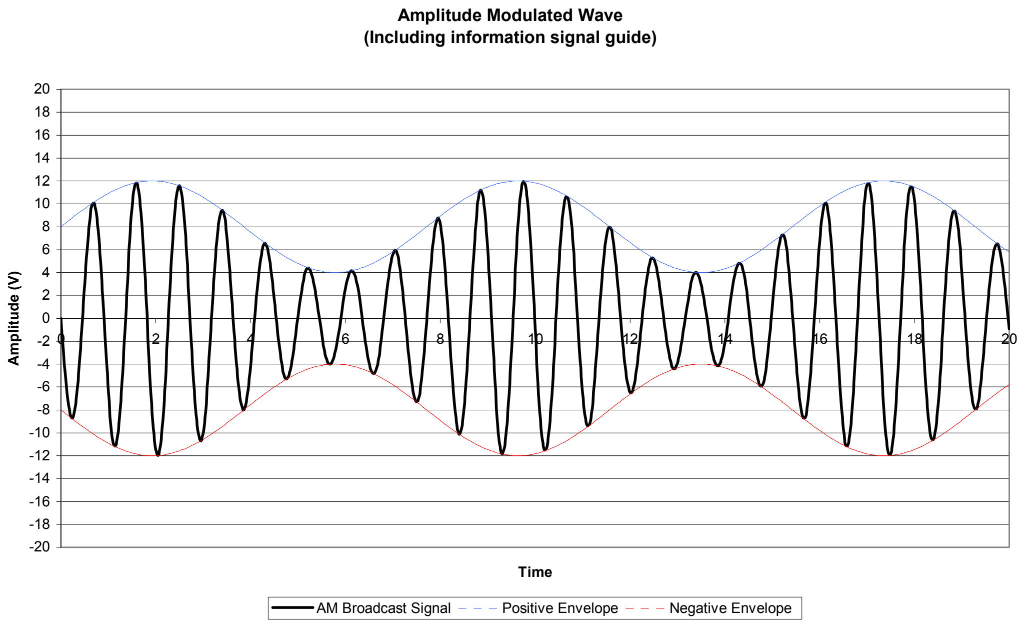




Example 2.

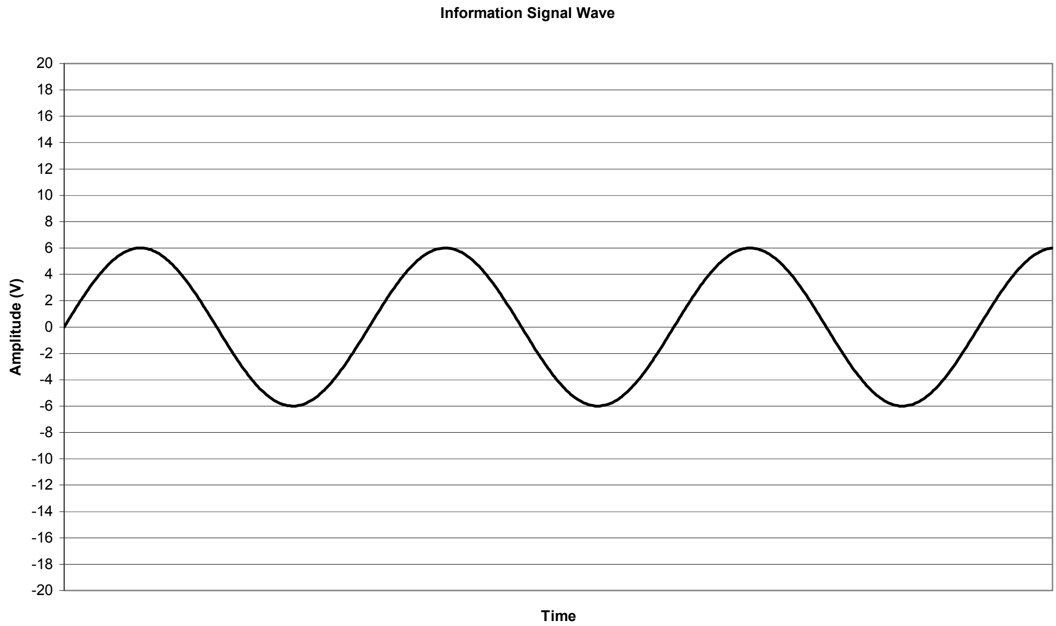
In this example, the information signal has an amplitude of 4V.

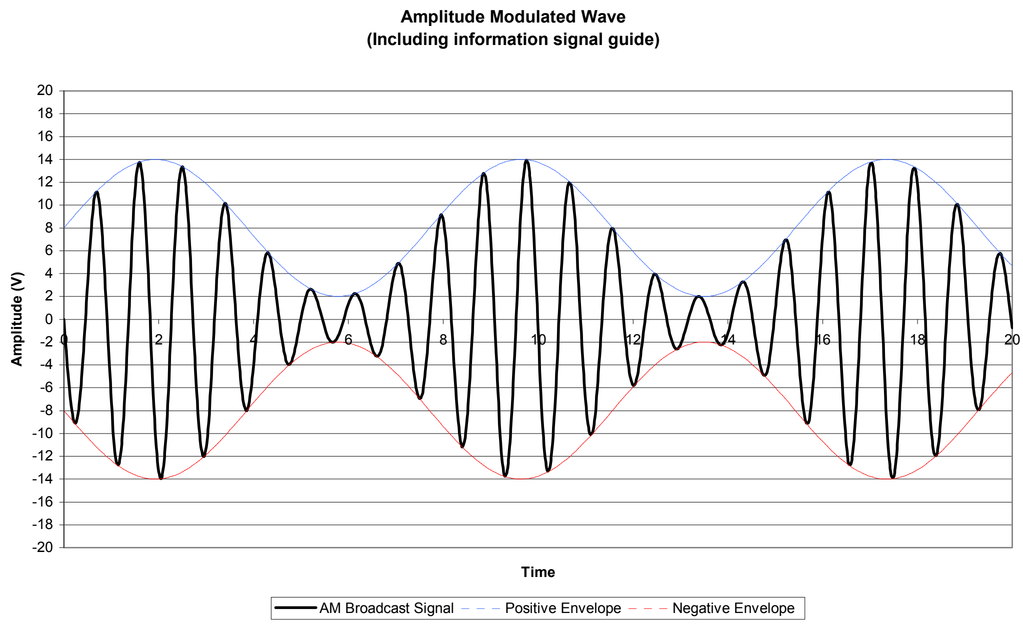




Example 3.

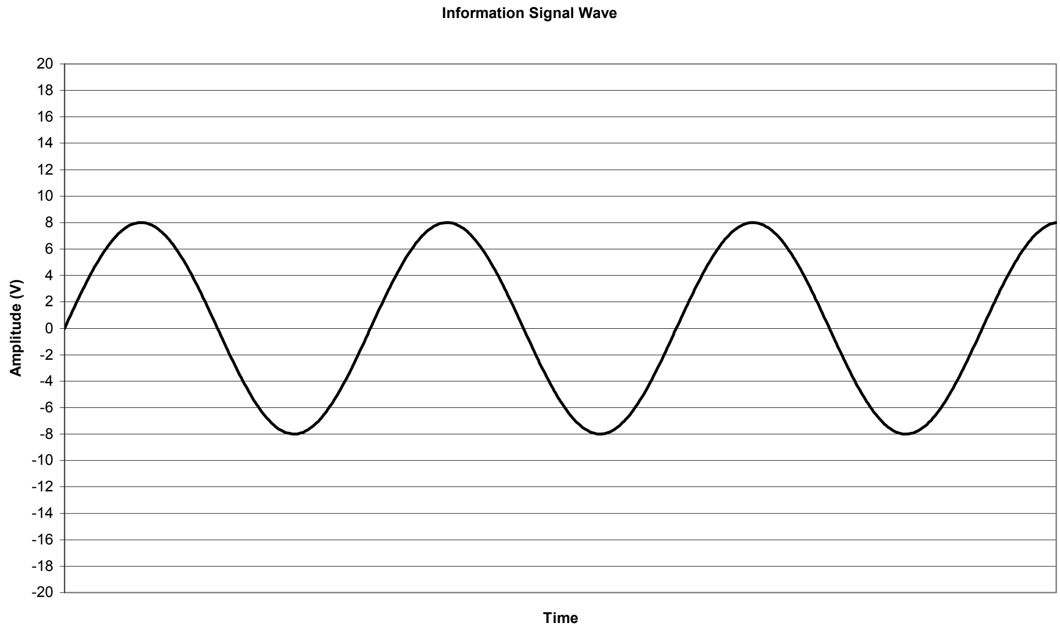
In this example, the information signal has an amplitude of 6V.

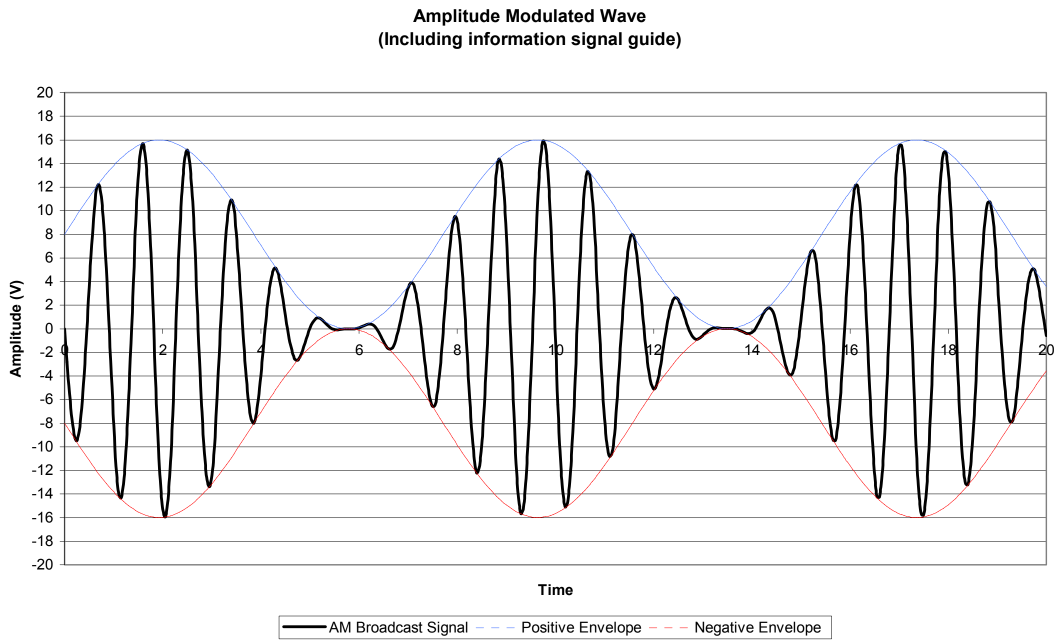




Example 4.

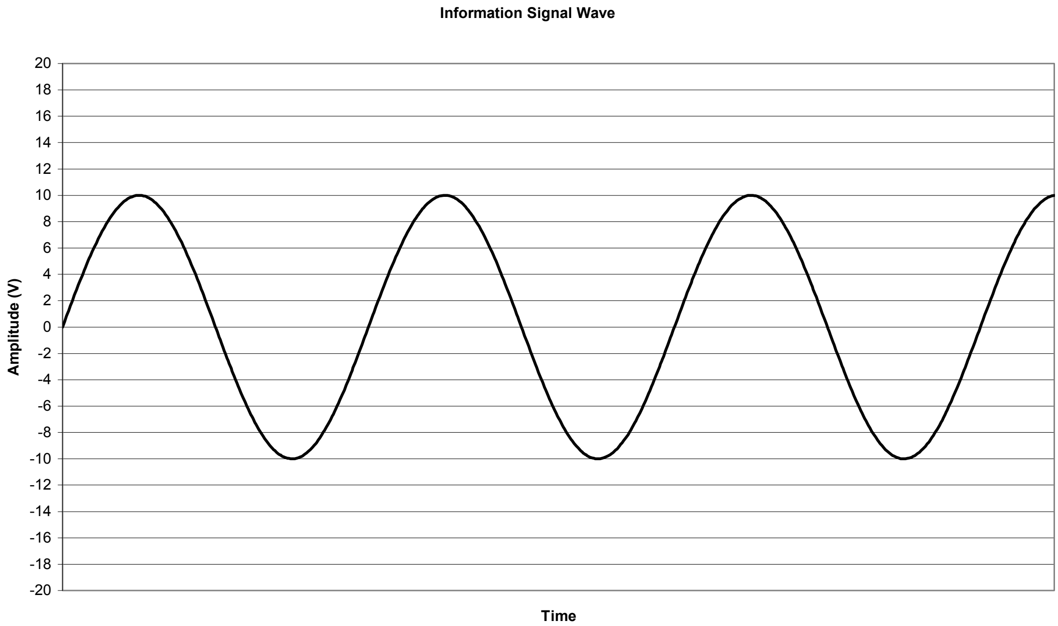
In this example, the information signal has an amplitude of 8V.

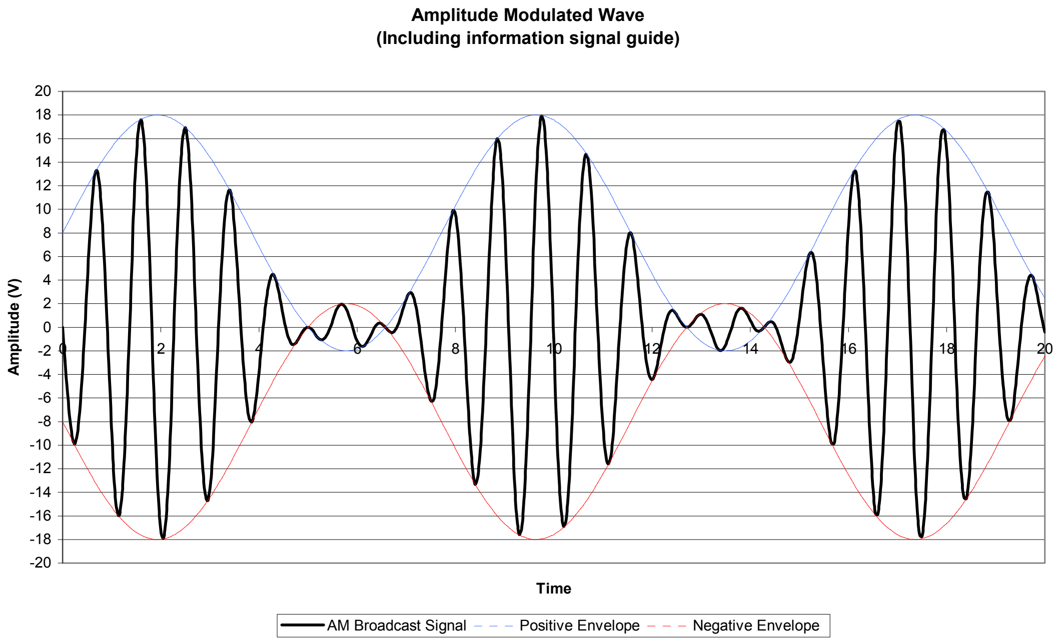




Example 5.

In this example, the information signal has an amplitude of 10V.





The previous diagrams should have given you some indication of what happens when the information signal is amplitude modulated with a carrier of fixed amplitude. As the signal amplitude increases, the carrier amplitude becomes significantly more varied.

When the signal amplitude and carrier amplitude are equal as in Example 4, there is a point where the carrier amplitude actually reaches 0 V. In the case of Example 5, where the information signal amplitude is larger than that of the carrier, an amplitude modulated signal is produced, but there are areas where the information signal overlaps the 0V carrier amplitude and this would lead to distortion, if it actually occurred during transmission. This variation in amplitude is known as the depth of modulation.

Being able to calculate the depth of modulation more accurately would be beneficial, and can be achieved simply by using the following equation. Depth of modulation is given the symbol m and the equation is:

$$m = \frac{(V_{max} - V_{min})}{(V_{max} + V_{min})} \times 100\%$$

V_{max} is the maximum amplitude of the AM signal.

V_{min} is the minimum amplitude of the AM signal.

If we consider Example 1, V_{max} = 10V, V_{min} = 6V. Therefore, we can calculate the depth of modulation by using:

$$m = \frac{(V_{max} - V_{min})}{(V_{max} + V_{min})} \times 100\%$$

$$m = \frac{(10 - 6)}{(10 + 6)} \times 100\%$$

$$m = \frac{4}{16} \times 100\% = 25\%$$

Using this formula is all well and good provided that you are given a graph or AM wave to work with, but what if you only have the amplitude of the carrier and the information signal ?

All is not lost, so do not worry. There is another version of the depth of modulation formula which deals only with the amplitudes of the carrier and information signals. The formula is as follows:

$$m = \frac{A_s}{A_c} \times 100\%$$

Where A_s = information signal amplitude, and

A_c = carrier signal amplitude

Let us consider Example 1 again, now looking at the amplitudes of the signal and carrier only. A_s = 2V, A_c = 8V, therefore the depth of modulation is given by:

$$m = \frac{A_s}{A_c} \times 100\%$$

$$m = \frac{2}{8} \times 100\% = 25\%$$

So, now it does not matter whether we are using an amplitude modulated carrier or dealing with an individual carrier and information signal. We will always be able to determine the depth of modulation.

Remember that anything over 100% modulation will result in distortion of the received signal, and that in practice the depth of modulation does not usually exceed 80%, to provide a safety zone and maintain signal clarity.

2. Experiment Procedure

A. Square wave modulation.

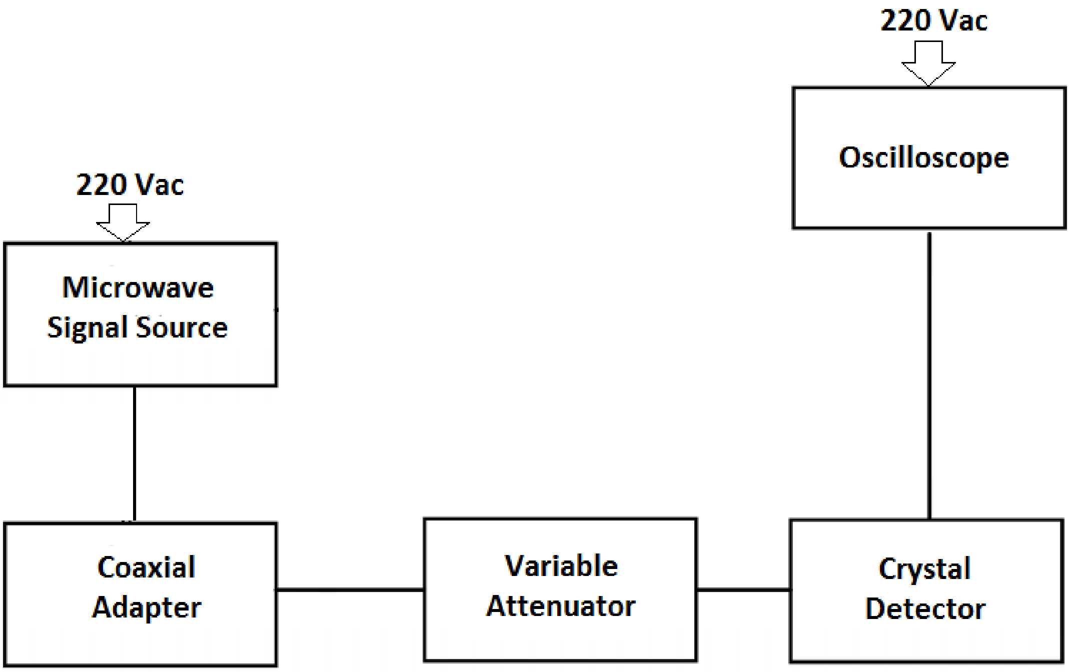


Figure 4.1.5. Schematic representation of the experiment.

Summary of the Experiments

(1) Set up the equipment as shown in Figure 4.1.5 and/or Figure 4.1.6.

(2) Power up the Signal Source. Press the FREQ button. Adjust the microwave frequency to 10 GHz.

(3) Set the variable attenuator to 10.

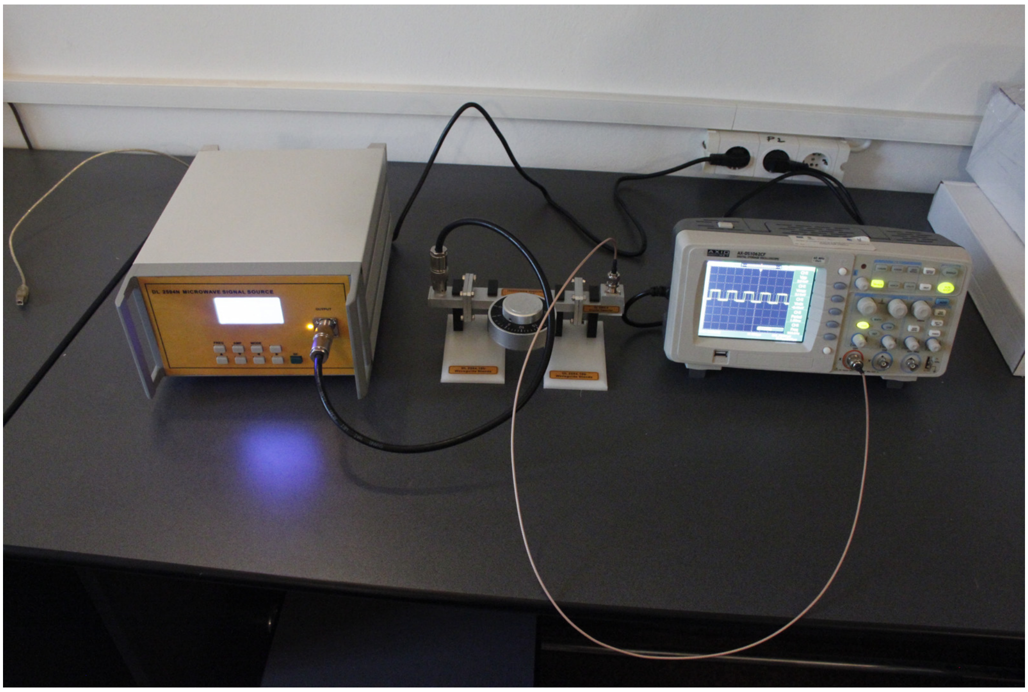


Figure 4.1.6. Real representation of the experiment.

(4) Press the MODE button. Adjust the value of the modulator signal to 1 kHz. Read and write the V_{max} and V_{min} values on the oscilloscope screen. The modulation depth can be expressed in dB (steps 4, 5 and 6 are performed) by the value of A_{dB} or it can be calculated as the fraction using the formula (4.1-8).

(5) Adjust the scope so that the top of the square wave aligns to the zero level on the screen.

(6) Adjust the attenuator so that the bottom of the square wave aligns to the zero level on the screen. Read and write the value from the variable attenuator. It is very possible that you can not obtain zero level on the screen even if the Variable Attenuator is adjusted to position 20.

(7) Calculate the modulation depth using the following equations.

$$AdB = 20\log\left(\frac{V\max}{V\min}\right) \qquad (4.1\text{-}7)$$

where A is the difference in the attenuator settings between step (3) and (6) and m is the modulation depth.

$$m = \frac{V\max / V\min^{-1}}{V\max / V\min^{+1}} \qquad (4.1\text{-}8)$$

A sketch of the waveforms of the square wave modulation and detection is shown in Figure 4.1.7.

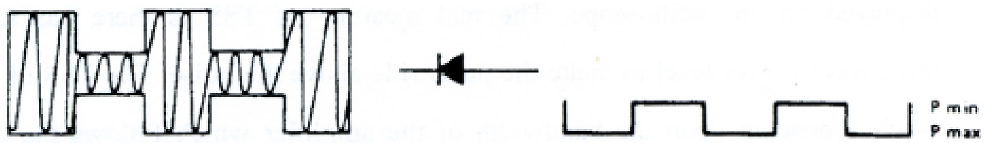


Figure 4.1.7. Square wave modulation and detection.

As one can see from Figure 4.1.7, the attenuator setting deviation A can be expressed as:

$$AdB = 10\log\frac{P\max}{P\min} = 20\log\frac{V\max}{V\min} \qquad (4.1\text{-}9)$$

The V_{max} and V_{min} values can be read from the oscilloscope screen as shown in the Figure 4.1.8.

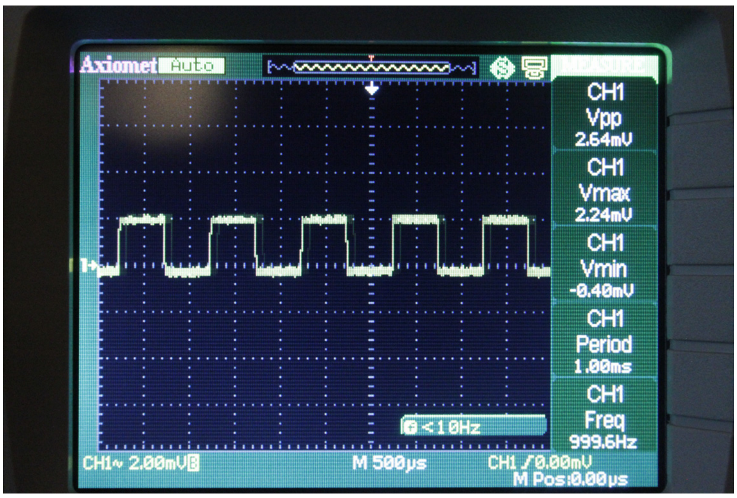


Figure 4.1.8. Square wave modulation and detection on the oscilloscope screen.

B. The square law characteristics of a crystal detector.

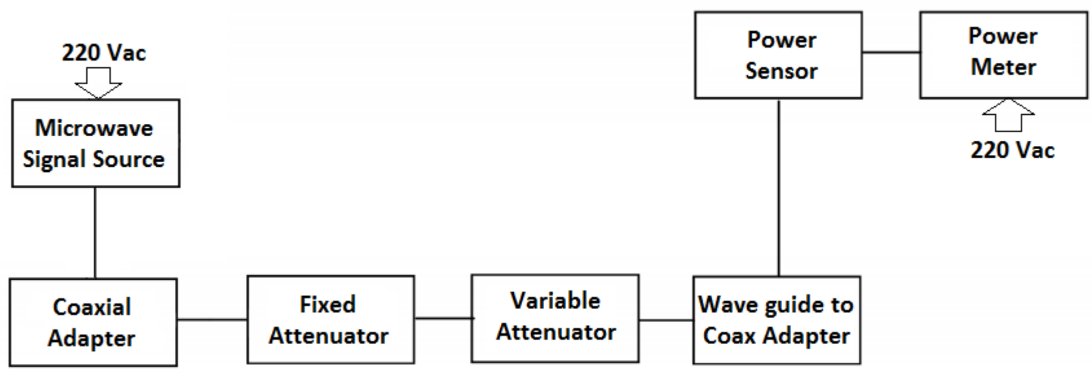


Figure 4.1.9. Schematic representation of the experiment.

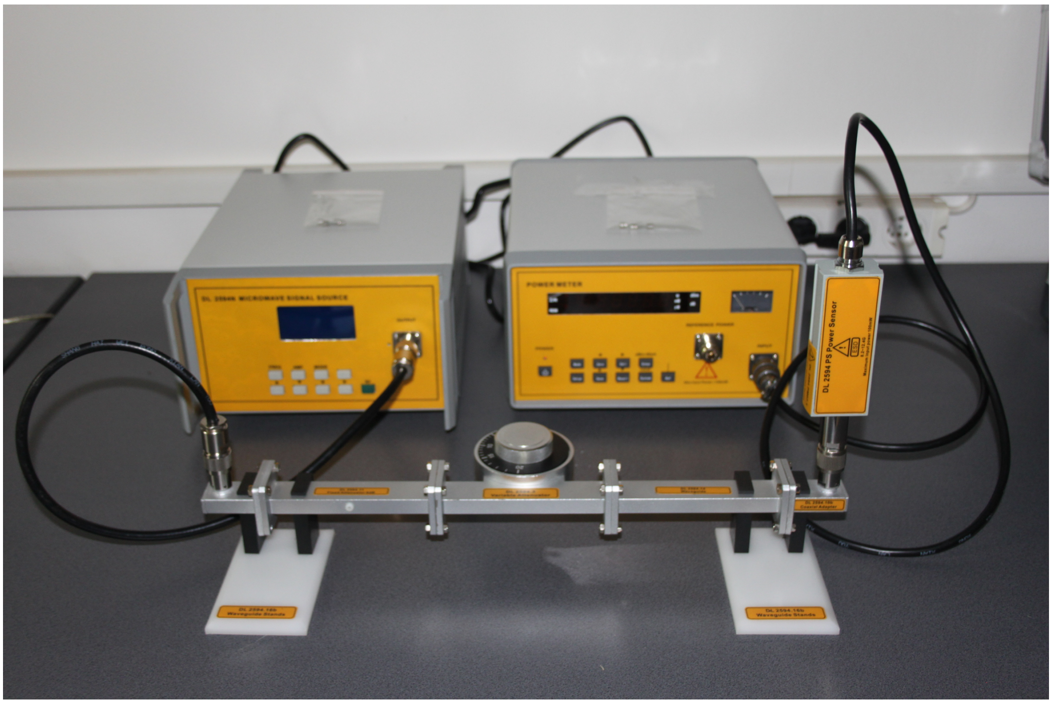


Figure 4.1.10. Real representation of the experiment.

To identify each component in the assembly, it is recommended to view and to zoom the following figure.

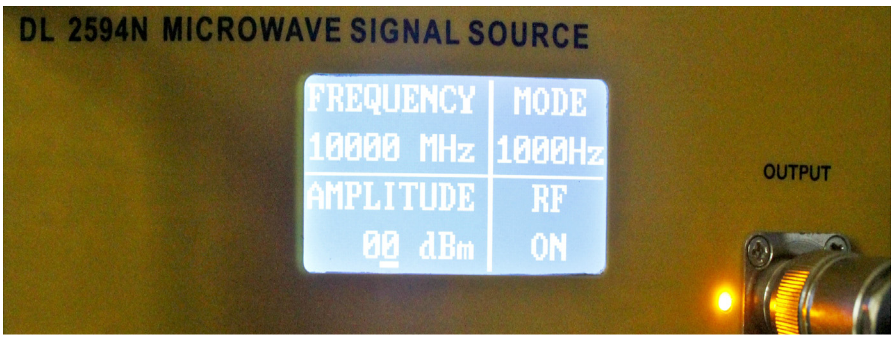
Figure 4.1.11. Real representation of the experiment with inscriptions view.

Summary of the Experiment

In the text and images in the following figures are presented the manual action modes for preparing the devices so that they are stable in operation and calibrated according to the instructions in subchapters 1.2.1 and 1.2.2.

a) Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

d) Press to ON position the power button of the Power Meter and let it run for 30 minutes minimum.

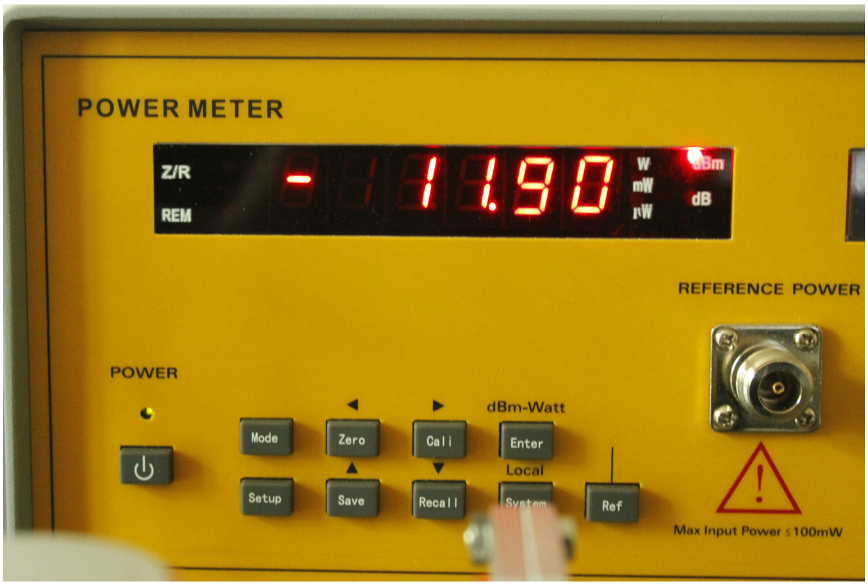
e) Press the Setup button once. The display will show the set of instances as in the figure below:

f) If the number displayed on the right of the display is not 10, press the Save button several times successively, which in this case is meant to increase the value of the number by one unit each time you press.

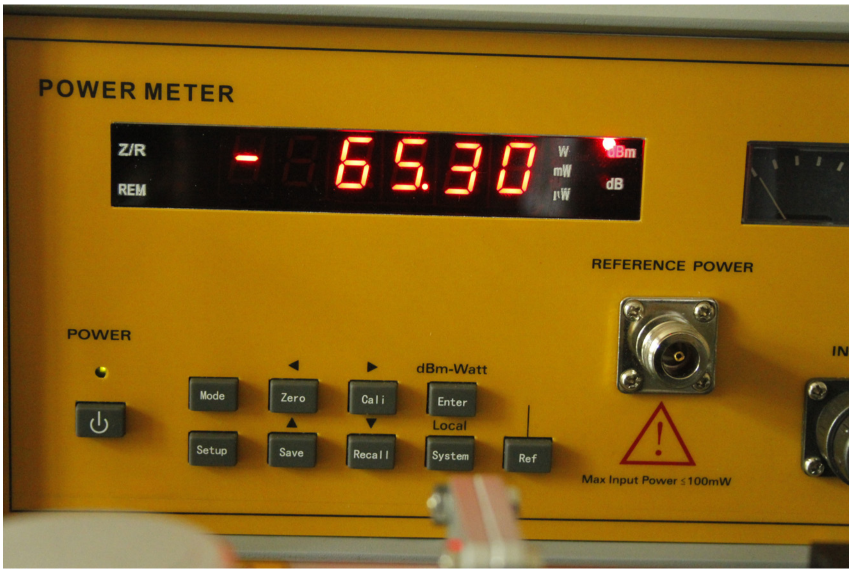
g) After the number is 10, press the Setup button one time again. The display will show the set of instances as in the figure below:

h) Do not modify anything at this setting.

i) Press the Enter button once. The display will show the set of instances as in the figure below:



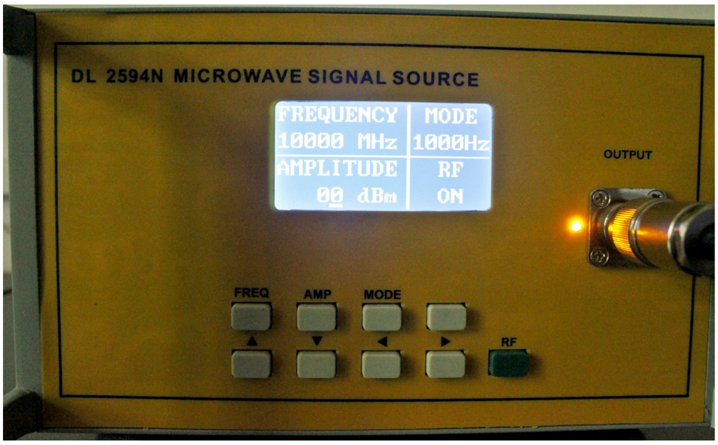
j) If the Microwave Signal Source RF is OFF on the display, then the Power Meter display will show the information as in the picture below:



k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

1) *Before using this equipment, you should read the instructions and operations in the user manual carefully!*
2) *The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument;.*
3) *The instrument can work more stable after 30 minutes of preheating after initialization.*
4) *Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display.*

(1) Apply power to the Gunn oscillator. Also apply 1kHz square wave. At this point, modulation should take place (see figure below).



(2) Set the variable attenuator to 0. The power meter should indicate between -0.01 dBm and -0.04 dBm (see figure below).

Referring to the conversion table on the power meter, change mW reading to dBm. For example, 0.1mW is equal to -10dBm.

(3) As shown in Figure 4.1.12 and/or Figure 4.1.13, replace the waveguide to the coax adapter, the power sensor and the power meter with a crystal detector and a SWR indicator. Adjust the modulating frequency such that the deflection of the SWR meter is maximized (see the images below).

a) In analog systems, the full scale may be defined by the maximum voltage available, or the maximum deflection (full scale deflection or FSD) or indication of an analog instrument such as a moving coil meter or galvanometer.

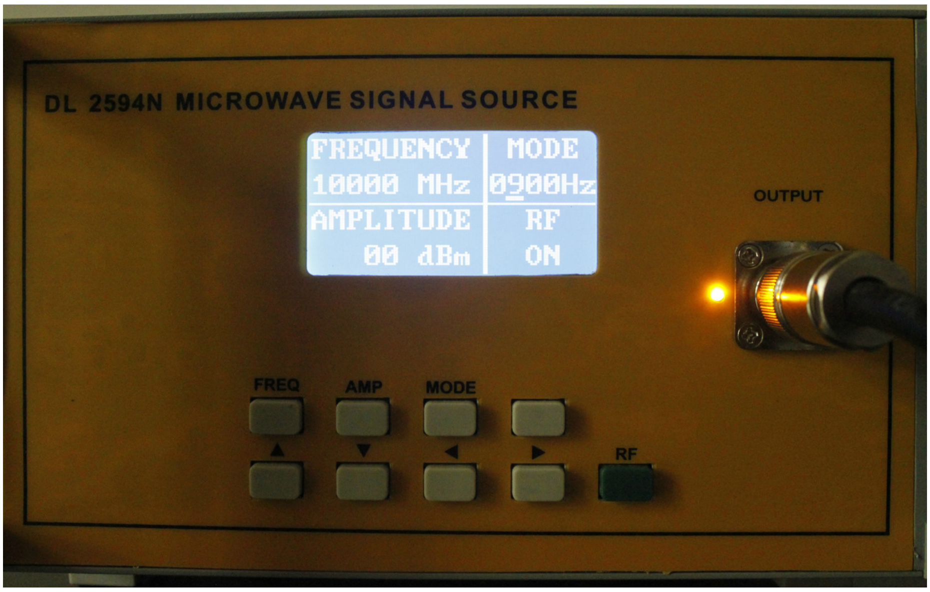
b) Full scale deflection refers to the full range of motion of an analog 'needle' of an analog meter, or a galvanometer.

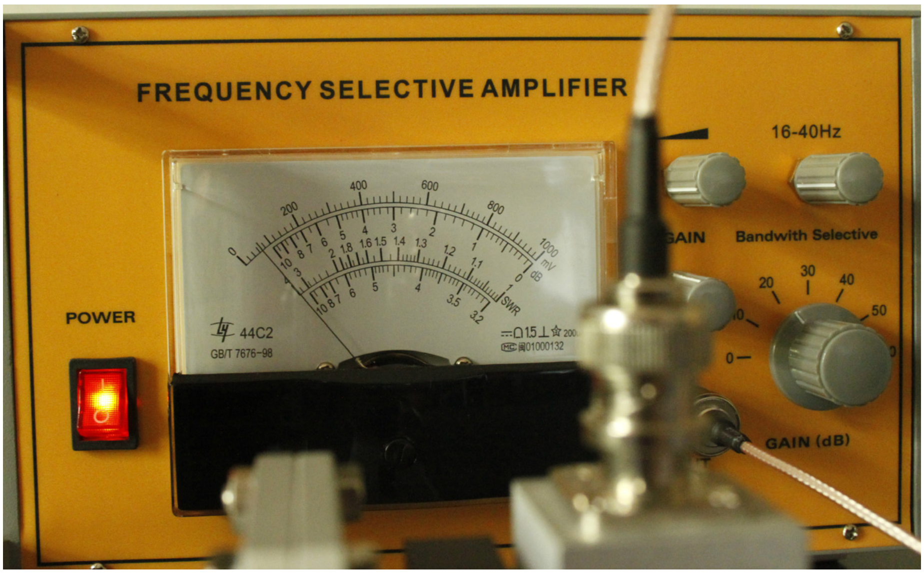
c) In the above meter, the amount that the needle moves away from 0 is called the deflection. Full scale deflection is, well, deflection that goes all the way to the end of the scale, in other words, full scale. Anything beyond this scale is not really measurable by this insturment, and so the term 'full scale' actually originates from the older term and concept of 'full scale deflection'. Be it an analog coil-actuated meter, a digital ADC, or even a DAC (though it is used to mean the output range available, not measurement), full scale is now used to mean the complete minimum to maximum range of something. We have mostly dropped the deflection part, however, as deflection is rarely relevant anymore.

d) Note that it needs not be referring to voltage specifically. One could correctly say '0 to 100mA full scale' for example.

e) Full scale deflection has its history in analogue meters where the moving needle could "deflect" and that deflection was proportional to what it measured i.e. current, voltage or power. FSD is the maximum deflection the needle moved and this represents the "full scale".

f) Full scale is also a term that defines how much an output can rise or fall to i.e. the limits to which an output can be raised or lowered to. In a simple opamp circuit, the FS is usually a couple of volts inside the power rails. The terms are interchangeable generally and we have seen an output defined to have this or that full scale deflection (although strictly speaking it should be defined as full scale and not FSD).





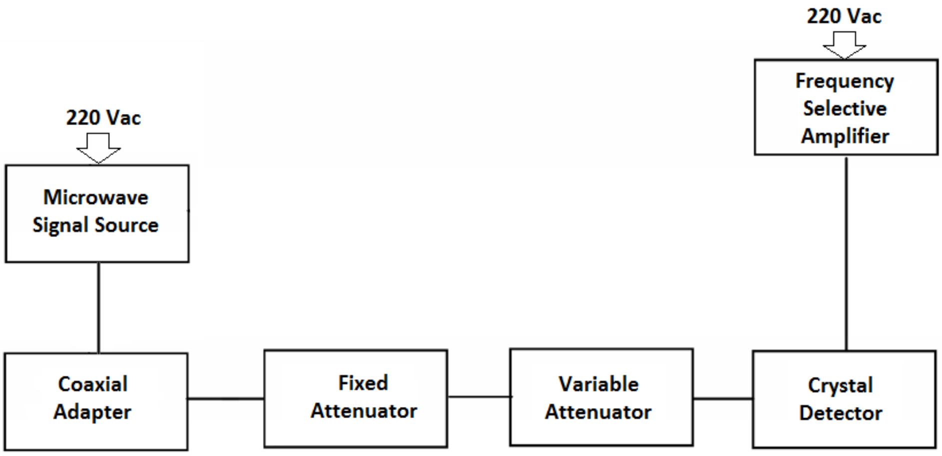


Figure 4.1.12. Setup diagram for measuring the square law characteristics of a crystal detector.

Figure 4.1.13. Real representation of the experiment.

To visually distinguish the inscriptions on each component of the assembly, it is recommended to zoom in on this figure.

Note

In the images in the following figures the manual action modes for assembling the components in the assembly are presented. These techniques, used and shown in the figures, are valid for assembling the microwave components in all the experiments in this manual.

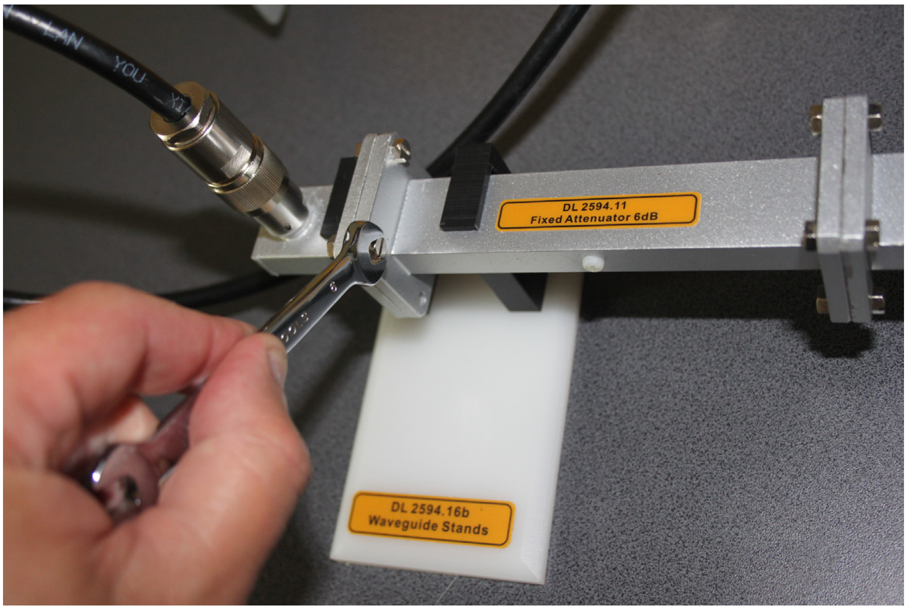


Figure 4.1.14. How to assemble components using screw, nut, and fixed key.

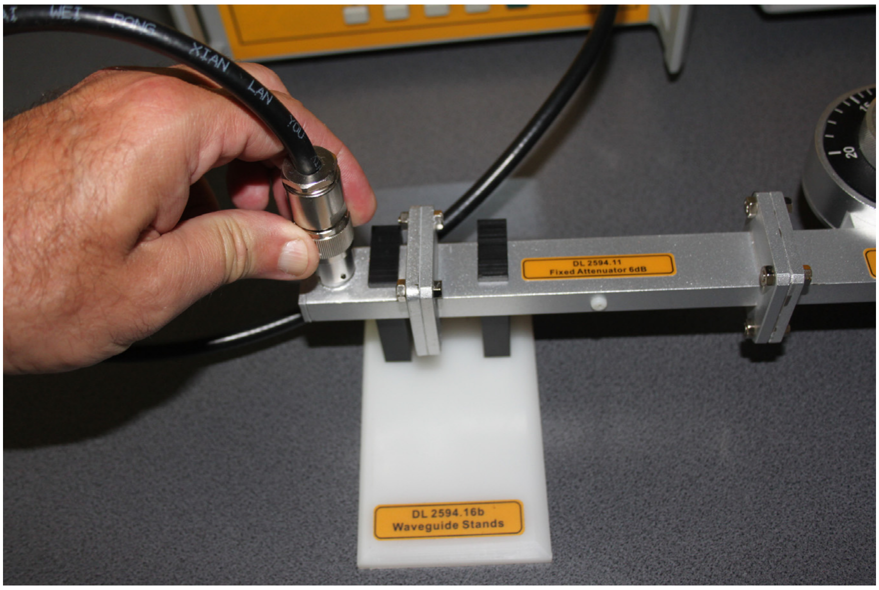


Figure 4.1.15. How to connect the Coaxial Adapter to the line cord with the Microwave Signal Source.

Figure 4.1.16. How to connect the line cord with the Microwave Signal Source.

Figure 4.1.17. How to connect the line cord with the Power Meter.

Figure 4.1.8. How to connect the Power Sensor with the Coaxial Adapter.

Figure 4.1.19. How to connect the BNC line cord with the SWR Meter.

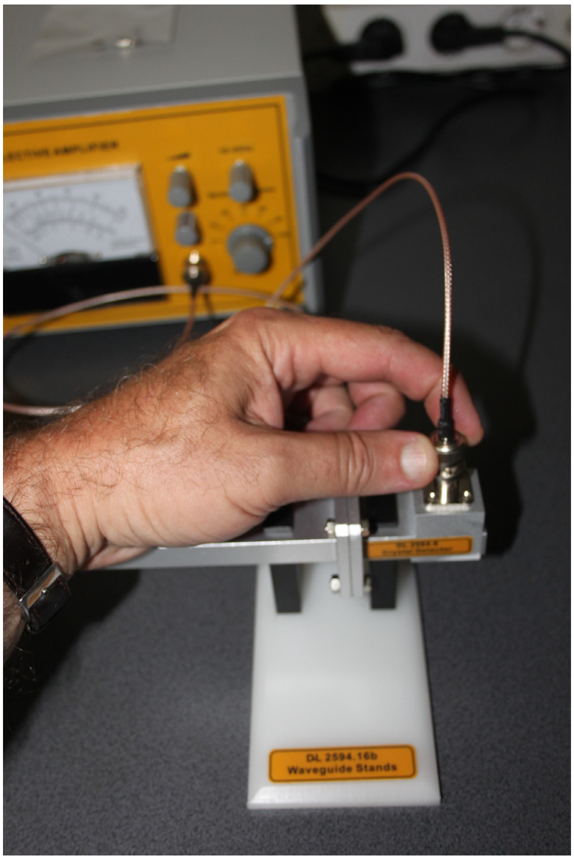


Figure 4.1.20. How to connect the BNC line cord with the Crystal Detector.

(4) Select a range on the SWR meter. Adjust the gain control of the SWR meter to obtain a convenient reading on the dB scale. Once the range and the gain control are set, do not touch the gain control.

(5) Vary the attenuator from 0 to 20 in 1 by 1 step increment. At each step, record the SWR meter deflection (in dB) (using the Frequency Selective Amplifier) and the gain range in Table 4.1-1.

Table 4.1-1 Input power vs attenuation and SWR reading.

A	INPUT POWER	SWR - INDICATOR		DEFLECTION AND RANGE
		DEFLECTION	RANGE	
	dBm	dB	dB	dB

4.2. Experiment 2: Propagation modes, wavelength and phase velocity in waveguide

Objectives

- To learn the theory of waveguide.
- To experiment the propagation characteristics of the microwave in free space as well as in waveguide.

1. Theory:

A microwave waveguide is a hollow metallic pipe having rectangular or circular cross section. In our experiments, rectangular waveguides are used. The following mathematical analysis are based on the rectangular waveguides. Also it is assumed that the user has a basic knowledge about the wave equation. Circular waveguides can be analyzed in the similar way using cylindrical coordinate. We begin our analysis with the wave equation. The reduced wave equation is expressed as:

$$\Delta^2\Phi + K^2\Phi = 0 \qquad (4.2\text{-}1)$$

where (x, y, z) is the scalar wave function and k, the wave number, is defined as:

$$K^2 = \omega^2 \mu \varepsilon \qquad (4.2\text{-}2)$$

In the rectangular coordinate system, (4.2-1) becomes:

$$\frac{\vartheta^2\Phi}{\vartheta x^2} + \frac{\vartheta^2\Phi}{\vartheta y^2} + \frac{\vartheta^2\Phi}{\vartheta z^2} + K^2\Phi = 0 \qquad (4.2\text{-}3)$$

The rectangular coordinate system is established in this case such that z is the direction of propagation as shown in Figure 4.2.1.

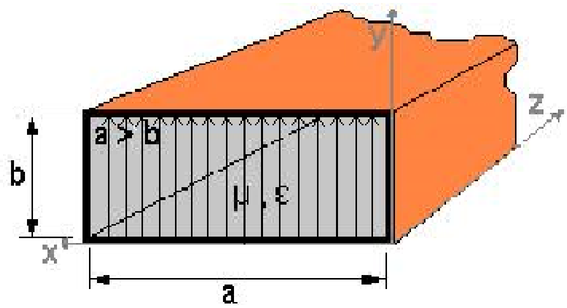


Figure 4.2.1. Rectangular waveguide in a rectangular coordinate system.

Our goal is to obtain a solution that has a form of:

g(x,y) f(z) (4.2-4)

where f is a function of z only and g is a function of x and y or other suitable transverse coordinates only.

Solving (4.2-3) for ϕ using the separation of variables method gives:

$$\Phi=\{A_1\cos(K_xX)+A_2\sin(K_xX)\}\{B_1\cos(K_yX)+B_2\sin(K_yX)\} \quad (4.2\text{-}5)$$

Where $K_x{}^2+K_y{}^2=K^2$

and $\frac{\vartheta}{\vartheta z}=-j\beta g$ (βg=2/wavelength)

since the propagation takes place only in the z-direction. A wave propagating in the positive z direction is represented by $e^{-j\beta gz}$ and, therefore, $e^{-j\beta gz}$ corresponds to a wave propagating in the negative z-direction.

Three types of propagation modes are of particular interest for us:

- TEM (transverse electromagnetic) modes: in these modes, both electric and magnetic fields are transverse to the direction of propagation. Thus, there is no field components in the direction of travel. TEM modes do not exist in waveguides.
- TE {transverse electric) modes or H-modes: in these modes, no electric field exists in the z-direction. However, a magnetic field does exist in the z-direction. All the field components, therefore, may be derived from the axial component Hz of the magnetic field.
- TM (transverse magnetic) modes or E-modes: in these modes, no magnetic field exists in the z-direction. However, an electric field does exist in the z-direction. All the field components, therefore, may be derived from the axial component E_z of the electric field.

TE and TM modes are the modes of propagation in a hollow empty waveguide. We will continue our efforts in mathematically deriving field components for TE modes. The inside walls of the waveguide are assumed to be made out of a perfect conductor ($\sigma = \infty$). Also, the waveguide is assumed to be filled with perfect dielectric (σ = 0). These conditions are necessary to simplify the field solutions.

(1) TEmn modes.

The equation (4.2-5) can be rewritten for Hz. Considering only for +z direction.

$$Hz=(A_1\cos K_xX+A_2\sin K_xX)(B_1\cos K_yX+B_2\sin K_yX)(C_1e^{-j\beta gz})=De^{-j\beta gz} \quad (4.2\text{-}6)$$

The boundary conditions are applied at the waveguide walls: the normal component of the transverse magnetic field must vanish at the perfectly conducting waveguide walls. Also, the tangential electric field also vanishes on the waveguide walls. Then, the requirements on "D" as was defined in (4.2-6) are:

$$\frac{\vartheta D}{\vartheta x}=0 \ at \ x=0, a \quad (4.2\text{-}7)$$

$$\frac{\vartheta D}{\vartheta x}=0 \ at \ y=0, b \quad (4.2\text{-}8)$$

Applying (4.2-7) and (4.2-8) to (4.2-6) specifies the values of the characteristic constants K_x and K_y.

$K_x = (n\pi/a)$ n = 0, 1, 2, 3…

$K_y = (m\pi/a)$ m = 0, 1, 2, 3…

Using the above relations and substituting A_1B_1 = Anm, the solutions for "D" are:

$$D = Anm\cos\frac{n\pi X}{a}\cos\frac{n\pi Y}{b} \quad (4.2\text{-}9)$$

For n=0, 1, 2, …; m=0, 1, 2, …; and n=m≠0.

The final form of H_z is now:

$$H_z = Anm\cos\frac{n\pi X}{a}\cos\frac{n\pi Y}{b}e^{-j\beta gz} \quad (4.2\text{-}10)$$

The associated transverse E and H fields are obtained from (4.2-10) and the Maxwell's equations in rectangular coordinates:

$$E_x = \frac{j\omega\mu m\pi}{K_c^2 b} A_{nm} \cos\frac{n\pi X}{a} \sin\frac{n\pi Y}{b} e^{-j\beta gz} \qquad (4.2\text{-}11)$$

$$E_y = \frac{j\omega\mu m\pi}{K_c^2 b} A_{nm} \sin\frac{n\pi X}{a} \cos\frac{n\pi Y}{b} e^{-j\beta gz} \qquad (4.2\text{-}12)$$

$$H_x = \frac{j\omega\mu m\pi}{K_c^2 b} A_{nm} \sin\frac{n\pi X}{a} \cos\frac{n\pi Y}{b} e^{-j\beta gz} \qquad (4.2\text{-}13)$$

$$E_y = \frac{j\omega\mu m\pi}{K_c^2 b} A_{nm} \cos\frac{n\pi X}{a} \sin\frac{n\pi Y}{b} e^{-j\beta gz} \qquad (4.2\text{-}14)$$

It should be noted that:

$$K_C^2 = (\frac{n\pi}{a})^2 + (\frac{n\pi}{b})^2 =$$

the cut off wave number for the nm-th mode. Also,

$$\beta_g = \sqrt{K^2 - K_C^2}$$ and n=m$\neq$0.

The significance of the integer n and m: the value of n or m indicates the number of half cycle variations of each field component with respect to X and Y. In other words, each combination of the m and n values represent a different field configuration (or mode) in the waveguide.

(2) TM modes: Very much the same steps are required to obtain the field solutions for the TM modes except that, this time, H_z must be set to zero.

***Characteristics of the rectangular waveguide*.**

(1) Cut off frequency and cut off wavelength. The exponential form of $e^{-j\beta gz}$ represents a wave travelling in the +z direction. Let us re-examine the relationship of:

$$\beta_g = \sqrt{K^2 - K_C^2}$$

i) K > Kc : The βg is real and $e^{-j\beta gz}$ is indeed travelling in +z direction (propagating).

ii) K < Kc : The β_g is imaginary and the propagation mode decays rapidly with the distance z in the +z direction, resulting in propagation cut off. The frequency separating the propagation and no-propagation is called the cut-off frequency. Since ωc=2πfc,

$$\omega_C \sqrt{\mu\varepsilon} = K_C = \sqrt{\left(\frac{n\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \qquad (4.2\text{-}15)$$

$$fc = \frac{1}{2\pi\sqrt{\mu\varepsilon}} \sqrt{\left(\frac{n\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

Also, from:

$$K = \omega\sqrt{\mu\varepsilon}$$

and replacing with ω=2πf and:

$$\sqrt{\mu\varepsilon} = \frac{1}{f\lambda}$$

Then, $K = 2\pi/\lambda$, let λ_c be the cut-off wavelength when $K=K_c$:

$$\frac{2\pi}{\lambda_c} = \sqrt{\left(\frac{n\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \tag{4.2-16}$$

$$\frac{2\pi}{\lambda_c} = \frac{2}{\sqrt{\left(\frac{n\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}}$$

(2) Wavelength in the rectangular waveguide.

Let λ_g be the guide wavelength, from:

$$\beta_{G2} = K_2 - K_{C2},\ \beta_g = \frac{2\pi}{\lambda g},\ K = \frac{2\pi}{\lambda} \text{ and } K_C = \frac{2\pi}{\lambda c}$$

$$\left(\frac{2\pi}{\lambda g}\right)^2 = \left(\frac{2\pi}{\lambda}\right)^2 - \left(\frac{2\pi}{\lambda c}\right)^2 \tag{4.2-17}$$

$$\lambda g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{\lambda c}\right)^2}} \tag{4.2-18}$$

where λ is the wavelength in free space.

In order to support the propagation in the waveguide, $\lambda<\lambda_c$ (λ_c is required). This implies the fact that λ_g is greater than λ in the waveguides. In other words, the guide wavelength is longer than the wavelength in the free space.

(3) Phase velocity.

The phase velocity or the velocity of a constant-phase point in a waveguide is readily obtained from the frequency and the guide wavelength:

$$V_p = f \bullet \lambda_g \tag{4.2-19}$$

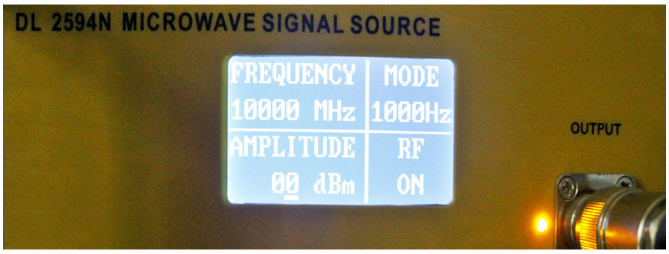
It should be noted from (3-19) that the phase velocity in the waveguide can exceed the speed of light in free space, which is 3×10^8 m/sec.

2. Experiment procedure

In the text and images in the following figures are presented the manual action modes for preparing the devices so that they are stable in operation and calibrated according to the instructions in subchapters 1.2.1 and 1.2.16.

a) Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

d) Press to ON position the power button of the Power Meter and let it run for 30 minutes minimum.

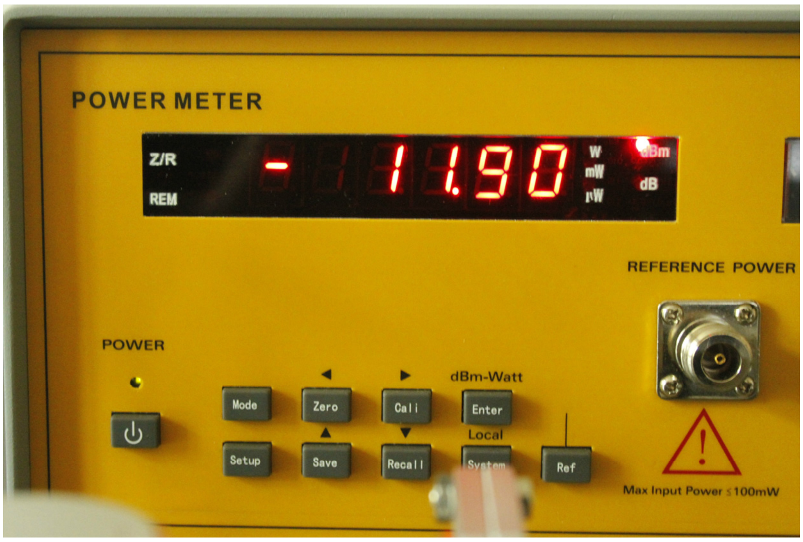
e) Press the Setup button once. The display will show the set of instances as in the figure below:

f) If the number displayed on the right of the display is not 10, press the Save button several times successively, which in this case is meant to increase the value of the number by one unit each time you press.

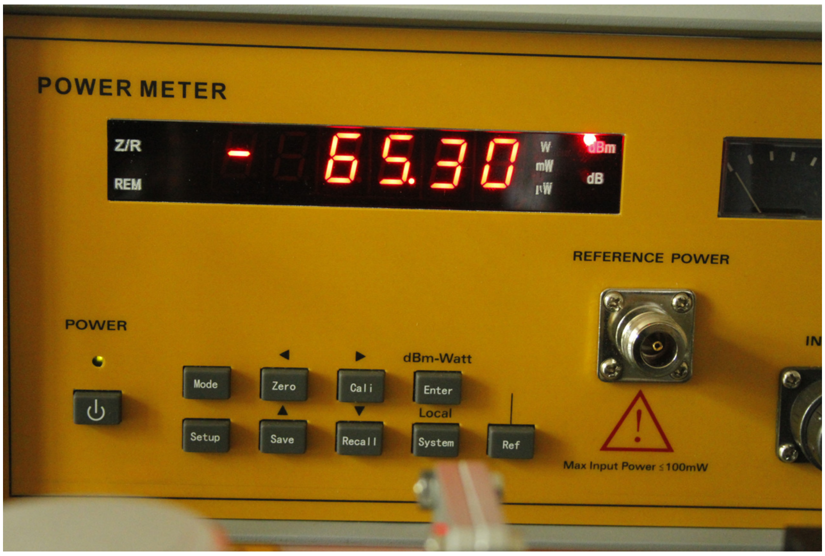
g) After the number is 10, press the Setup button once again. The display will show the set of instances as in the figure below:

h) Do not modify anything at this setting.

i) Press the Enter button once. The display will show the set of instances as in the figure below:



j) If the Microwave Signal Source RF is OFF on the display, then the Power Meter display will show the information as in the picture below:



For the Frequency Selective Amplifier (SWR) the following settings will be made:

a) Adjust the Gain Adjust Knob in the middle position.

b) Adjust the Frequency Tuning Knob in the middle position.

c) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales: 1 ~ 4 and 3.2 ~ 10.

d) Gain selective switch: select the current coarse amplifier gain. The gain range is from 0 to 60 db, with a 10 db step.

e) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, the gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

f) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

g) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity.

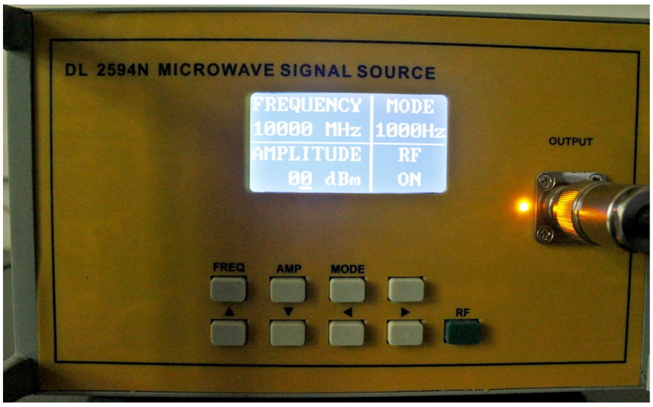
h) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

Set up the equipment as shown in Figure 4.2.2.

A. Frequency measurement.

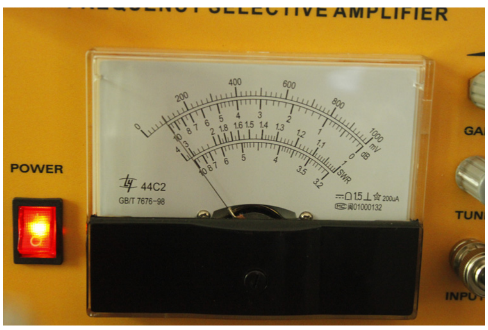
(1) Apply power to the Microwave Signal Source. Also, set 1kHz modulation mode.

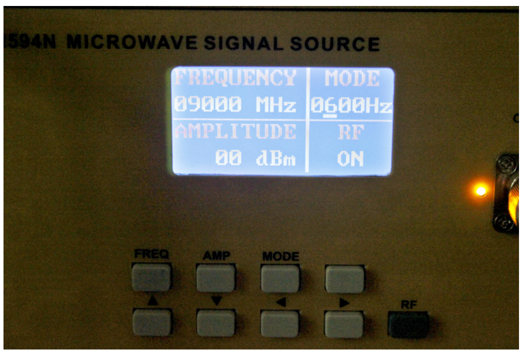
(2) At this point, modulation should take place (see the figure below).



(3) Adjust the variable attenuator to 10dB. Set the Frequency Selective Amplifier (SWR meter) such that the meter indicates approximately the middle of the scale (see the figure below).

(4) Adjust the frequency modulation of the Microwave Signal Source so that the SWR indication is maximized (see the figures below).





(5) Turn the frequency meter until there is a significant drop in the SWR indicator. Record the frequency in Table 4.2-1. De-tune the frequency meter.

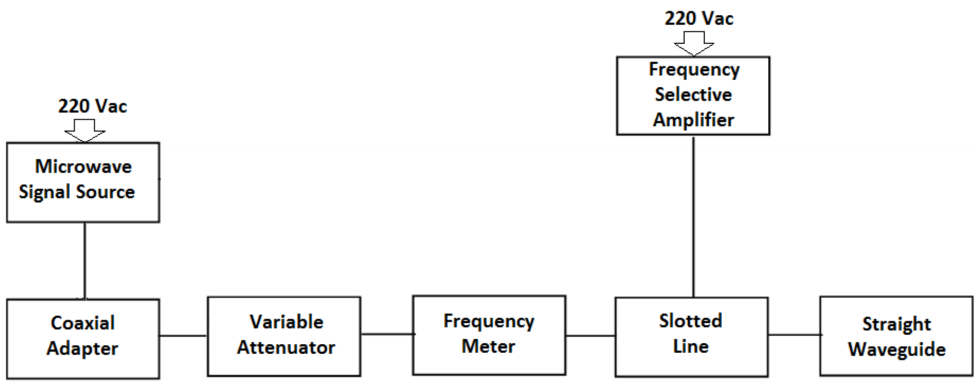


Figure 4.2.2. Equipment setup for measurements of frequency, λ_g and λ.

Figure 4.2.3. Real equipment setup for measurements of frequency, λ_g and λ.

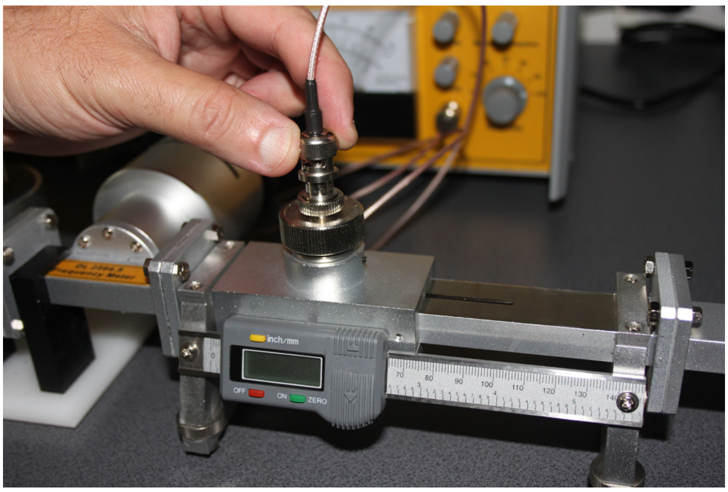
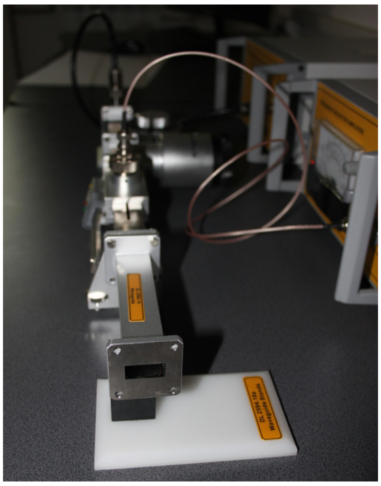


Figure 4.2.4. How to connect the BNC line cord with the Slotted Line.

The end of the waveguide is open (without the short circuit plate)! This is illustrated in the following figure.



B. Measurement of free space wavelength and with the shorting plate.

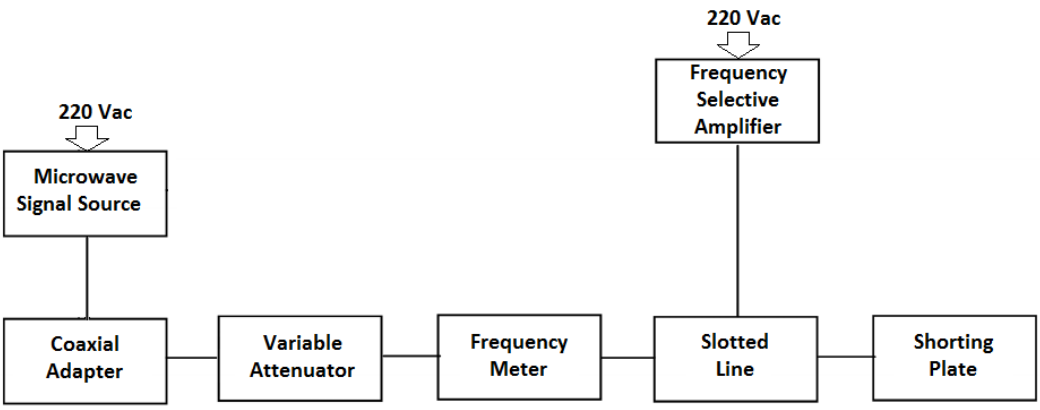


Figure 4.2.5. Equipment setup for measurements of frequency, λ_g and λ with the Shorting Plate

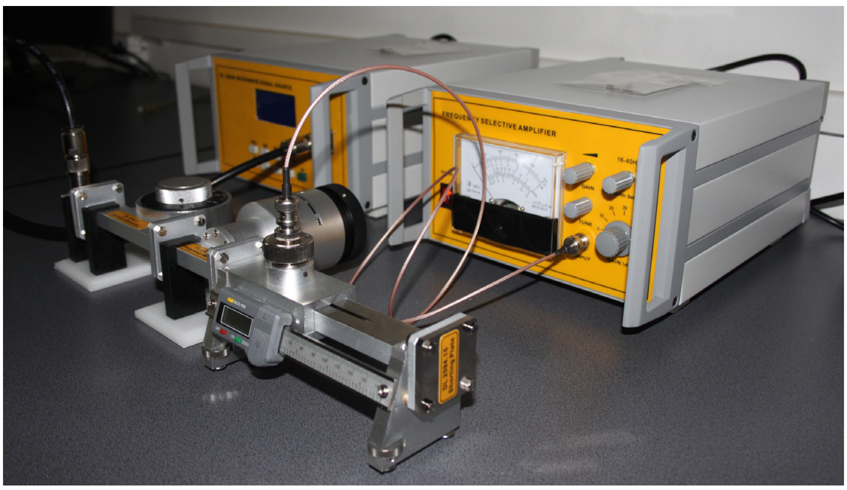
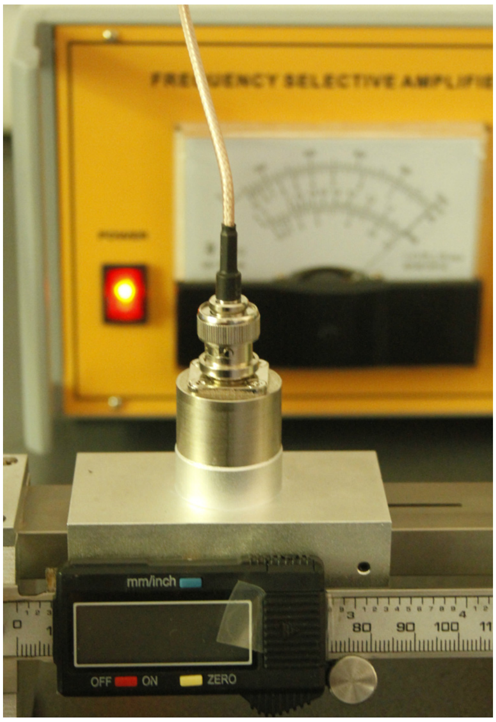


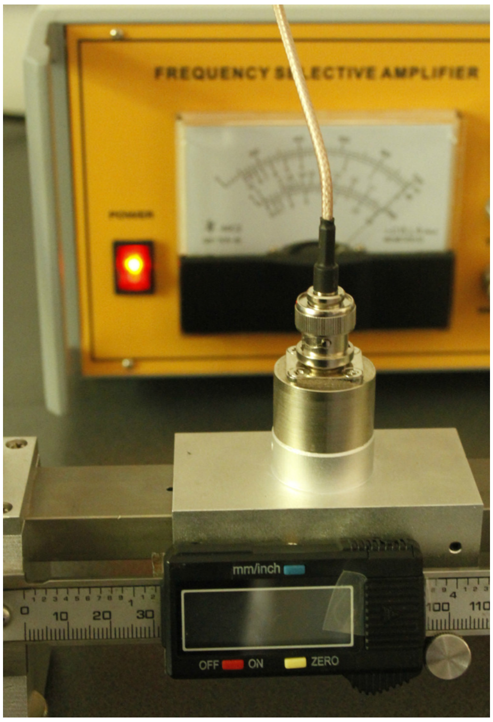
Figure 4.2.6. Real equipment setup for measurements of frequency, λ_g and λ with the Shorting Plate

(1) When the straight waveguide is open, we also have a standing wave because of the different characteristic impedance of the free space:

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \, .$$

This variance of the standing wave is detected by the probe in the slotted line. Find two adjacent positions where the two detected values are minimum. The distance between these two points corresponds to the half wavelength in free space. Record the distance in Table 4.2-1.





(2) Cover the output of the slotted line with the shorting plate. Vary the slotted line and locate a position where the detected output voltage is minimum. From that point, find another adjacent point where a minimum is detected again. The distance between the two points is the half of the guide wavelength. Record the value in Table 4.2-1.

Table 4.2-1. Comparison of measured and calculated values of frequency, free space wavelength and guide wavelength.

Frequency					
Measured values λ					
Measured values λg					
Calculated values λ					
calculated values λg					

4.3. Experiment 3: Q Value and bandwidth of a resonance cavity

Objectives

- To learn the theory of a resonance cavity.
- To experiment the relationship between Q and bandwidth. To learn how to measure the f_r of a resonance cavity.

1. Theory:

Resonant circuits are of great importance for microwave oscillators, tuned amplifiers and frequency measurements, etc. A resonant circuit such as the one shown in Figure 4.3.1 can be defined in terms of R, L, and C when the frequency is limited up to approximately 100 MHz.

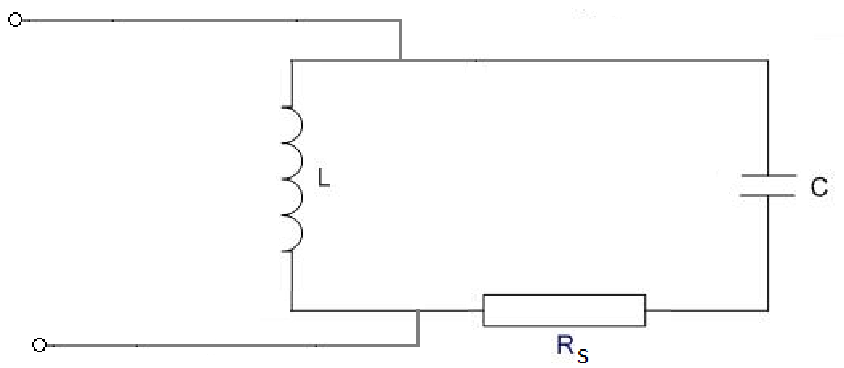


Figure 4.3.1. A resonant circuit.

In fig. 4.3-1

$$L = \frac{Q_0}{\omega_0 Q_0},\ C = \frac{Q_0}{\omega_0 R_0},\ R_S = \frac{Q_0}{Q_0^{\,2}} \qquad (4.3\text{-}1)$$

where R_o is the parallel equivalent resistance.

ω_o is the resonant frequency

Q_o is the Q of the resonant tank

$$\omega_0^{\,2} = \frac{1}{LC},\ \ Q_0 = \frac{\omega L}{R_S},\ \ R_0 = \omega_0 L Q_0 = \frac{(\omega_0 L)^2}{R_S} \qquad (4.3\text{-}2)$$

When the R, C and L are known, ω_o, Q_o and R_o can be easily calculated. However, in microwave circuits, the analysis of the resonant cavity becomes difficult due to the extremely high value of Q.

The other characteristics of the microwave resonator that make the analysis difficult are:

- The circuit parameters vary depending upon the propagation modes.
- Unlike the low frequency case, the meaning of the voltage and the current in the tank becomes ambiguous, making the definition of R_o difficult.

Usually, the R_o is defined in microwave as:

$$R_0 = \frac{(\int E \bullet dz)^2}{2W} \tag{4.3-3}$$

where E is the maximum potential between two points in the cavity and W is the power dissipated in the cavity. The ω_o, Q_o and R_o of simple cavities can be found from the dimensions of the cavity and the power loss on the cavity walls.

However, due to the complexity of the cavity structure, it is almost impossible to calculate ωo, Q_o and R_o. Instead, actual measurements of a few parameters of the cavity make it possible to determine the entire characteristics of the device.

Let us consider a cavity system in Figure 4.3.2. (a).

In Figure 4.3.2(a), Z_{01} is the characteristic impedance of the input waveguide. Z_{02} is the characteristic impedance of the output waveguide. R_g is the internal resistance of the generator. R_L is the load resistor. An equivalent circuit of Figure 4.3.2(a) can be developed by letting $Z_{01} = R_g$, $Z_{0z} = R_L$. See Figure 4.3.2(b).

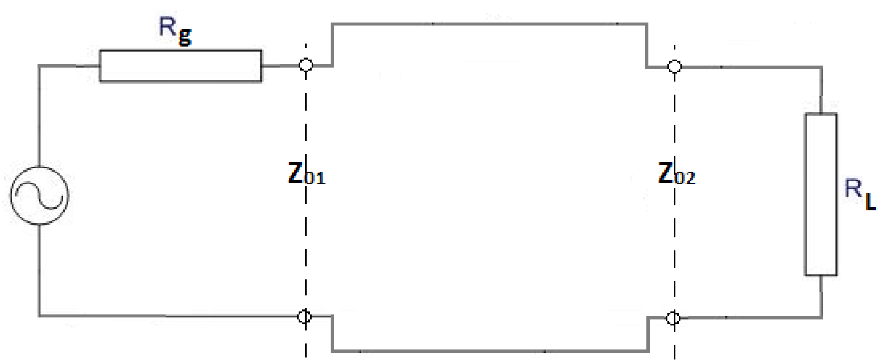


Figure 4.3.2.(a) A transmission cavity.

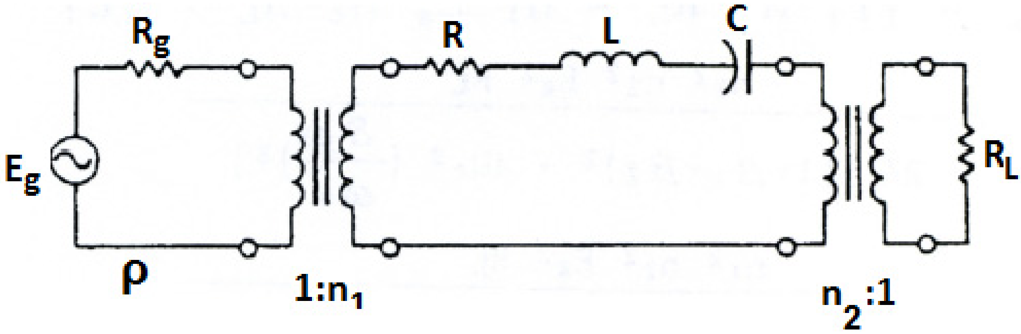


Figure 4.3.2(b) An equivalent circuit of Fig. 4.3.2(a).

In Figure 4.3.2(b), the cavity is effectively a series resonant circuit coupled by two ideal transformers with $1:n_1$ and $n_2:1$ turns ratio.

The output power in this case is $P_o = E_{y2} / 4Z_o$.

A resonant curve is a relationship between the frequency and the output power of a resonant cavity. Consider two points on the resonant curve like the ones shown in Figure 4.3.5.

Assume the points are several dB below where the maximum output power occurs.

$$1 + (Q_L \bullet \frac{\Delta f}{f_0}) = \frac{1}{f}$$

$$Q_L \bullet \frac{\Delta f}{f_0} = \frac{1-F}{F} \approx \alpha \qquad (4.3\text{-}4)$$

$$Q_L = \alpha \bullet \frac{f_0}{\Delta f}$$

where F is the ratio between the maximum power and the power of the two points on the curve. Δf is the bandwidth of the cavity. α is the bandwidth coefficient.

The cavity portion of the Figure 4-2(b) is presented in detail in Figure 4.3.3.

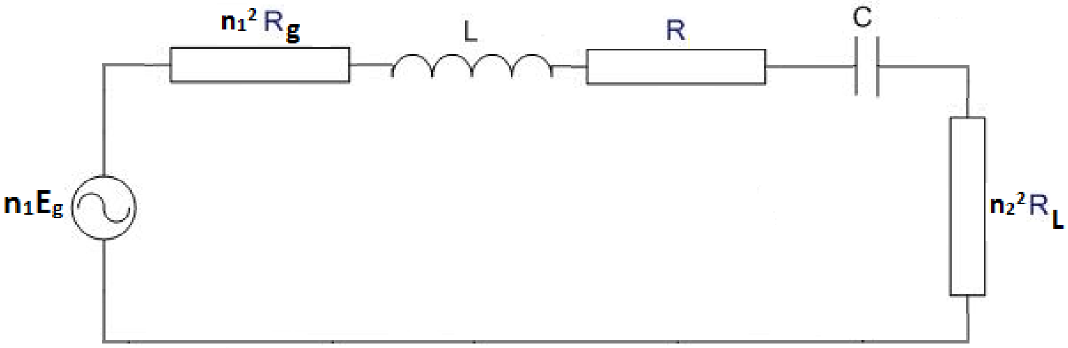


Figure 4.3.3. Equivalent circuit of the cavity portion of Figure 4.3.2(b).

The following relationships are obtained by carefully observing Figure 4.3.3.

$$Q_0 = \frac{\omega_0 L}{R}, \sin ce\ \omega_0 = \frac{1}{\sqrt{LC}}, Q_L = \frac{\omega_0 L}{R + n_1{}^2 Rg + n_2{}^2 R_L} = \tag{4.3-5}$$

$$= \frac{\omega_0 L / R}{1 + n_1{}^2 Rg / R + n_2{}^2 R_L / R} = \frac{Q_0}{1 + \beta_1 + \beta_2}$$

Where:

$$\beta_2 = \frac{n_1{}^2 R_g}{R}$$

and

$$\beta_2 = \frac{n_2{}^2 R_L}{R}$$

The impedance of the equivalent circuit is:

$$Z = R\left[1 + \beta_1 + \beta_2 + jQ_0\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right] \tag{4.3-6}$$

The power delivered to the load is:

$$P_L = |I|^2 \; n_1^2 R_L = n_1^2 E_g^{\;2} n_2^2 R_L / |Z|^2$$

$$P_L = \frac{n_1^{\;2} \; n_2^{\;2} \; Eg^{\;2} \; R_L}{R^{\;2}\left[(1+\beta_1+\beta_2)^2 + 4Q_0^{\;2}\left(\dfrac{\delta\omega}{\omega_0}\right)^2\right]} \tag{4.3-7}$$

$$P_L = \frac{n_1^{\;2} \; n_2^{\;2} \; Eg^{\;2} \; R_L}{R^2(1+\beta_1+\beta_2)^2\left[1 + 4Q_0^{\;2}\left(\dfrac{\delta\omega}{\omega_0}\right)^2\right]}$$

At resonance, the imaginary portion of (4.3-6) becomes 0.

$$P_L = \frac{n_1^{\;2} \; n_2^{\;2} \; Eg^{\;2} \; R_L}{R^2(1+\beta_1+\beta_2)^2} \tag{4.3-8}$$

The bandwidth of the resonant circuit is defined as the difference of two frequencies where the maximum power is reduced to one half. This happens when:

$$4Q_0^{\;2}\left(\frac{\delta\omega}{\omega_0}\right)^2 = 1$$

$$Q_L = \frac{\omega_0}{2\delta\omega} = \frac{\omega_0}{\Delta\omega} = \frac{f_0}{\Delta f} \tag{4.3-9}$$

where Δf is the half-power bandwidth.

2. Experiment procedure

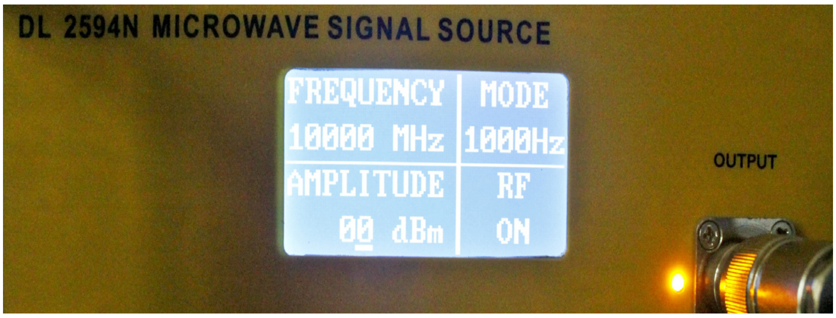
A. Measurement of Q values using the power measurement technique.

Note

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapters 1.2.1 and 1.2.2.

a) *Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.*

b) *The display will show the set of instances as in the figure below:*



c) *If RF is off, press the RF button.*

d) *Press to ON position the power button of the Power Meter and let it run for 30 minutes minimum.*

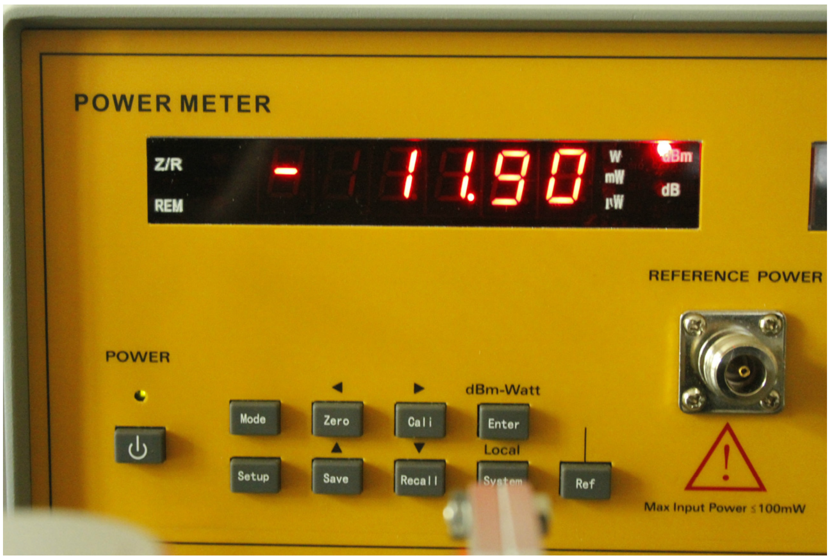
e) *Press the Setup button once. The display will show the set of instances as in the figure below:*

f) If the number displayed on the right of the display is not 10, press the Save button several times successively, which in this case is meant to increase the value of the number by one unit each time you press.

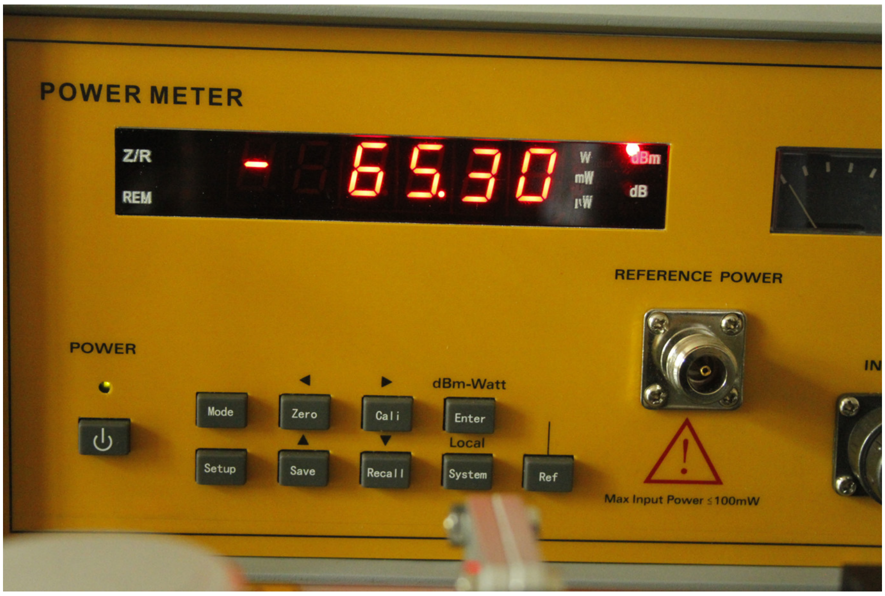
g) After the number is 10, press the Setup button once again. The display will show the set of instances as in the figure below:

h) Do not modify anything at this setting.

i) Press the Enter button once. The display will show the set of instances as in the figure below:



j) If the Microwave Signal Source RF is OFF on the display, then the Power Meter display will show the information as in the picture below:



k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

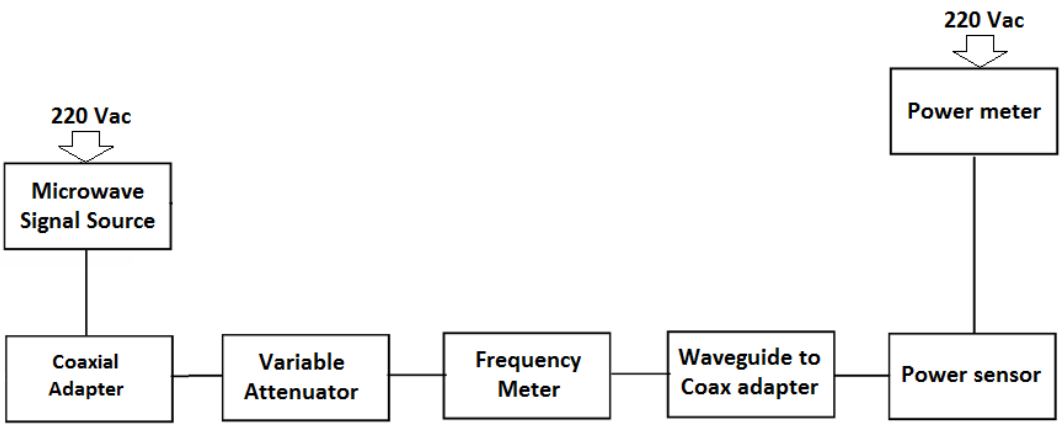
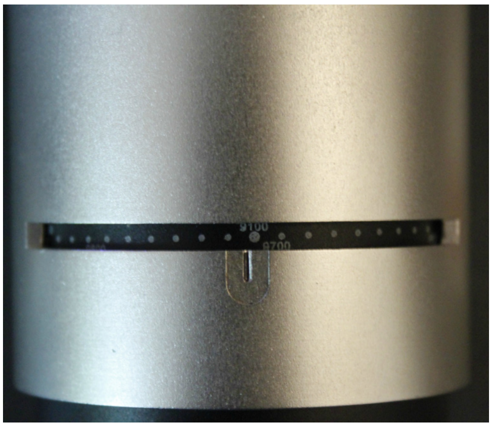


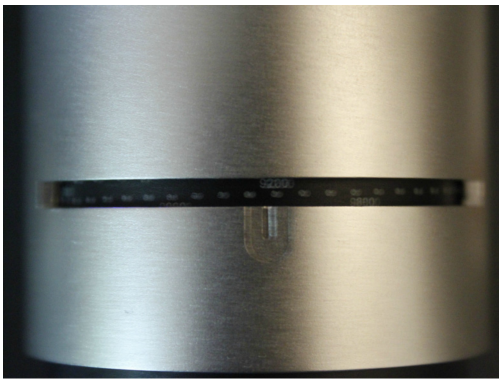
Figure 4.3.4. Setup diagram of Q-measurement.

(1) Set up the equipment as shown in Figure 4.3.4 and/or Figure 4.3.5.

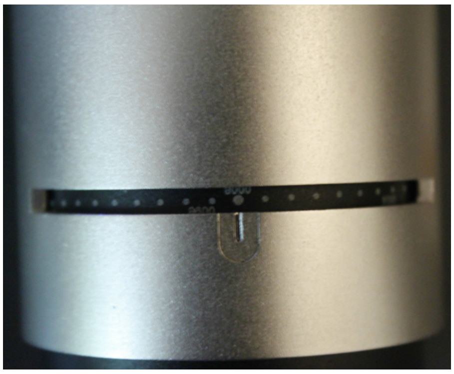
(2) Apply supply to the Microwave Signal Source and adjust the frequency at 9.1 GHz. Set the measurement in mW on the Power meter. Adjust the variable attenuator to 0 dB value. Turn the frequency meter slowly and find the power and frequency reading when the power meter reading is minimized. Call these values P_B for power and f_o for frequency. Refer this value as P_s (see figures below).



(3) Turn to right the frequency meter slowly and find the power and frequency reading when the power meter reading is maximized. Call these values P_0 for power and f_R for frequency (see figure below).



(4) Turn to left the frequency meter slowly and find the power and frequency reading when the power meter reading is maximized, approximately equal with P0. Name this frequency fL (see figure below).



(5) Find two frequencies (f_1 and f_2) where the power reading is equal to $\Delta P/2$ (see Figure 4.3.6).

Figure 4.3.5. Real representation of the experiment.

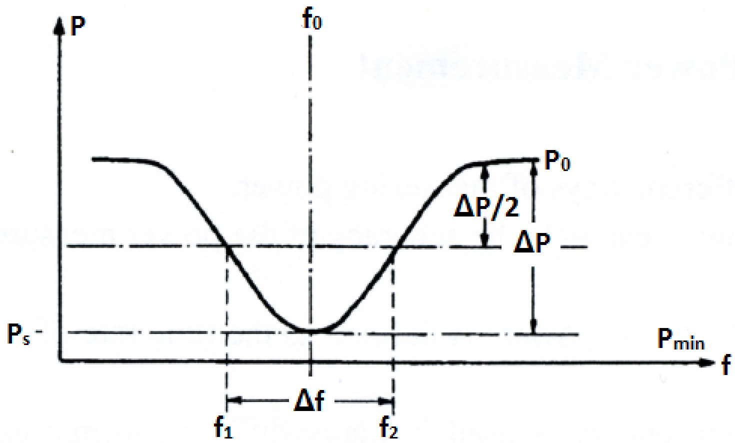


Figure 4.3.6. The resonant curve of a resonant cavity.

B. Measurement of Q using the SWR method.

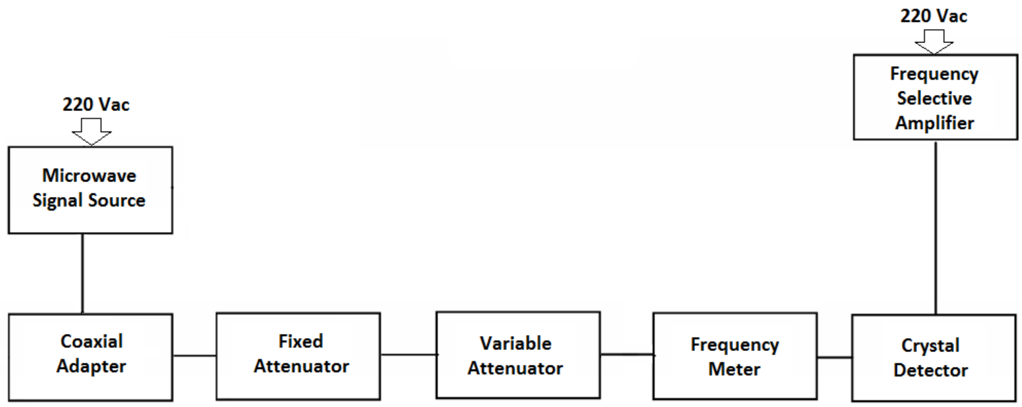
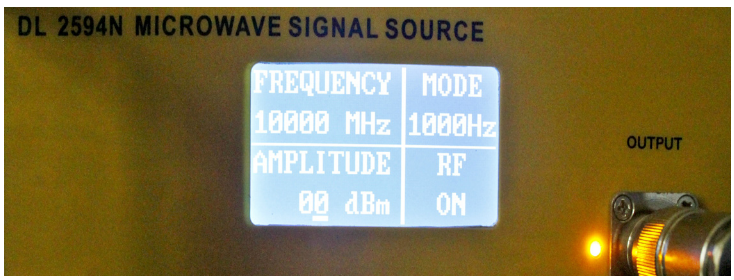


Figure 4.3.7. Setup diagram of Q-measurement using the SWR method.

In the text and images in the following figures are presented the manual action modes for prepare the devices so they are stable in operation and calibrated according to the instructions in subchapters 1.2.1 and 1.2.16.

a) Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

For the Frequency Selective Amplifier (SWR) the following settings will be made:

d) Adjust the Gain Adjust Knob in the middle position.

e) Adjust the Frequency Tuning Knob in the middle position.

f) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales:1 ~ 4 and 3.2 ~ 10.

g) Gain selective switch: select the current coarse amplifier gain. the gain range is from 0 to 60 db, with a 10 db step.

h) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, the gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

i) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, the bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

j) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity.

k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

Figure 4.3.8. Real representation of the experiment.

(1) Set up the equipment as shown in Figure 4.3.7 and/or Figure 4.3.8.

(2) Turn ON the Microwave Signal Source and set the attenuator to 10dB.

(3) Adjust the range switch and the gain to obtain 0dB on the SWR meter.

(4) Slowly rotate the frequency meter. Find the point where the SWR meter reading is minimum. Read the dB indication on the meter (P).

(5) Plug-in the value obtained from (4) into the following equation to get the ratio P_s.

$$P_{dB} = 10\log\frac{1}{P_B}$$

(6) Since Δ_P=1-P_B, calculate $P_B + \Delta_P/2$ and convert it to dB. For example:

$$X_{dB} = 10\log\frac{1}{P_B + \frac{\Delta_P}{2}}$$

(7) Slowly rotate the frequency meter and find f1, f2 and Δf where the SWR meter reading indicates X_{dB} as calculated above.

4.4. Experiment 4: Power Measurement

Objectives

- To learn different ways of measuring the power.
- To learn how to evaluate the accuracy of the power measurements.

1. Theory:

In general, the term "power" is defined as the time rate of transferring or transforming energy. In case of the microwave, the energy is used in many different forms: exchange of information over long distance, heating a microwave oven, or acceleration of particles in nuclear engineering, etc.

The most common practice of power measurement at low frequencies is to measure the voltage and the current of the device under test, then to calculate the power from the lumped value of the circuit parameters. However, at microwave frequencies, the difficulty arises due to the distributed nature of the circuit elements.

Another factor affecting is the reflection of the signal wherever there is an impedance mismatch. Two types of power measurements are involved in the microwave power measurements: average power or peak power.

The average power is the time average of the sum of the product of the instantaneous voltage and current over the time period. This relationship is illustrated in Figure 4.4.1 and a mathematical expression is given in (4.4-1).

$$P_{avg} = \frac{1}{T}\int_0^T eidt \qquad (4.4\text{-}1)$$

where:

T = period

e = instantaneous voltage

i = instantaneous current

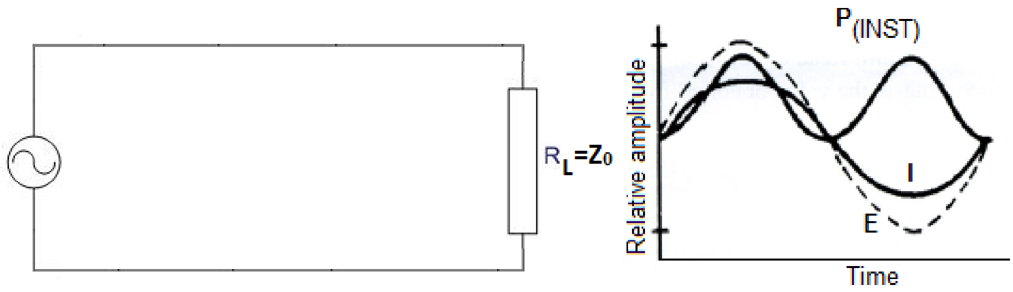


Figure 4.4.1. Instantaneous power appearing at the load resistor.

It should be noted in Figure 4.4.1 that the frequency of the instantaneous power (P_{inst}) is two times the frequency of e and i. The average power in an alternating current circuit is expressed as:

$P_{agv} = E_{RMS} \cdot I_{RMS} \cdot \cos\theta$ (4.4-2)

where θ is the phase angle between E and I.

Now, consider a duty-cycled pulse as shown in Figure 4.4.2. The peak power of the pulse is related to the average power of the pulse by the duty cycle of the pulse.

$$\text{Ppeak} = \frac{\text{Pavg}}{\text{duty cycle}}$$

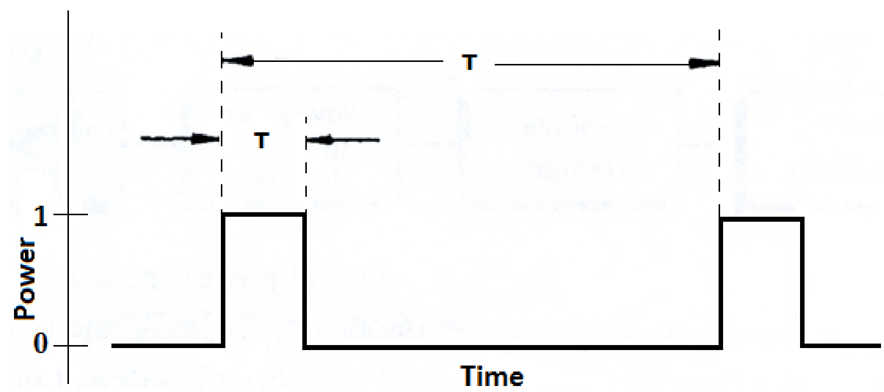


Figure 4.4.2. Peak power of a pulse.

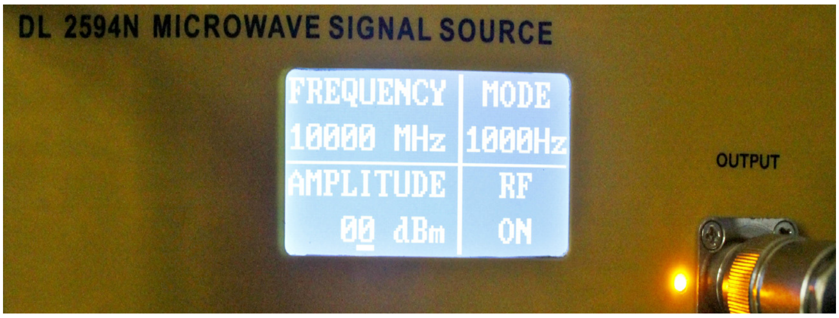
2. Experiment procedure

Note

In the text and images in the following figures are presented the manual action modes for preparing the devices so that they are stable in operation and calibrated according to the instructions in subchapters 1.2.1 and 1.2.2.

a) Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

d) Press to ON position the power button of the Power Meter and let it run for 30 minutes minimum.

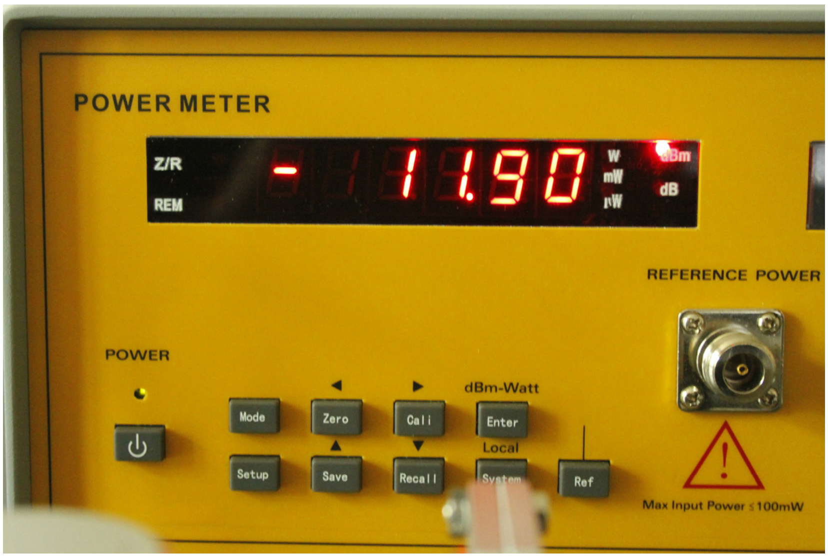
e) Press the Setup button once. The display will show the set of instances as in the figure below:

f) If the number displayed on the right of the display is not 10, press the Save button several times successively, which in this case is meant to increase the value of the number by one unit each time you press.

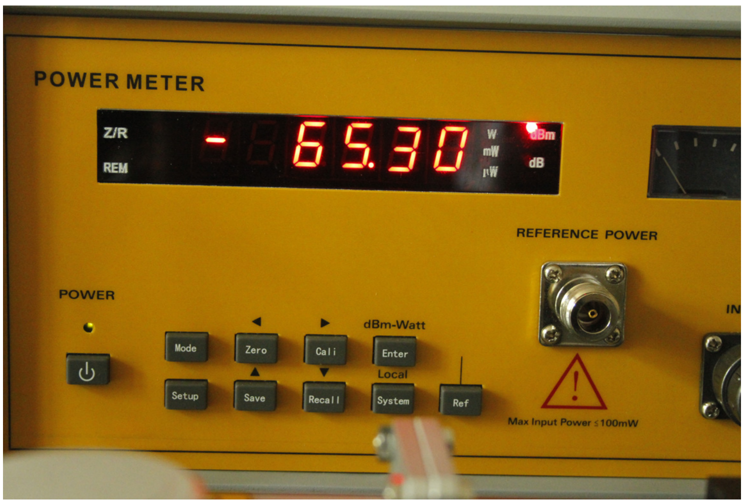
g) After the number is 10, press the Setup button once again. The display will show the set of instances as in the figure below:

h) Do not modify anything at this setting.

i) Press the Enter button once. The display will show the set of instances as in the figure below:



j) If the Microwave Signal Source RF is OFF on the display, then the Power Meter display will show the information as in the picture below:



k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

1) *Before using this equipment, you should read the instructions and operations in the user manual carefully!*
2) *The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument.*
3) *The instrument can work more stable after 30 minutes of preheating after initialization.*
4) *Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display*

A. Direct measurement.

Setup the equipment as shown in Figure 4.4.3 and/or Figure 4.4.4.

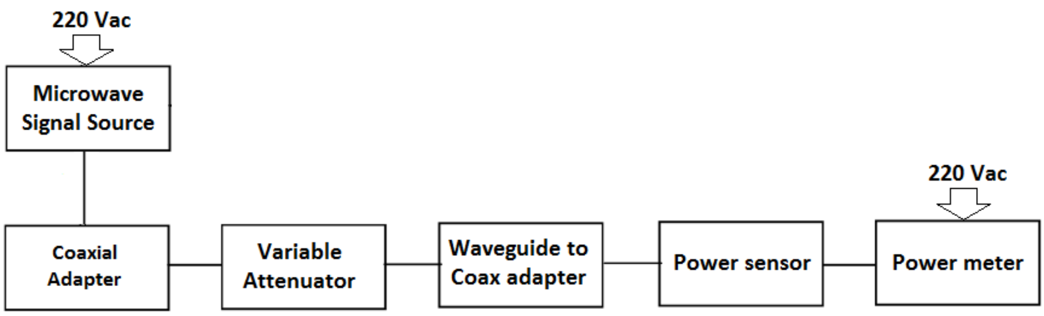


Figure 4.4.3. Direct power measurement setup.

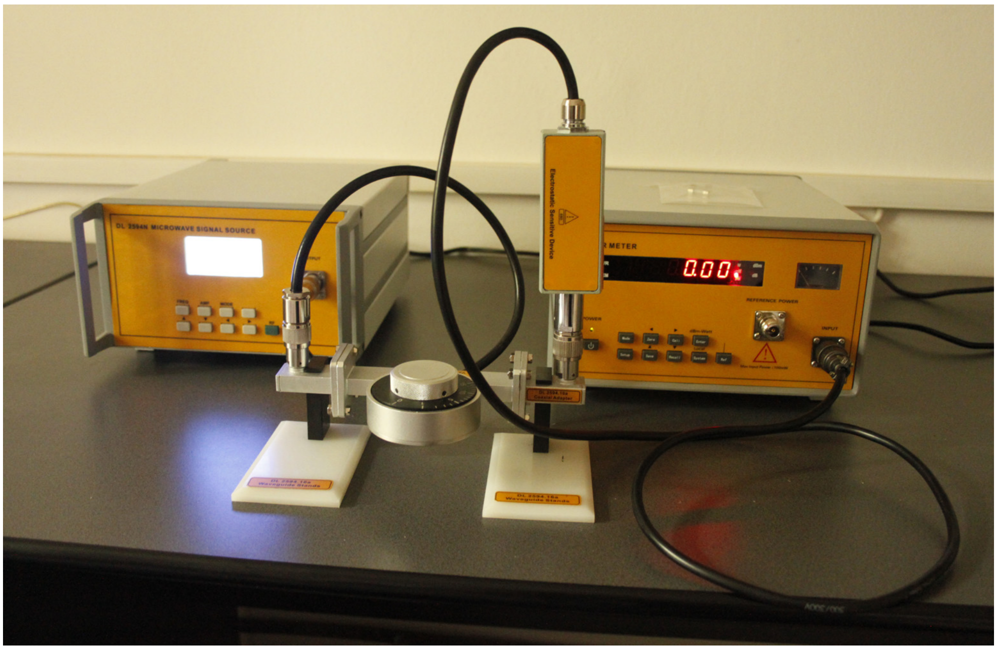


Figure 4.4.4. Real representation of the experiment.

(1) Without the signal activated, set the measure in mW and the Power Meter to zero.

Zero/◀ key (Zero) and Cali/▶ key (Cali)

1) *In order to ensure the accuracy of the data, the instrument often needs to set zero and calibration operation in the measurement process.*

2) *Press Zero/◀, the LED displays ''Zero'', and the instrument is in waiting mode. Then, press the Enter key to confirm the instrument's setting zero operation. The setting zero operation takes a few seconds, then the instrument returns to the measurement state. If you press the Zero/◀ key (Zero) to keep the instrument in waiting mode, press the Zero key again to return the measurement state.*

(2) Turn ON the Microwave Signal Source. Adjust the Variable Attenuator to 2 in order to have approximately 3 dB of attenuation. Read the Power Meter and record the reading.

B. Power measurement using a directional coupler.

Setup the equipment as shown in Figure 4.4.6 and/or Figure 4.4.7.

Note

Do not forget:

Use the microwave assembly techniques specified in the descriptions and the images presented at the beginning of this section.

Any damage to the components or the threading of the connectors may compromise the assembly of the components.

(1) Turn ON the Microwave Signal Source.

(2) Adjust the Variable Attenuator to 2 in order to have approximated 3 dB of attenuation.

(3) Record the power meter reading.

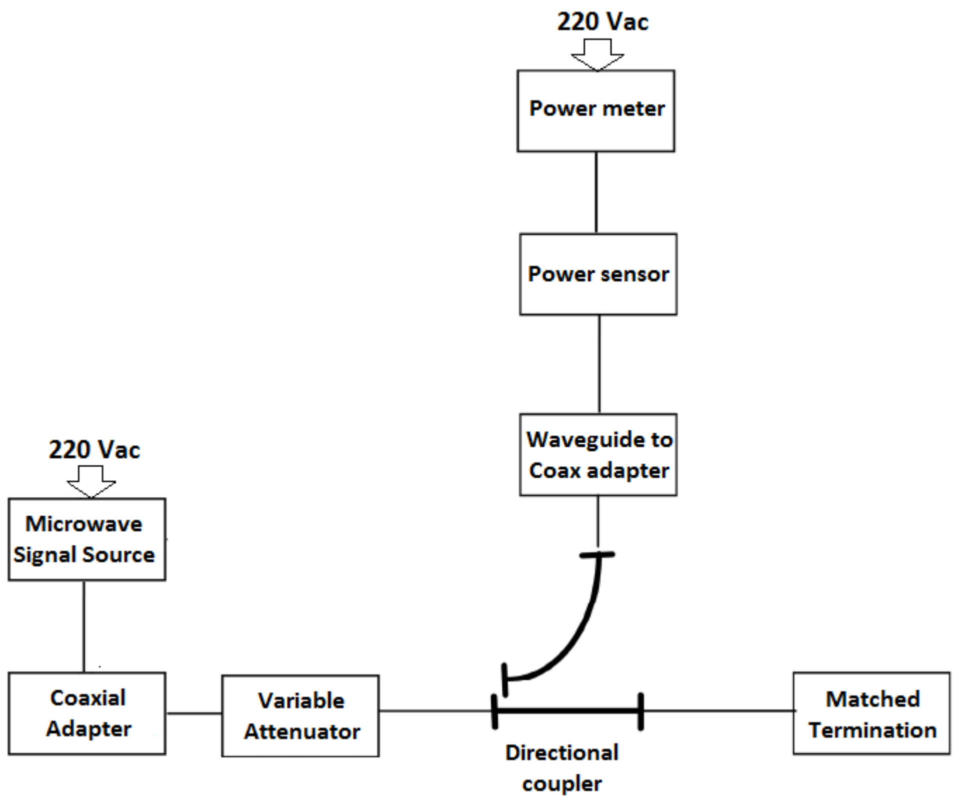


Figure 4.4.5. Setup for power measurement using a directional coupler.

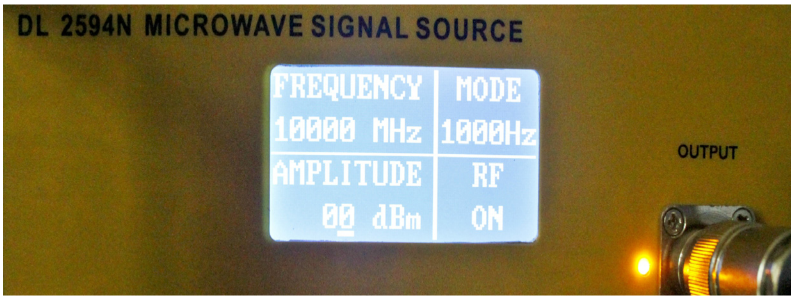
Figure 4.4.6. Real representation of the experiment with inscriptions view.

C. Measurement of conjugate and Z_0 power.

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapters 1.2.1 and 1.2.16.

a) *Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.*

b) *The display will show the set of instances as in the figure below:*



c) *If RF is off, press the RF button.*

d) *Press to ON position the power button of the Power Meter and let it run for 30 minutes minimum.*

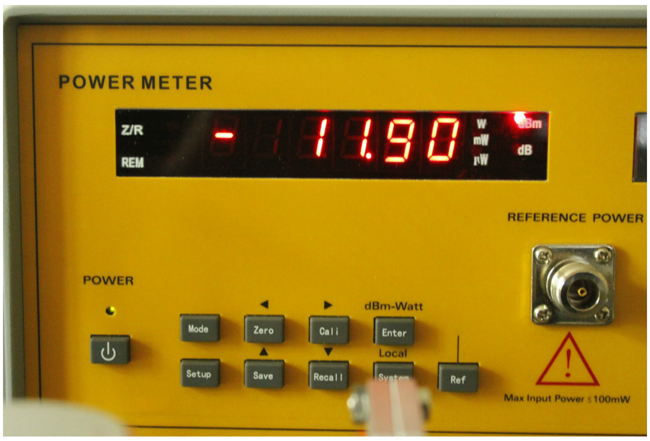
e) Press the Setup button once. The display will show the set of instances as in the figure below:

f) If the number displayed on the right of the display is not 10, press the Save button several times successively, which in this case is meant to increase the value of the number by one unit each time you press.

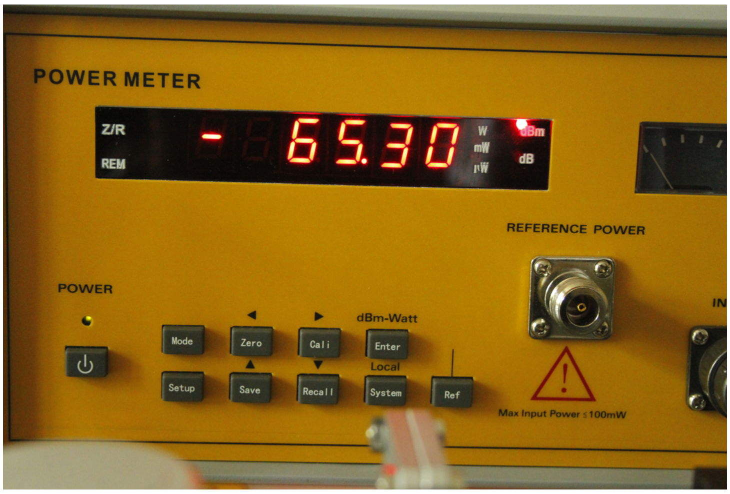
g) After the number is 10, press the Setup button once again. The display will show the set of instances as in the figure below:

h) Do not modify anything at this setting.

i) Press the Enter button once. The display will show the set of instances as in the figure below:



j) If the Microwave Signal Source RF is OFF on the display, then the Power Meter display will show the information as in the picture below:



For the Frequency Selective Amplifier (SWR), the following settings will be made:

a) Adjust the Gain Adjust Knob in the middle position.

b) Adjust the Frequency Tuning Knob in the middle position.

c) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales:1 ~ 4 and 3.2 ~ 10.

d) Gain selective switch: select the current coarse amplifier gain. the gain range is from 0 to 60 db, with a 10 db step.

e) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, the gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

f) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, the bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

g) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity.

h) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

Setup the equipment as shown in Figure 4.4.7 and/or Figure 4.4.9.

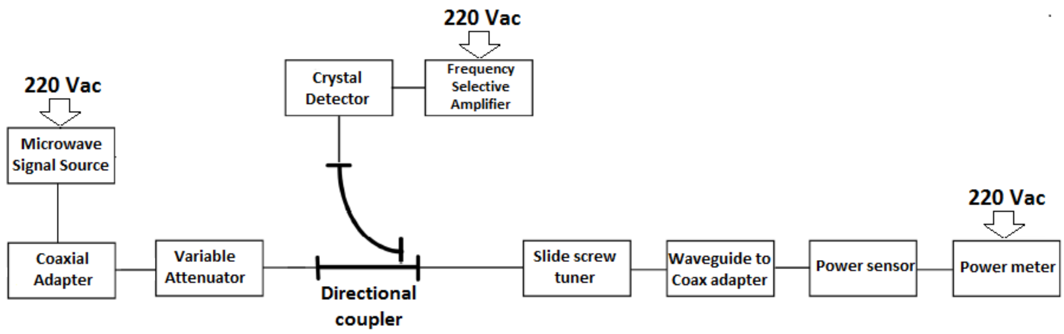


Figure 4.4.9. Setup for measurement of conjugate and Z_o power.

Set the Variable Attenuator to 2 in order to have approximately 3dB.

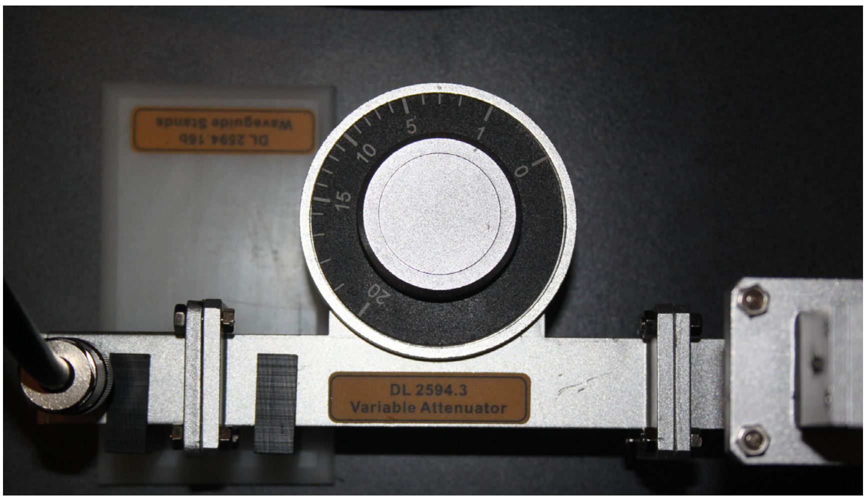


Figure 4.4.9. Setup for Variable Attenuator.

(1) Modulate the output of the directional coupler with a square wave of 1 kHz. Adjust the pulse frequency to maximize the SWR meter.

Z_o power: _______

(2) Do not change the signal power level. Adjust the Slide Screw Tuner for the minimum indication on the SWR meter. Use the most sensitive range of the SWR meter.

(3) Record the reading on the Power Meter.

Conjugate power: _______

(4) Adjust the Slide Screw Tuner to get the maximum indication on the Power Meter. Record the reading.

Figure 4.4.9. Real representation of the experiment with inscriptions view.

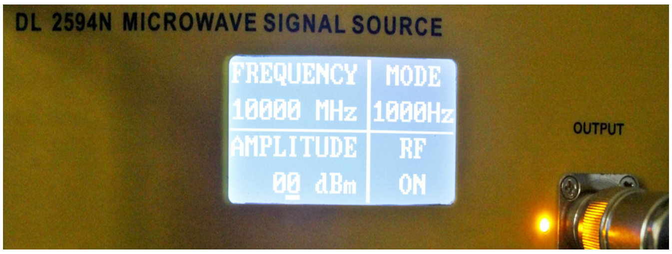
D. Modulated signal.

Note

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapters 1.2.1 and 1.2.2.

a) *Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.*

b) *The display will show the set of instances as in the figure below:*



c) *If RF is off, press the RF button.*

d) *Press to ON position the power button of the Power Meter and let it run for 30 minutes minimum.*

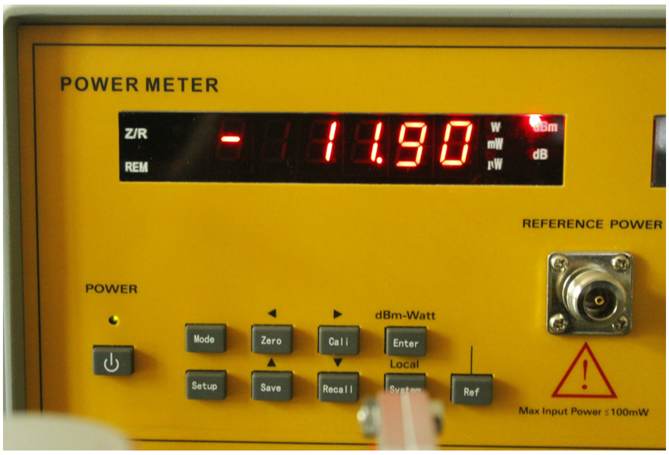
e) *Press the Setup button once. The display will show the set of instances as in the figure below:*

f) *If the number displayed on the right of the display is not 10, press the Save button several times successively, which in this case is meant to increase the value of the number by one unit each time you press.*

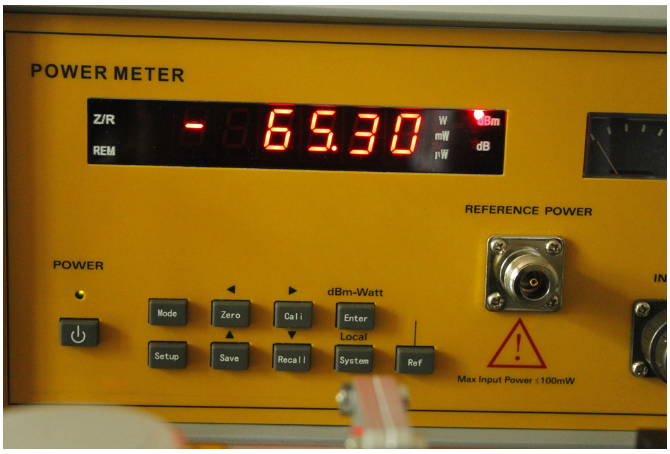
g) After the number is 10, press the Setup button once again. The display will show the set of instances as in the figure below:

h) Do not modify anything at this setting.

i) Press the Enter button once. The display will show the set of instances as in the figure below:



j) If the Microwave Signal Source RF is OFF on the display, then the Power Meter display will show the information as in the picture below:



k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

Setup the equipment as shown in Figure 4.4.10 and/or Figure 4.4.11.

(1) Adjust the Variable Attenuator to 10.

(2) Record the power meter reading.

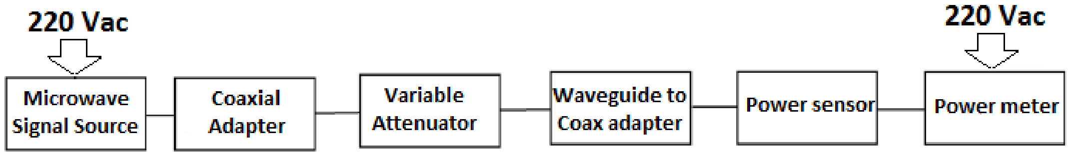


Figure 4.4.10. Setup diagram for measuring the output power of a modulated signal.

(3) Replace the power sensor and the Power Meter with the crystal detector. Connect the oscilloscope to the crystal detector. Adjust the vertical position of the scope to align the top of the square wave to the zero level on the screen. The reason for this adjustment is that the output of the crystal detector is negative. Therefore, the power at the top of the pulse is actually less than the power at the bottom of the pulse.

(4) Reduce the attenuation of the attenuator until the bottom of the square wave lines up with the zero level of the scope. Record the change in the attenuation.

Figure 4.4.12. Real representation of the experiment with inscriptions view.

E. The dB-scale.

Repeat the setup of Figure 4.4.4 and/or Figure 4.4.5 with the Variable Attenuator set at 20.

(1) Vary the attenuator as specified in Table 4.4-1. At each time, record the Power Meter reading. When the meter is switched into a new range, make sure the meter is properly zeroed.

Table 4.4-1. Attenuator position vs. Power Meter reading.

Attenuator setting	Power meter reading [mW]
5	
8	
10	
12	
15	
20	

Considerations of mismatch loss and maximum power transfer. Mismatch loss is defined as the power loss in the system due to reflections. In fact, the impedance mismatch between the generator and the load causes multiple reflections, which produce a random phase determined by the electrical equivalent length of the waveguide.

The random phase makes the power and attenuation measurements difficult due to the errors occurring and the power level deviations. When the SWRs are known for the source and the load, the maximum and the minimum of the signal level deviations can be found, assuming the attenuation of the waveguide can be ignored. One way to determine the deviation values is to use a chart such as the one shown in Figure 4.4.12.

The maximum power transfer takes place when the load impedance is equal to the complex conjugate of the source impedance. For example, a source with 50 + j25 ohm impedance delivers the maximum power to the load when the load impedance is 50 - j25 ohm.

When the load impedance is not the conjugate of the source impedance, the conjugate mismatch loss = the available power of source/power delivered to the load. The above relationship can be expressed in terms of the reflection coefficient.

$$\text{mismatch loss} = \frac{\left|1 - \overline{\rho}_S\,\overline{\rho}_L\right|^2}{\left(1-\left|\overline{\rho}_S\right|^2\right)\left(1-\left|\overline{\rho}_S\right|^2\right)}$$

where:

$\overline{\rho}_S$ = the reflection coefficient of the source.
$\overline{\rho}_L$ = the reflection coefficient of the load.

Although $\overline{\rho}_S$ and $\overline{\rho}_L$ are not directly known in most cases, the above equation is still useful in determining the maximum and the minimum mismatch power losses.

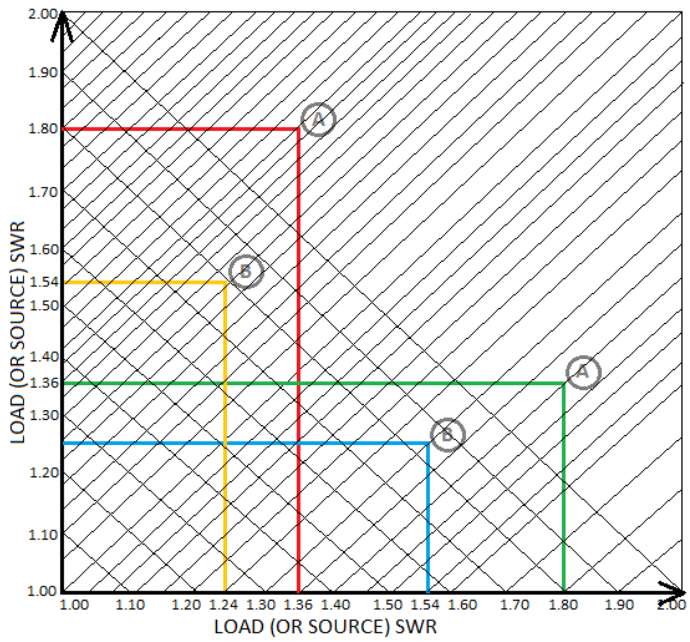


Figure 4.4.13. Conjugate mismatch loss chart.

A. Maximum mismatch loss: this happens when the argument of:

$\overline{\rho}_S$ plus the argument of $\overline{\rho}_L$ is equal to 180 degrees.

Then, the maximum mismatch:

$$= \frac{\left(1+|\rho_S||\rho_L|\right)^2}{\left(1-|\rho_S|^2\right)\left(1-|\rho_L|^2\right)} = 1 + \frac{\left(SWR_S \bullet SWR_L - 1\right)^2}{4 \bullet SWR_S \bullet SWR_L}$$

where SWR_S = SWR at the source

SWR_L = SWR at the load.

B. Minimum mismatch loss: this happens when the argument of

$\overline{\rho}_S$ plus the argument of $\overline{\rho}_L$ is equal to zero degrees.

Then, the minimum mismatch:

$$= \frac{\left(1-|\rho_S||\rho_L|\right)^2}{\left(1-|\rho_S|^2\right)\left(1-|\rho_L|^2\right)} = 1 + \frac{\left(SWR_S - SWR_L\right)^2}{4 \bullet SWR_S \bullet SWR_L}$$

Example: For SWR_S = 1.5 and SWR_L = 1.25,

Calculate the maximum and the minimum mismatch loss.

$$\text{Maximum mismatch loss} = 1 + \frac{(1.5 \bullet 1.25 - 1)^2}{4 \bullet 1.5 \bullet 1.25} = 1.102$$

$$\text{Minimum mismatch loss} = 1 + \frac{(1.5 - 1.25)^2}{4 \bullet 1.5 \bullet 1.25} = 1.009$$

4.5. Experiment 5: Standing Wave Measurement

Objectives

- To learn how to measure the SWR using the slotted line.

1. Theory:

At any point along a transmission line, we can think of the electromagnetic field as a sum of two waveforms: one is travelling toward the load (incident) and the other is travelling toward the generator (reflected).

The reason for the reflection is, as was already discussed in the previous chapter, due to the impedance mismatch. Any open spot on the line is considered to be an impedance mismatch and becomes a cause of the reflection as well. The amplitude and the phase of the reflected wave depend upon the load impedance. The degree of the attenuation of the line affects the amplitude of the reflected wave also.

The only way the reflection can be eliminated is when either the line is infinitely long or there is impedance match between the load and the transmission line. A standing wave results from the two travelling waves in opposite direction.

As was discussed in the previous chapter, the vector sum of the two waves creates minimum and maximum points on the standing wave pattern. Typical standing wave patterns in a lossless transmission line are shown in Figure 4.5.1.

Note

Do not forget:

the theoretical part presented in this section is a minimum of knowledge to understand the functioning of the experimental assembly.

The setting and operation of the devices are described in the Composition & Operations section.

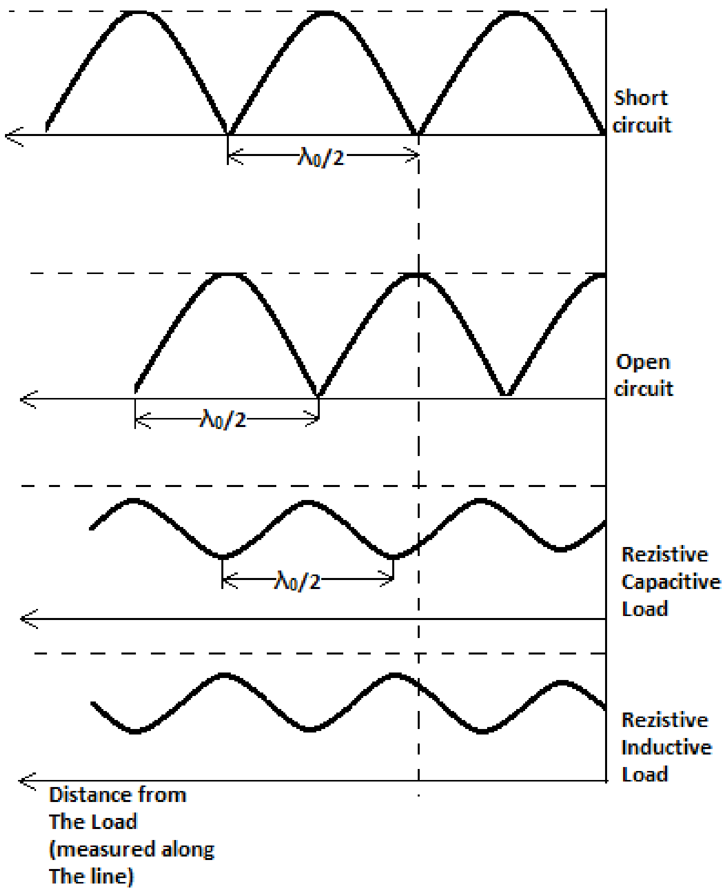


Figure 4.5.1. Standing wave patterns in a lossless line.

In Figure 4.5.2, a voltage standing waveform in a transmission line having a characteristic impedance of Z_o and a load impedance of Z_L is shown.

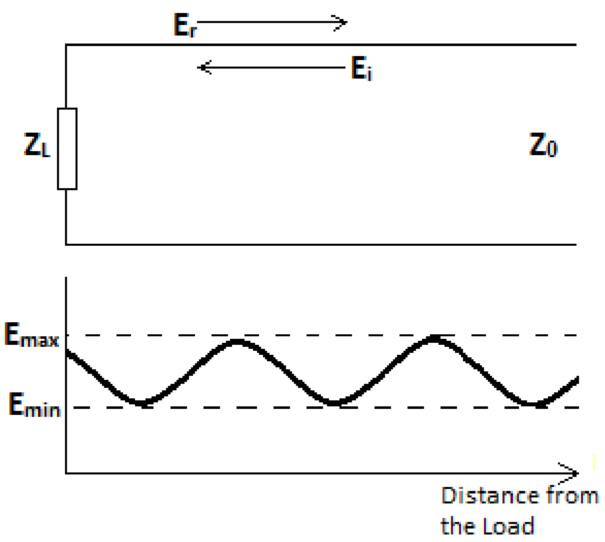


Figure 4.5.2. A voltage standing waveform.

In Figure 4.5.2, the complex reflection coefficient is:

$$\bar{\rho} = \frac{\bar{E_r}}{\bar{E_i}} = \frac{\bar{z} - Z_o}{\bar{z} + Z_o} \qquad (4.5\text{-}1)$$

where:

$\bar{E_r}$ = reflected signal:

$\bar{E_i}$ = incident signal:

$\bar{Z}$ = complex impedance at a given point.

At the load it is:

$$\bar{\rho}_L = \frac{\bar{Z}_L - Z_O}{\bar{Z}_L + Z_O} \qquad (4.5\text{-}2)$$

Then:

$$V_{SWR} = S \frac{E_{MAX}}{E_{MIN}} = \frac{|\bar{E_i}| + |\bar{E_r}|}{|\bar{E_i}| - |\bar{E_r}|} \qquad (4.5\text{-}3)$$

Therefore,

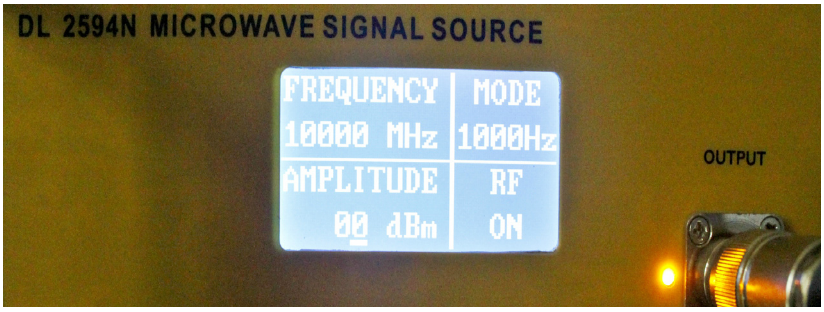
$$|\bar{\rho}| = \frac{S - 1}{S + 1} \qquad (4.5\text{-}4)$$

2. Experiment Procedure

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapter 1.2.1 and 1.2.16.

a) *Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.*

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

For the Frequency Selective Amplifier (SWR) the following settings will be made:

d) Adjust the Gain Adjust Knob in the middle position.

e) Adjust the Frequency Tuning Knob in the middle position.

f) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales:1 ~ 4 and 3.2 ~ 10.

g) Gain selective switch: select the current coarse amplifier gain. the gain range is from 0 to 60 db, with a 10 db step.

h) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, the gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

i) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, the bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

j) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity.

k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

1) Before using this equipment, you should read the instructions and operations in the user manual carefully!
2) The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument.
3) The instrument can work more stable after 30 minutes of preheating after initialization.
4) Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display.

(1) Set up the equipment as shown in Figure 4.5.3 and/or Figure 4.5.4.

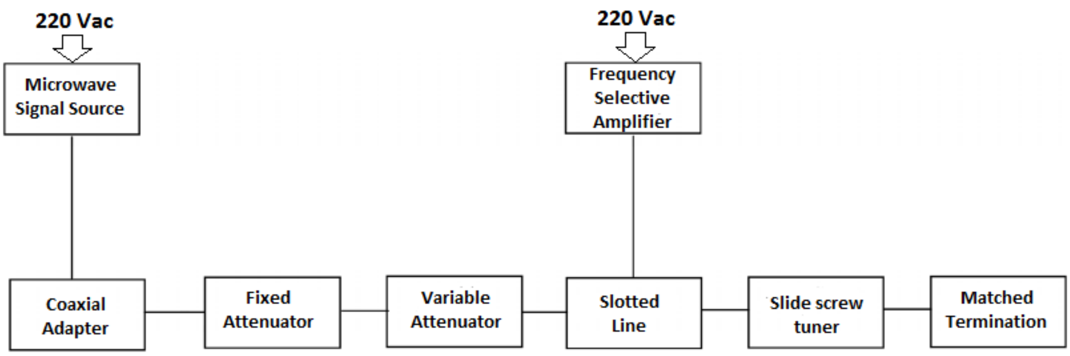


Figure 4.5.3. Setup diagram for SWR measurement.

Figure 4.5.4. Real representation of the experiment.

(2) Set to ON the Microwave Signal Source.

(3) Set the variable attenuator to 0 dB.

(4) Set the SWR indicator range switch to 40~50dB. Turn ON the indicator.

(5) Apply the mode of modulation signal by the Microwave Signal Source menu.

(6) Adjust the Frequency Selective Amplifier (SWR indicator frequency) for the maximum meter deflection.

a) In analog systems, full scale may be defined by the maximum voltage available, or the maximum deflection (full scale deflection or FSD) or indication of an analog instrument such as a moving coil meter or galvanometer.

b) Full scale deflection refers to the full range of motion of an analog 'needle' of an analog meter, or a galvanometer.

c) In the above meter, the amount that the needle moves away from 0 is called the deflection. Full scale deflection is, well, deflection that goes all the way to the end of the scale, in other words, full scale. Anything beyond this scale is not really measurable by this insturment, and so the term 'full scale' actually originates from the older term and concept of 'full scale deflection'.

Be it an analog coil-actuated meter, a digital ADC, or even a DAC (though it is used to mean the output range available, not measurement), full scale is now used to mean the complete minimum to maximum range of something. We've mostly dropped the deflection part however, as deflection is rarely relevant anymore.

d) Note that it needs not be referring to voltage specifically. One could correctly say '0 to 100mA full scale', for example.

e) Full scale deflection has its history in analogue meters where the moving needle could "deflect" and that deflection was proportional to what it measured i.e. current, voltage or power. FSD is the maximum deflection the needle moved and this represents the "full scale".

f) Full scale is also a term that defines how much an output can rise or fall to i.e. the limits to which an output can be raised or lowered to. In a simple opamp circuit, the FS is usually a couple of volts inside the power rails. The terms are interchangeable generally and we have seen an output defined to have this or that full scale deflection (although strictly speaking it should be defined as full scale and not FSD).

A. Measuring low and medium range SWR.

(1) Move the probe of the Slotted Line and observe the SWR indicator meter deflection.

(2) Completely disengage the probe of the Slide Screw Tuner. At this point, the V_{SWR} indication should be very small (less than 1.3). Therefore, use the expanded scale for better reading.

(3) Move the probe in the Slotted Line until a maximum deflection is observed on the SWR indicator. Adjust the gain of the SWR indicator until the expanded meter reading reaches 1.0. Both the coarse and the fine gain adjustment are needed in the expanded scale.

(4) Move the probe to where a minimum deflection is observed. Take the reading on the expanded scale and record it in Table 4.5-1.

(5) Repeat the above procedure with three different probe depths. The three different depths are required to be greater than the depth used in the above procedure. Fill in the Table 4.5-1.

Table 4.5-1. Probe depth vs. V_{SWR},

Probe depth(mm)				
V_{SWR}				

B. Measuring high range SWR.

(1) Maximize the depth of the probe of the slide screw tuner. A large depth of the probe is necessary for high SWR measurements.

(2) Move the probe along the Slotted Line until a minimum is observed on the indicator.

(3) Adjust the gain of the indicator until 3dB is shown on the dB scale. If necessary, reduce the attenuation of the Variable Attenuator.

(4) Move the probe along the Slotted Line until 0dB (full scale) is obtained on the dB scale.

(5) Record the position of the probe under the d_1 Column in Table 4.5-2.

Table 4.5-2 - Recording the 3dB measurement.

Probe penetration	d_1 [mm]	d_2 [mm]	1^{st} min [mm]	2^{nd} min [mm]	λg [mm]	SWR

(6) Repeat the above procedure while moving the probe toward the right and record the position of the probe under the d_2 column. Repeat the measurement at three different probe depths.

(7) Replace the Slide Screw Tuner with a Shorting plate. Find the distance between two adjacent minimums. The guide wavelength λ_2 is twice the distance.

(8) Compute the SWR using the following formula.

$$SWR = \sqrt{1 + \frac{1}{Sin^2 \frac{\pi (d_1 - 2)}{\lambda g}}} \cong \frac{\lambda g}{\pi (d_1 - 2)}$$

C. Measuring high SWR using a calibrated attenuator.

(1) Maximize the probe depth of the Slide Screw Tuner.

(2) Move the probe along the Slotted Line until a minimum is observed.

(3) Set the Variable Attenuator to 10dB (call this value A_1). Adjust the gain of the SWR indicator until a 3dB deviation is observed.

(4) Move the probe along the Slotted Line and adjust the Variable Attenuator until the same maximum value as in the previous step. Read the dB value (call this value A2) and record it in Table 4.5-3.

Table 4.5-3. SWR measurement using a calibrated attenuator.

Probe penetration	A_1 [dB]	A_2 [dB]	SWR

(5) Calculate the SWR using the following formula and fill in the Table 4.5-3.

$$S = 10 \frac{A_2 - A_1}{20} \quad (4.5\text{-}6)$$

Repeat the procedure at the different probe depths.

4.6. Experiment 6: Study of microwave propagation in waveguide

Objectives

- To learn the Smith chart and its application in determining unknown impedances.

1. Theory:

In a transmission line with the characteristic impedance of Z_o, the reflection coefficient between the incident and the reflected signal is defined as:

$$\overline{\rho} = \frac{\overline{Z} - Z_O}{\overline{Z} + Z_O} \qquad (4.6\text{-}1)$$

where $\overline{Z} = R + jX =$ load impedance connected to the line:

$$\overline{\rho} = \left|\overline{\rho}\right| e^{J\theta} = \text{complex reflection coefficient.}$$

The magnitude of $\overline{\rho}$, that is $\left|\overline{\rho}\right|$, is the ratio of the amplitude between the incident and the reflected signal. The angle θ represents the angle of rotation of the phase at the point of reflection. The voltage at any given point on a transmission line is the vector sum of the incident and the reflected voltage waveforms. The resultant voltage waveforms are called the standing wave pattern. In fact, when the two waveforms add phase, a peak is formed at that point. Likewise, when the two waveforms add out of phase, a valley or a minimum voltage is observed at that point. The voltage standing wave ratio V_{SWR} is defined as:

$$V_{SWR} = \frac{E_{MAX}}{E_{MIN}} = \frac{1 + \left|\frac{E_r}{E_i}\right|}{1 - \left|\frac{E_r}{E_i}\right|} = \frac{1 - \left|\overline{\rho}\right|}{1 + \left|\overline{\rho}\right|} \qquad (4.6\text{-}2)$$

The angle of rotation of the phase of the reflection coefficient at a distance "d" from the load is determined by:

$$\theta = 2\pi d/\lambda_g \qquad (4.6\text{-}3)$$

The determination of the load impedance can be a three step process:

1) Obtain data on the waveguide through well defined measurements.

2) Determine the magnitude and the phase of the reflection coefficient.

3) Calculate the load impedance.

The Smith chart is used for the third process of determining the load impedance at any given point on the waveguide (or a transmission line in general) from known reflection coefficients. The Smith chart is a graphical representation of the impedance transformation property of a length of a transmission line. The chart coordinates give the normalized resistance and reactance. They are normalized to Z_o, the characteristic impedance of the waveguide. The V_{SWR} circles are usually not included, but can be constructed as needed with a compass cantered on the centre point of the chart.

Notice that the distance scale on the outside periphery is normalized to the guide wavelength. Usually, the best way to learn the Smith chart is to try to solve actual problems. Let us take a look at a sample problem.

Example:

A waveguide is attached to a normalized load impedance of 0.6 + j1.2; the guide wavelength λ_1 is 42 millimeters:

a. Find the impedance 10mm from the load (see Figure 4.6.1).

b. Find the distance from the load where the first minimum of V_{SWR} occurs.

Solution:

a. Refer to the Smith chart shown in Figure 7-2.

(1) Locate the point A on the chart representing the load impedance of 0.6 + j1.2.

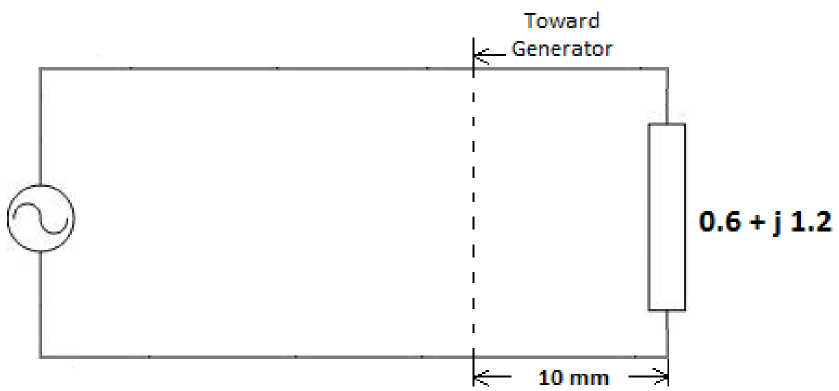


Figure 4.6.1. Sample problem for the Smith chart.

(2) Draw a straight line from 0 to A. This line intersects the distance circle (outer most circle) at 0.15A toward the generator. Travelling 10 mm. from the load is the same as travelling 10 mm/42 mm = 0.238 λ from the load.

(3) Locate a point on the distance circle which is equal to 0.15 λ + 0.238 λ = 0.388 λ.

Draw a straight line from the point to 0.

(1) Draw a circle with radius A centered at 0. The impedance at point B represents the impedance of a point 10 mm. away from the load toward the generator. The normalized impedance of point B is 0.38-j0.78.

b. The V_{SWR} of 4.3 at point C is where the maximum of the V_{SWR} pattern occurs. The first minimum occurs at point D.

The distance between point A and point D is 0.5 λ - 0.15 λ = 0.35 λ.

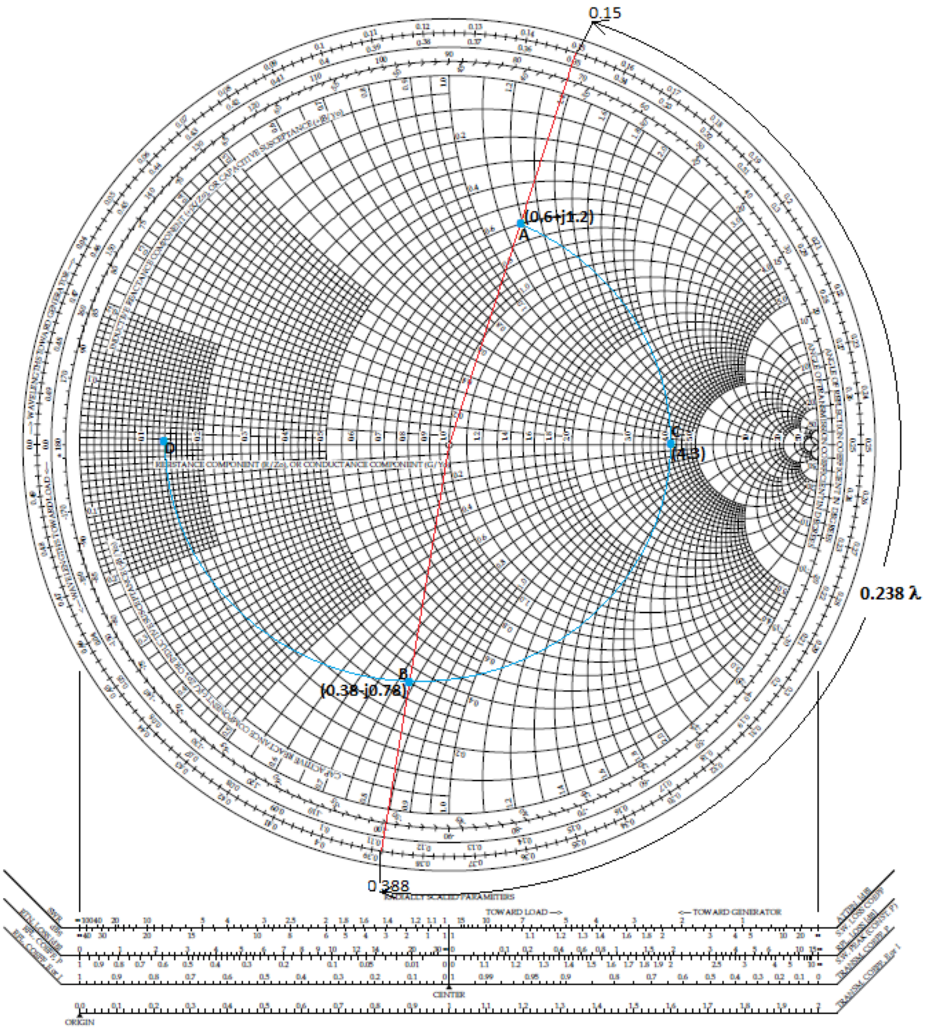


Figure 4.6.2. Solving the example using the Smith chart.

When working on a determination of an unknown impedance, it is necessary to establish a reference plane which the impedance can be related to. For example, the input terminals of the unknown impedance can be a reference plane. Once the reference plane is established, the unknown impedance can be measured.

a. Connect the unknown impedance to a slotted line, then measure the V_{SWR} and the position of minimum value.

b. Replace the unknown with a short at the output of the slotted line, then measure the distance between two adjacent minimum values. The distance obtained should be equal to 0.5 λ of the guide wavelength.

c. Choose one of the minimum points as a reference (see Fig. 4.6.3).

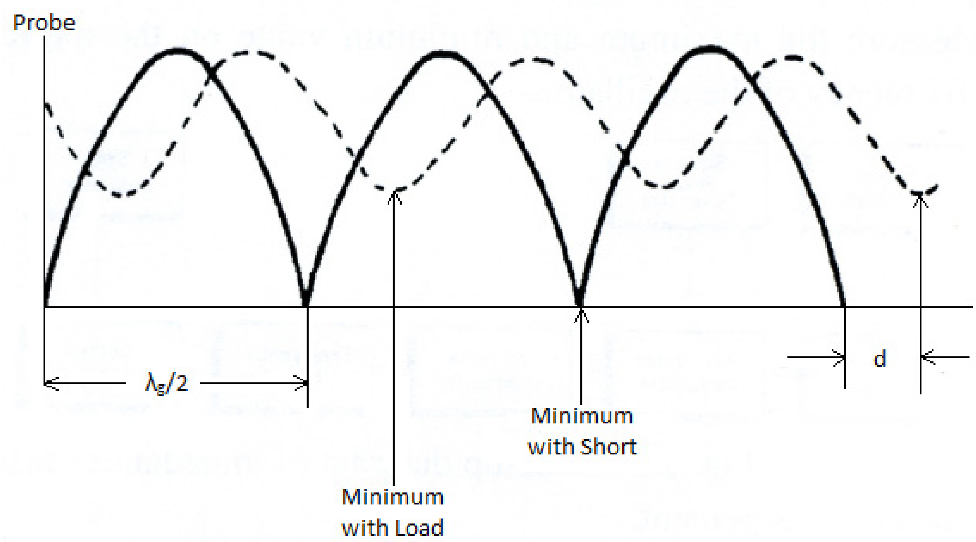


Figure 4.6.3. Fundamentals of impedance measurement.

Draw a V_{SWR} circle on the Smith chart (see Figure 4.6.4).

The impedance at the minimum voltage is 1/SWR. When a short is placed across the load, the minimum of the V_{SWR} moves toward the load (see Figure 7-3).

Therefore, the impedance at the load is determined by drawing a straight line from a point d/λ = away from the zero of the outer most circle to the centre of the V_{SWR} circle.

The intersection of the circle and the straight line represents the load impedance.

Notice that the line impedance equals the load impedance at λ, λ /2, 3/2 λ from the load.

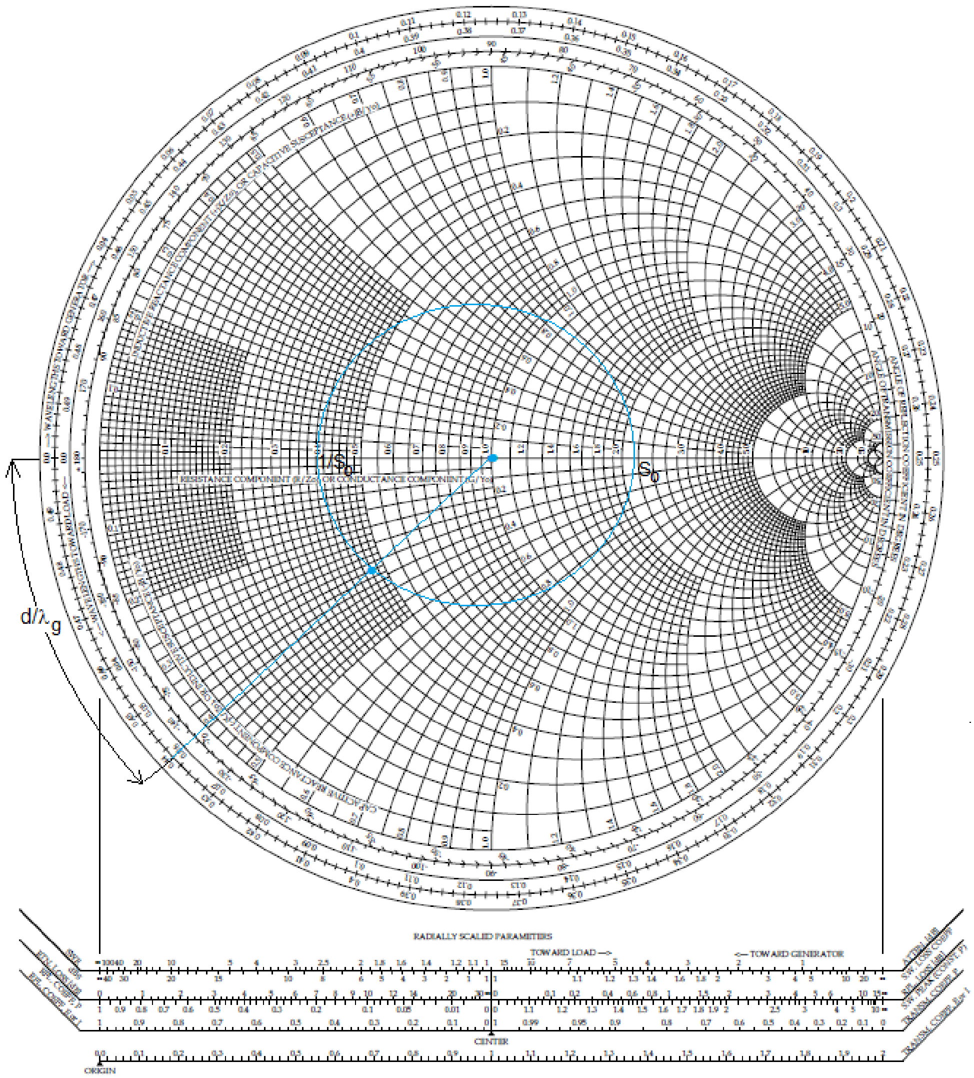


Figure 4.6.4. Finding the load impedance using the Smith chart.

So far, the analysis assumed that the waveguide was lossless.

In case the waveguide is lossy, any traces on the Smith chart becomes a spiral rather than a circle.

In a lossy line, the SWR increases when the point of observation moves toward the load and decreases toward the generator.

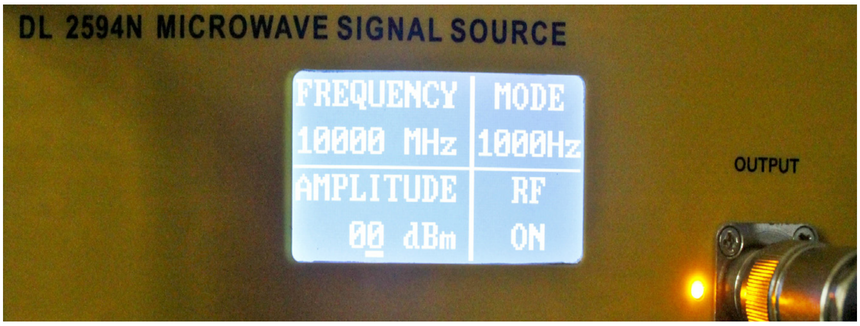
2. Experiment Procedure

Note

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapters 1.2.1 and 1.2.16.

a) Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

For the Frequency Selective Amplifier (SWR) the following settings will be made:

d) Adjust the Gain Adjust Knob in the middle position.

e) Adjust the Frequency Tuning Knob in the middle position.

f) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales:1 ~ 4 and 3.2 ~ 10.

g) Gain selective switch: select the current coarse amplifier gain. the gain range is from 0 to 60 db, with a 10 db step.

h) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, the gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

i) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, the bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

j) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity

k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

1) Before using this equipment, you should read the instructions and operations in the user manual carefully!
2) The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument.
3) The instrument can work more stable after 30 minutes of preheating after initialization.
4) Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display.

A. Basic measurement.

(1) Set up the equipment as shown in Figure 4.6.5 and/or Figure 4.6.6.

(2) Completely unscrew the probe.

(3) Turn ON the Microwave Signal Source.

(4) Apply the modulation signal.

(5) Measure the maximum and minimum value on the SWR indicator. Also, measure the frequency of the oscillator.

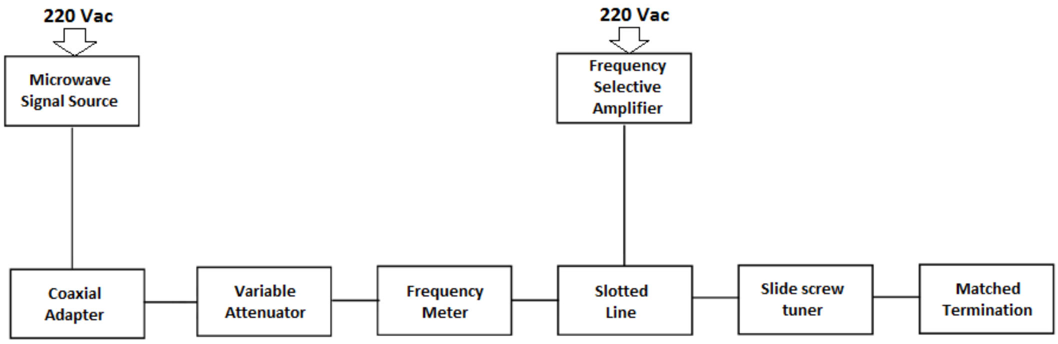


Figure 4.6.5. Setup diagram of impedance measurement.

Figure 4.6.6. Real representation of the experiment.

B. Impedance measurement.

(1) Observe the SWR indicator deflection at the 40dB range. Take the reading.

(2) Bring the probe of the Slide Screw Tuner into the device such that the depth of the probe is approximately 5 mm.

(3) Move the probe along the Slotted Line until a maximum deflection is observed on the SWR indicator.

a) In analog systems, full scale may be defined by the maximum voltage available, or the maximum deflection (full scale deflection or FSD) or indication of an analog instrument such as a moving coil meter or galvanometer.

b) Full scale deflection refers to the full range of motion of an analog 'needle' of an analog meter, or a galvanometer.

c) In the above meter, the amount that the needle moves away from 0 is called the deflection. Full scale deflection is, well, deflection that goes all the way to the end of the scale, in other words, full scale. Anything beyond this scale is not really measurable by this insturment, and so the term 'full scale' actually originates from the older term and concept of 'full scale deflection'. Be it an analog coil-actuated meter, a digital ADC, or even a DAC (though it is used to mean the output range available, not measurement), full scale is now used to mean the complete minimum to maximum range of something. We have mostly dropped the deflection part, however, as deflection is rarely relevant anymore.

d) Note that it needs not be referring to voltage specifically. One could correctly say '0 to 100mA full scale' for example.

e) *Full scale deflection has its history in analogue meters where the moving needle could "deflect" and that deflection was proportional to what it measured i.e. current, voltage or power. FSD is the maximum deflection the needle moved and, this represents the "full scale".*

f) *Full scale is also a term that defines how much an output can rise or fall to i.e. the limits to which an output can be raised or lowered to. In a simple opamp circuit FS is usually a couple of volts inside the power rails. The terms are interchangeable generally and we have seen an output defined to have this or that full scale deflection (although strictly speaking it should be defined as full scale and not FSD).*

(4) Adjust the SWR indicator until the meter indicates 1.0.

(5) Move the probe along the Slotted Line until the minimum deflection is observed. Record the SWR value (S_L) and the depth of the probe (d_L) in Table 4.6-1.

Table 4.6-1 Data recording table for the impedance measurement.

Probe Penetration (mm)	Load SWR	Load Min d_L(mm)	Short Minima d_{L1}(mm) d_{S2}(mm)	$\lambda_g = 2(d_{S1} - d_{S2})$ (mm)	$(d_L - d_{S2})$ λ_g see note	Load Impedance
frequency:	GHz					

Note

In the following measurements, in case $(d_L - d_{S1})$ turns out to be positive, move the probe toward the generator. If the value is negative move it toward the load.

Also, note that $|d_L - d_{S1}|\,\lambda_g$ is always less than 0.25.

(6) Remove the slide screw tuner and the matched termination from the setup. Place a Shorting plate to the Slotted Line.

(7) Obtain the distance d_{s1} and d_{s2} which correspond to two adjacent minimum V_{SWR}s.

The guide wavelength λg is $2x(d_{S1}-d_{S2})$.

When measuring the minimum, it may be helpful to increase the gain of the SWR indicator to obtain a better accuracy.

(8) Repeat the procedure for two more different probe depths.

4.7. Experiment 7: Basic properties of a directional coupler

Objectives

- To learn the basic properties of a Directional Coupler including the coupling coefficient and the directivity.

1. Theory:

The directional coupler, as shown in Figure 4.7.1, is basically a sampling device of the microwave signal. The importance of the directional coupler as a sampling device is that it does not introduce reflections to the main system.

The physical structure of a directional coupler can be thought as a transmission line with one input port and two output ports. The directivity of the directional coupler allows the energy coupling in one direction only.

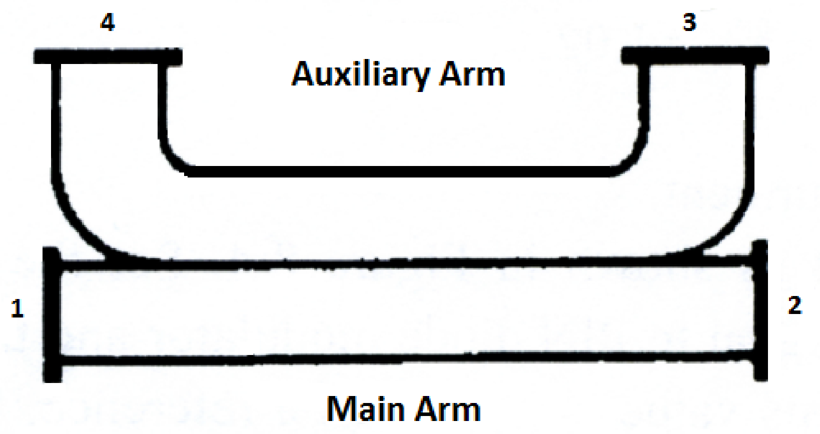
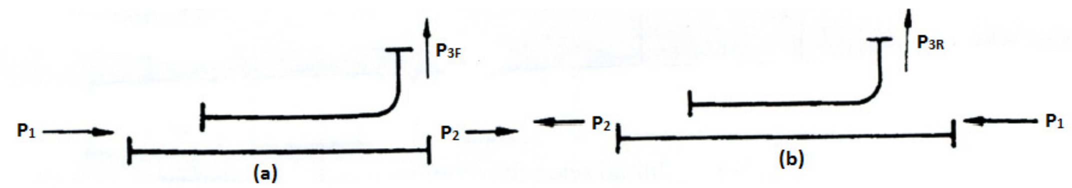


Figure 4.7.1. Directional coupler.

The basic properties of the directional coupler is graphically presented in Figure 4.7.2 and Figure 4.7.3. Notice that one end of the Directional Coupler contains a Matched Termination.



(a) forward wave *(b) reflected wave.*

Figure 4.7.2. Sampling direction of a directional coupler.

The coupling coefficient and the directivity, which are the most important figure of merit of a Directional Coupler, are defined as the following:

$$\text{coupling coefficient} = 10\log\frac{P_1}{P_{3F}}\ (\text{dB}) \qquad (4.7\text{-}1)$$

$$\text{directivity} = 10\log\frac{P_{3F}}{P_{3R}}\ (\text{dB}) \qquad (4.7\text{-}2)$$

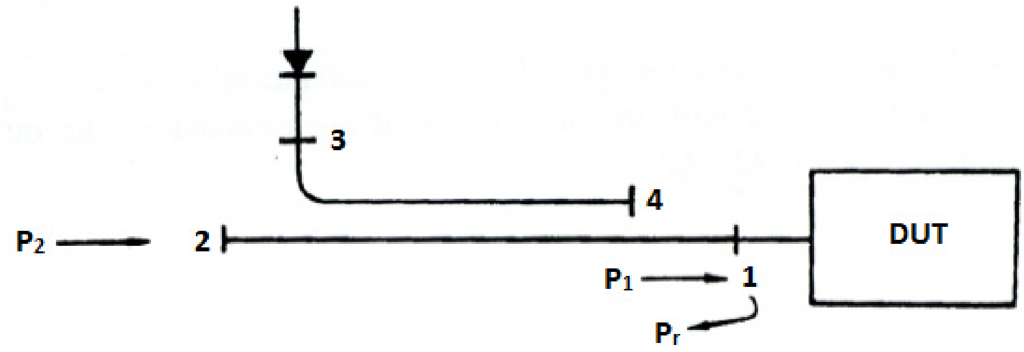


Figure 4.7.3. Return loss measurement.

When measuring the return loss of a device, the input signal is applied at port$_2$, and the device under test (DUT) is connected to port$_1$.

Then, the return signal is picked up at port$_3$ (See Figure 4.7.3). The power at the detector when the coupling coefficient is C (or 10 LogC dB):

$$P_3 = \frac{P_R}{C} \qquad (4.7\text{-}3)$$

Since the voltage reflection coefficient of the DUT is given by:

$$\sqrt{\frac{P_r}{P_i}} = |\rho|$$

P_1 should be known to make use of the expression. If the DUT is replaced by a short, all the input power is reflected back and, therefore, P_i should appear at port$_3$.

The actual power at port$_3$ is equal to P_1 /C. The ratio of the two signals detected at port$_3$ is:

$$(P_1 / C) \times (C / P_r) = 1 / |\rho|^2 \qquad (4.7\text{-}4)$$

The ratio as expressed in (4.7-4) is called return loss. The accuracy of the return loss measurement is dependent upon the directivity of the coupler, which describes how much of the input power at $port_2$ leaks into $port_3$.
For example, a directivity of 40 dB corresponds to a return loss of 40 dB, which, in terms of reflection coefficient, is:

$$\sqrt{10^{-4}} = 0.01$$

The SWR in this case is:

$$\mathrm{SWR} = \frac{1+0.01}{1-0.01} = 1.02$$

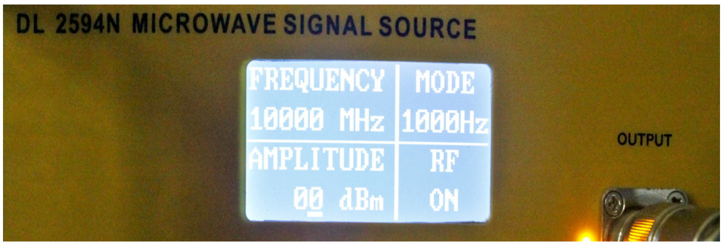
2. Experiment Procedure

Note

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapter 1.2.1 and 1.2.16.

a) Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

For the Frequency Selective Amplifier (SWR) the following settings will be made:

d) Adjust the Gain Adjust Knob in the middle position.

e) Adjust the Frequency Tuning Knob in the middle position.

f) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales:1 ~ 4 and 3.2 ~ 10.

g) Gain selective switch: select the current coarse amplifier gain. The gain range is from 0 to 60 db, with a 10 db step.

h) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

i) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, the bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

j) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity.

k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

1) Before using this equipment, you should read the instructions and operations in the user manual carefully!
2) The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument.
3) The instrument can work more stable after 30 minutes of preheating after initialization.
4) Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display.

A. Coupling factor measurement.

(1) Set up the equipment as shown in Figure 4.7.4 and/or Figure 4.7.5. Set the Variable Attenuator to 20. Turn ON the Microwave Signal Source and set the Modulation Mode at 1 kHz modulation signal. Read the SWR indicator.

Use this value as a reference. Fill in Table 4.7-1 A_1 with the value.

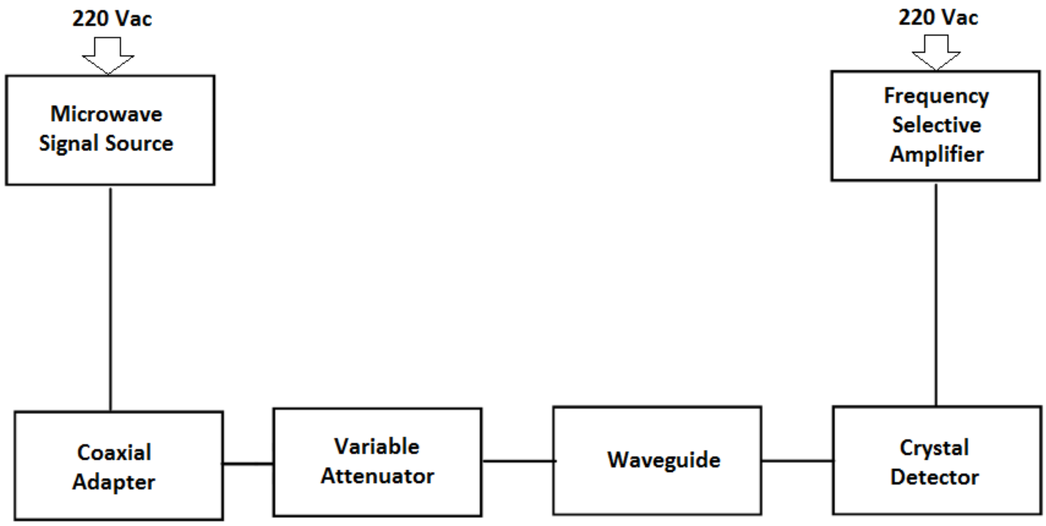


Figure 4.7.4. Initial setup for coupling factor measurement.

(2) Replace the Frequency Selective Amplifier (SWR meter) with a directional coupler (Figure 4.7.6 and/or Figure 4.7.7). Move the Crystal Detector to the auxiliary arm of the coupler.

Table 4.7-1. Data for coupling factor calculation

A_1 [dB]	A_2 [dB]	A_3 [dB]	$A_1 - A_2$ [dB]	A_4 [dB]	$A_3 - A_4 + n \times 10$ [dB]

(3) Adjust the Variable Attenuator until the same reference reading as in (1) is obtained.

(4) Fill in Table 4.7-1 A2 with the attenuation of the Variable Attenuator. The coupling factor of the Directional Coupler is A_1 - A_2.

Figure 4.7.5. Real representation of the experiment.

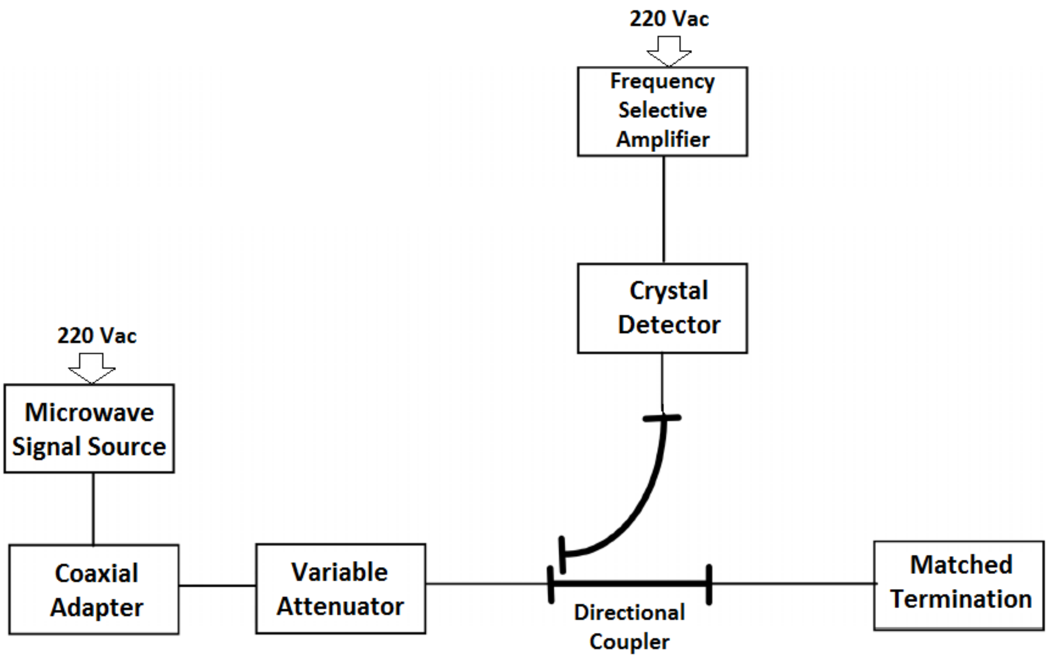


Figure 4.7.6. Setup diagram for coupling factor measurement.

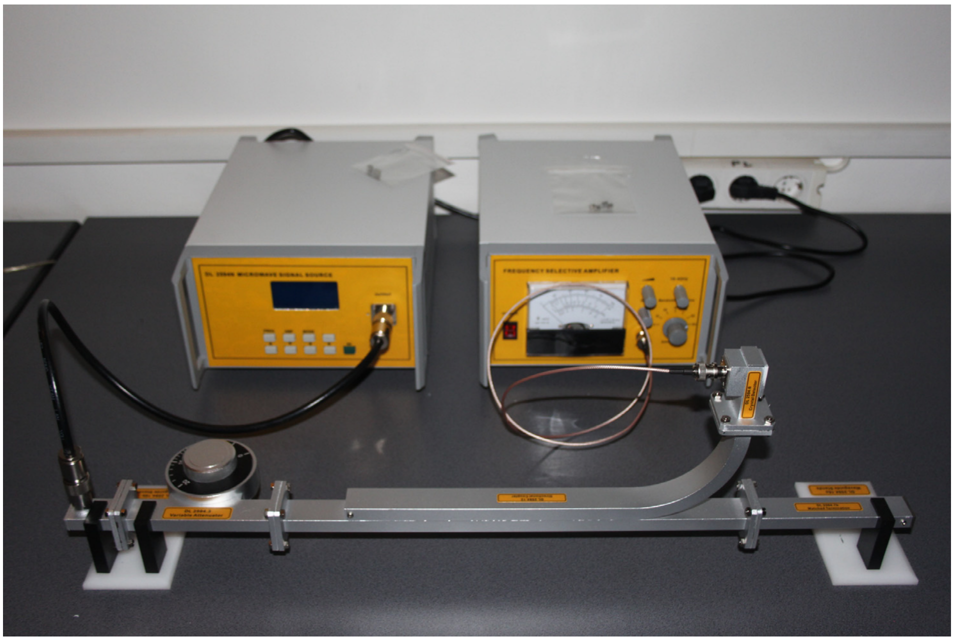


Figure 4.7.7. Real representation of the experiment.

B. Directivity measurement.

(1) Set the Variable Attenuator to 20.

(2) Read the SWR indicator. Use this value as a reference. Record the attenuator setting (20) in Table 4.7-1 A_3.

(3) Change the coupler's orientation as specified in Fig. 4.7.8 and/or Figure 4.7.9.

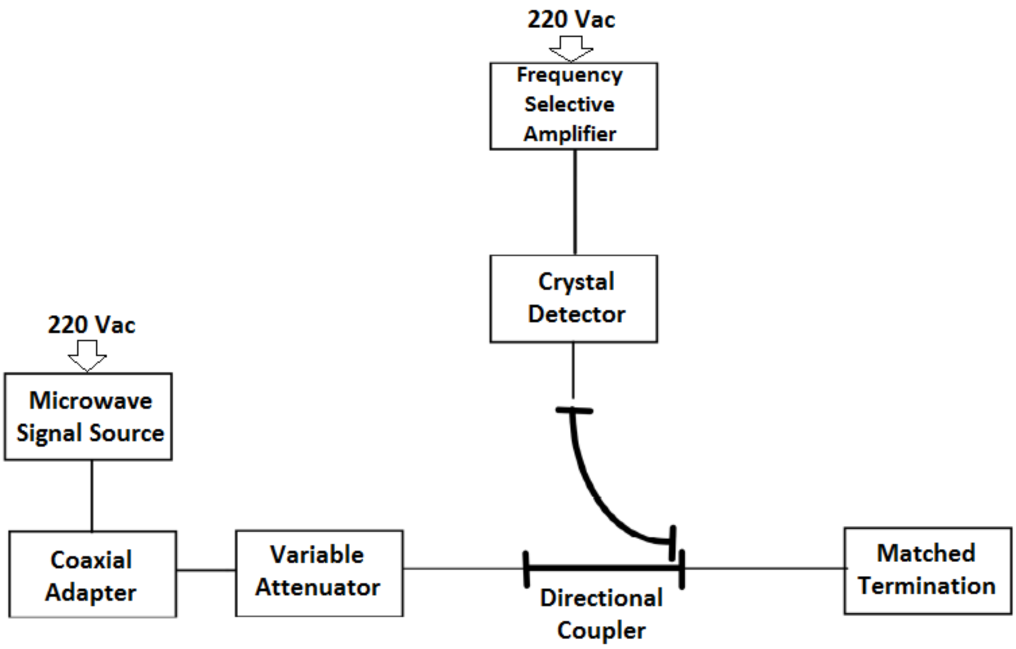


Figure 4.7.8. Setup diagram for directivity measurement.

(4) Reduce the attenuation and increase the SWR indicator gain by 10 or 20 (in 10 dB steps) until the same value as in (2) is obtained. Fill in Table 4.7-1 A_4 with the attenuation of the Variable Attenuator. The directivity is (A_3 - A_4 + n x 10) dB.

Figure 4.7.9. Real representation of the experiment.

C. Return loss measurement of a load.

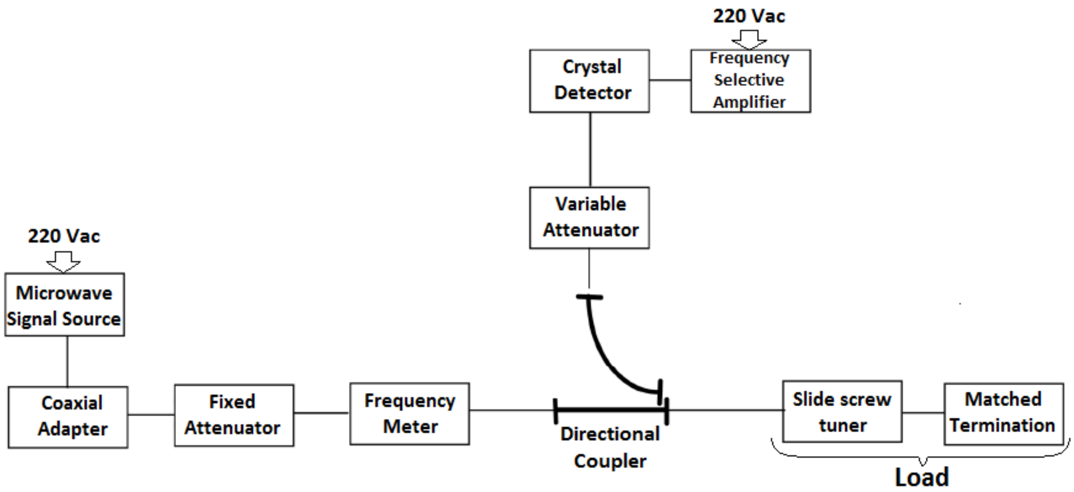


Figure 4.7.10. Setup diagram for return loss measurement.

(1) Set up the equipment as shown in Figure 4.7.10 and/or Figure 4.7.11.

(2) Set the probe depth of the Slide Screw Tuner to 5 mm.

(3) Set the attenuator to (A5). Read the SWR indicator. Use this as a reference.

(4) Change the Variable Attenuator to the maximum attenuation. Replace the load with a short.

(5) Decrease the attenuation until the reference level in (3) is obtained. Record the Variable Attenuator position (A5). In case it is necessary to change the range on the SWR indicator, add the increased value to the position of the attenuator to get A6.

(6) The return loss = (A5 – A6 + n x 10) dB

Figure 4.7.11. Real representation of the experiment.

Table 4.7-2. Data for return loss calculation.

A_5 [dB]	A_6 [dB]	$(A_5 - A_6)+n\times10)$ [dB]	$\lvert\overline{\rho}\rvert$	SWR

4.8. Experiment 8: Attenuation Measurement

Objectives

- To learn the attenuation measurement techniques of the microwave components.

1. Theory

Although attenuation in general means reduction or decrease of something, it specifically refers to the ratio between the input to the output power in microwaves.

$$A(dB) = 10\log\frac{P_1}{P_2} \quad (4.8\text{-}1)$$

where P_1 is the input power and P_2 is the output power.
The insertion loss, although it has mathematically the same expression as (4.8-1), has a completely different meaning; while the attenuation is introduced in the system on purpose, the insertion loss is an undesirable situation. The insertion loss is happening due to non-ideal physical components in the system. In microwave waveguides, two different measurement methods are popular: power ratio or RF substitution.

A. Power ratio method.

The power ratio method is simply taking the power measurement with the DUT and that the microwave detector operates at different power level in each case, causing errors due to the non-linearity of the device. Therefore, the measurement results need to be compensated. For example, when the Output power of the detector diode is maintained at less than 1 milliwatt level, about 3dB compensation is necessary for up to 20 dB attenuation.

B. RF substitution method.

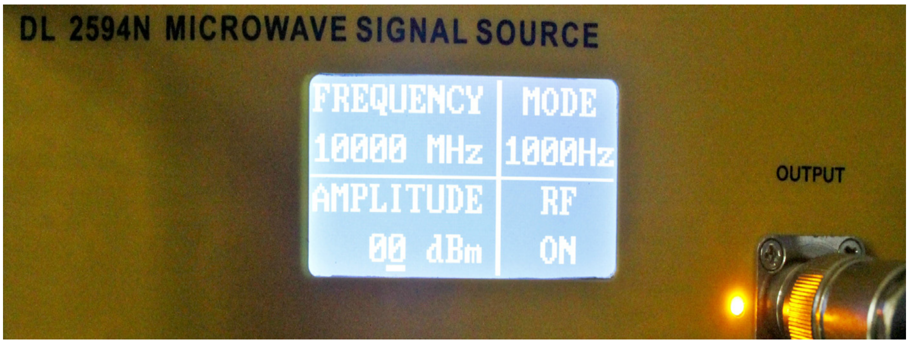
The error associated with the detector in the previous method is eliminated in the RF substitution method by first measuring the output power with the DUT, then replacing the DUT with a calibrated variable attenuator. By properly adjusting the variable attenuator to the same power level as before, the attenuation of the DUT is simply the amount of attenuation of the variable attenuator. So far, in both methods, we are based on the assumption that the errors due to the impedance mismatch is insignificant. Sometimes the SWR indicator itself introduces a small amount of errors. The DL 2594N components are designed with less than ±0.4 dB of error rate.

2. Experiment Procedure

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapter 1.2.1 and 1.2.16.

a) Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

For the Frequency Selective Amplifier (SWR) the following settings will be made:

d) Adjust the Gain Adjust Knob in the middle position.

e) Adjust Frequency Tuning Knob in the middle position.

f) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales:1 ~ 4 and 3.2 ~ 10.

g) Gain selective switch: select the current coarse amplifier gain. The gain range is from 0 to 60 db, with a 10 db step.

h) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

i) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, the bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

j) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity.

k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

1) Before using this equipment, you should read the instructions and operations in the user manual carefully!
2) The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument.
3) The instrument can work more stable after 30 minutes of preheating after initialization.
4) Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display.

A. Preliminary adjustment.

(1) Set up the equipment as shown in Figure 4.8.1 and/or Figure 4.8.2.

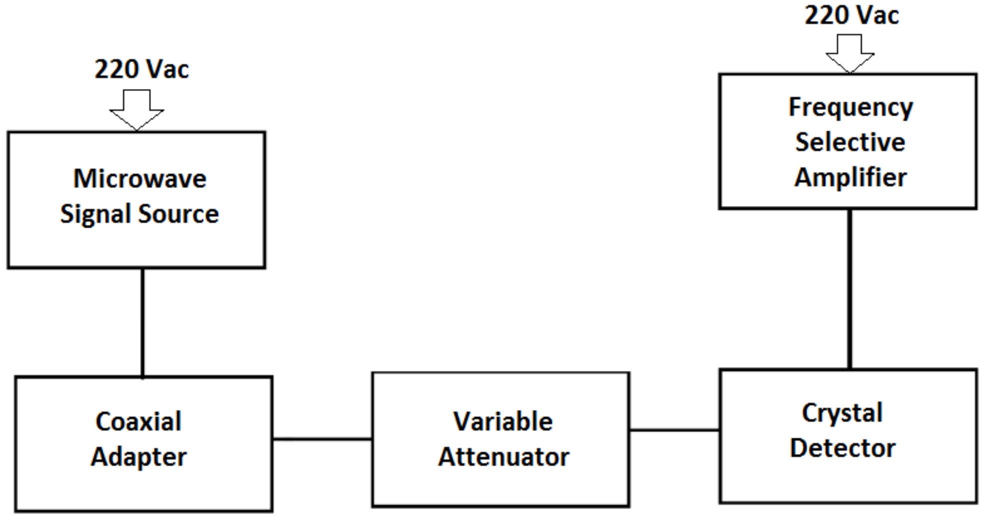


Figure 4.8.1. Setup for preliminary adjustment.

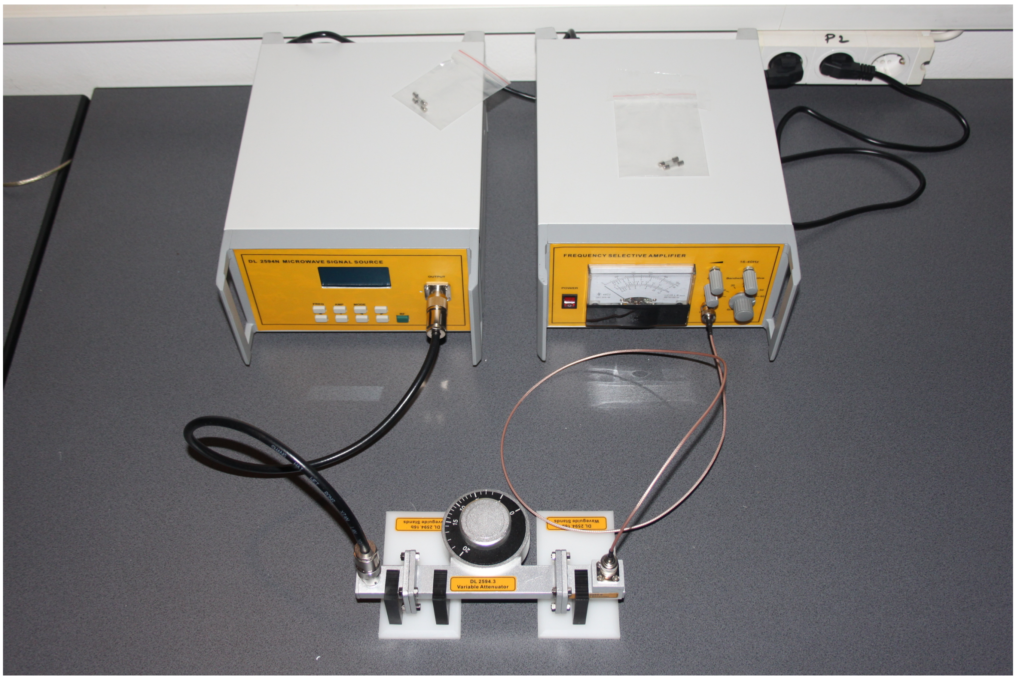


Figure 4.8.2. Real representation of the experiment.

(2) Turn ON the Microwave Signal Source.

(3) Set the Modulation Mode by the 1 kHz modulation signal.

(4) Adjust either the pulse repetition rate or the frequency on the SWR indicator for the maximum deflection on the SWR indicator.

a) In analog systems, full scale may be defined by the maximum voltage available, or the maximum deflection (full scale deflection or FSD) or indication of an analog instrument such as a moving coil meter or galvanometer.

b) Full scale deflection refers to the full range of motion of an analog 'needle' of an analog meter, or a galvanometer.

c) In the above meter, the amount that the needle moves away from 0 is called the deflection. Full scale deflection is, well, deflection that goes all the way to the end of the scale, in other words, full scale. Anything beyond this scale is not really measurable by this insturment, and so the term 'full scale' actually originates from the older term and concept of 'full scale deflection'. Be it an analog coil-actuated meter, a digital ADC, or even a DAC (though it is used to mean the output range available, not measurement), full scale is now used to mean the complete minimum to maximum range of something. We have mostly dropped the deflection part however, as deflection is rarely relevant anymore.

d) Note that it need not be referring to voltage specifically. One could correctly say '0 to 100mA full scale' for example.

e) Full scale deflection has its history in analogue meters where the moving needle could "deflect" and that deflection was proportional to what it measured i.e. current, voltage or power. FSD is the maximum deflection the needle moved and, this represents the "full scale".

f) Full scale is also a term that defines how much an output can rise or fall to i.e. the limits to which an output can be raised or lowered to. In a simple opamp circuit FS is usually a couple of volts inside the power rails. The terms are interchangeable generally and I have seen an output defined to have this or that full scale deflection (although strictly speaking it should be defined as full scale and not FSD).

B. Measurement using the power ratio method.

(1) Set the Variable Attenuator to 20.

(2) Set the SWR indicator gain to either 30 dB or 40 dB range and adjust the indicator for 0 dB.

(3) Using a directional coupler, add a matched termination to the setup as shown in Figure 4.8.3 and/or Figure 4.8.4.

(4) Obtain the reading of the SWR indicator. Calculate the actual coupling of the Directional Coupler.

(5) Repeat step (2), (3) and (4) with the Variable Attenuator set at 15 and 10 respectively.

(6) Repeat the above experiment using a fixed attenuator.

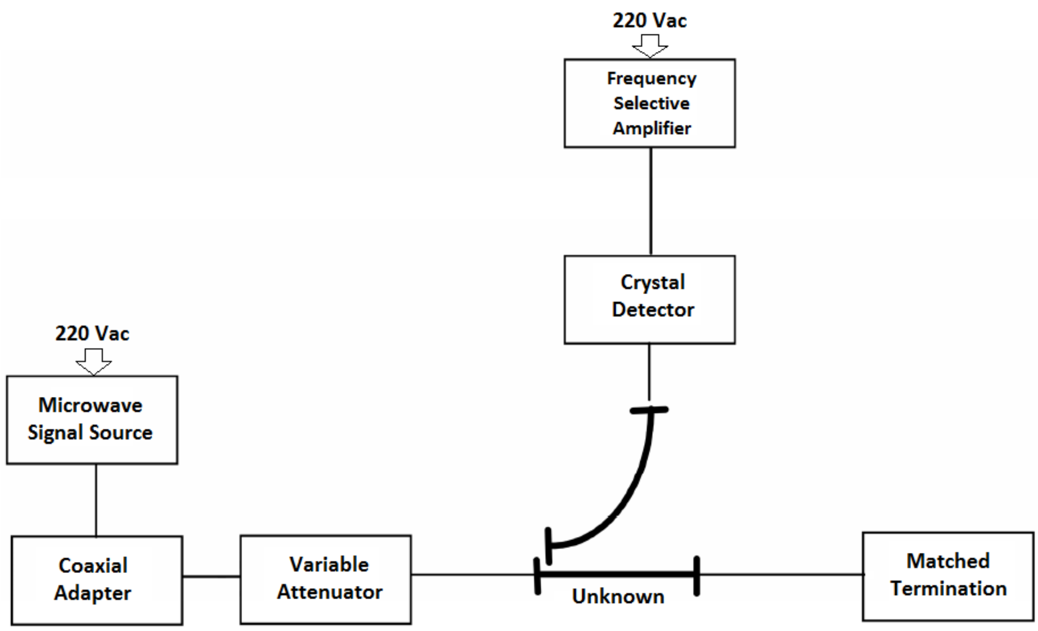


Figure 4.8.3. Measuring the attenuation using the power ratio method.

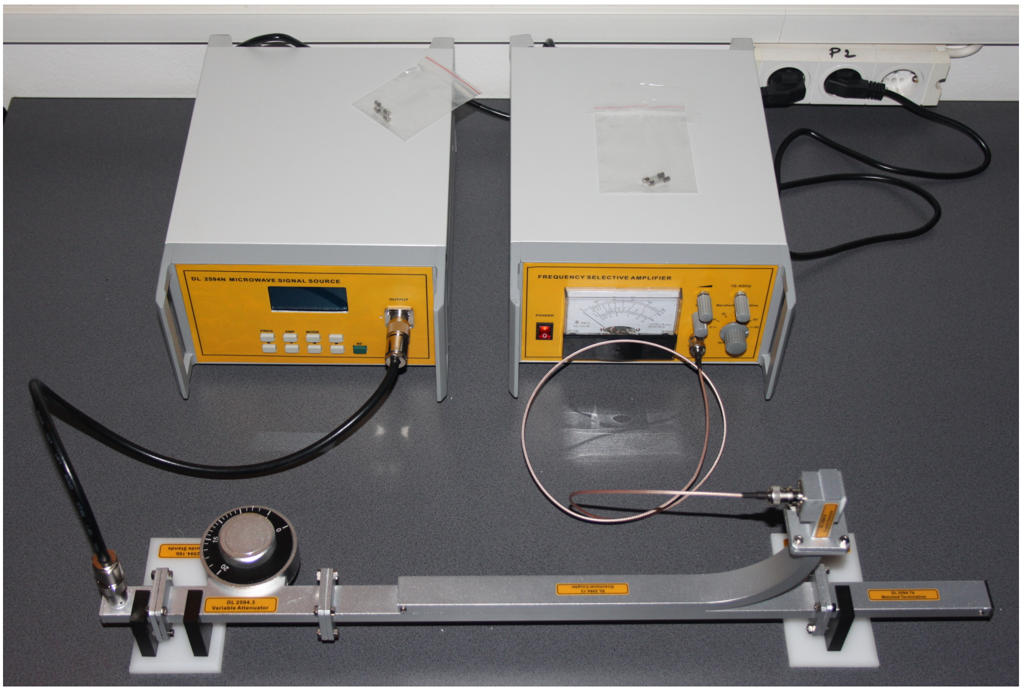


Figure 4.8.4. Real representation of the experiment.

C. Measurement using the RF substitution method.

(1) Set the Variable Attenuator to 20. Adjust the SWR indicator's range switch and gain control so that the indicator can indicate 0 dB.

(2) Insert the Directional Coupler and connect the Crystal Detector to the auxiliary arm of the Directional Coupler (see Figure 4.8.3 and/or Figure 4.8.4). Without altering the SWR indicator setting, adjust the Variable Attenuator until the SWR indication is the same as before. Record the attenuator setting. This is the actual value of the attenuation of the directional coupler in this case.

(3) Repeat the above experiment using a fixed attenuator as a DUT.

D. Measurement of low values of attenuation.

(1) Set up the equipment as shown in Figure 4.8.5 and/or Figure 4.8.6 and/or Figure 4.8.7.

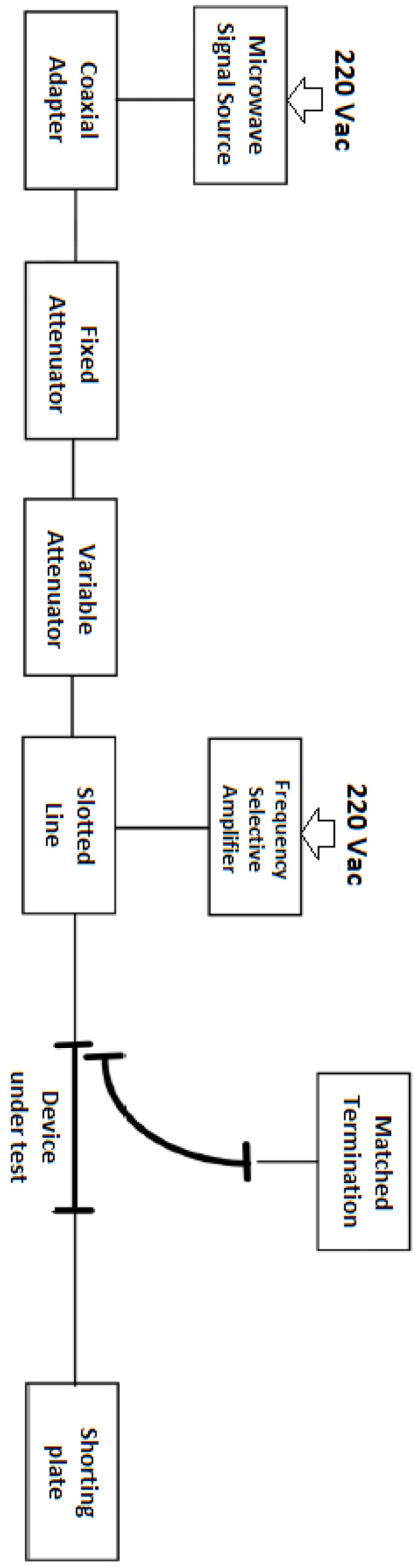


Figure 4.8.5. Setup diagram for the measurement of low values of attenuation.

(2) Set the Variable Attenuator to 20.

(3) Measure the input SWR of the device under test (a Directional Coupler in this case).

(4) Determine the attenuation using the following expression.

$$A = 10\log \frac{SWR + 1}{SWR - 1} \tag{4.8-2}$$

Figure 4.8.6. Real representation of the experiment.

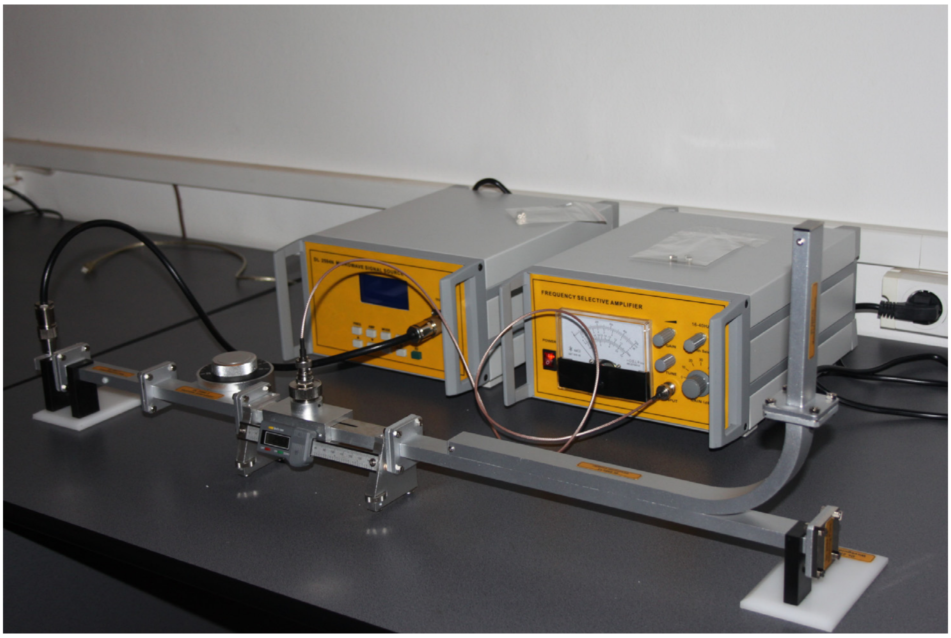


Figure 4.8.7. Real representation of the experiment (Angular view)

4.9. Experiment 9: Study of a waveguide Hybrid - Tee

Objectives

- To understand the basic principle of s Hybrid-T.
- To learn the measurement methods on Hybrid-T characteristics.

1. Theory:

A hybrid-T or a magic-T of Figure 4.9.1 is basically a microwave version of a hybrid coil of the type commonly used in telephone repeater circuits (see Figure 4.9.2).

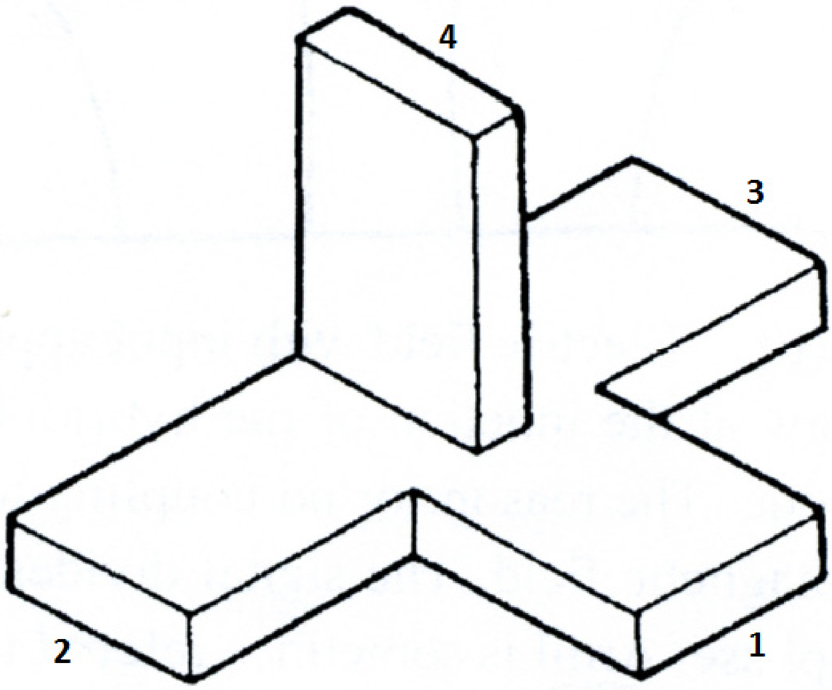


Figure 4.9.1. Waveguide Hybrid-T.

When the bridge circuit is properly matched by external impedances, the input signal applied at $port_1$ appears at $port_2$ and $port_3$, but no signal appears at $port_4$.

In the same manner, when the input is applied at $port_4$, then the signal appears at $port_2$ and $port_3$, but no signal appears at $port_1$.

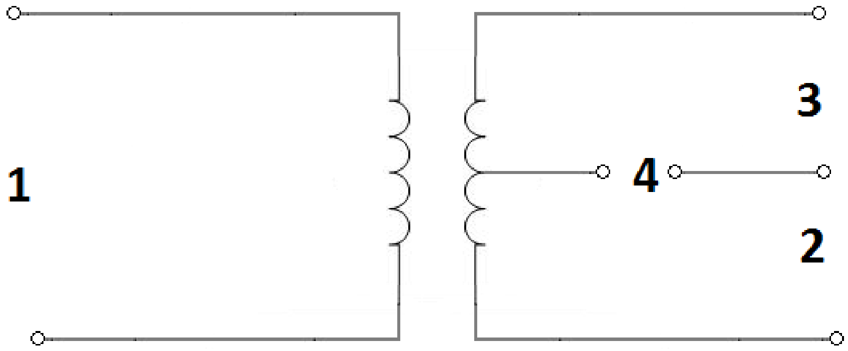


Figure 4.9.2. Balanced bridge circuit.

The above input to output relationship can be described in terms of the field distribution inside of the hybrid-T.

A view of the electric field, with the input applied at $port_1$, is shown in Figure 4.9.3(a). It is assumed that all arms of the hybrid-T are properly matched.

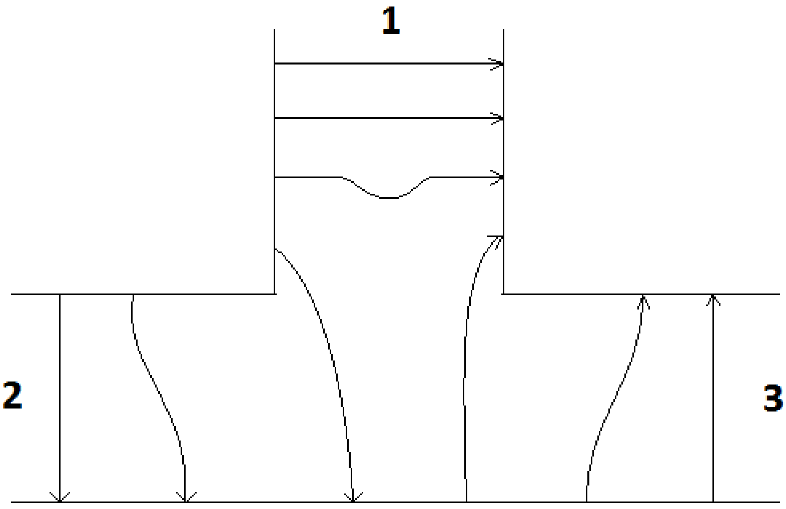


Figure 4.9.3(a). Electric field with input applied at port1.

The field, as shown in Fig. 4.9.3(a), is an even symmetry about the mid-plane. If the input signal is applied at $port_4$, the signal splits equally to $port_2$ and $port_3$ but no part of the signal enters $port_1$.

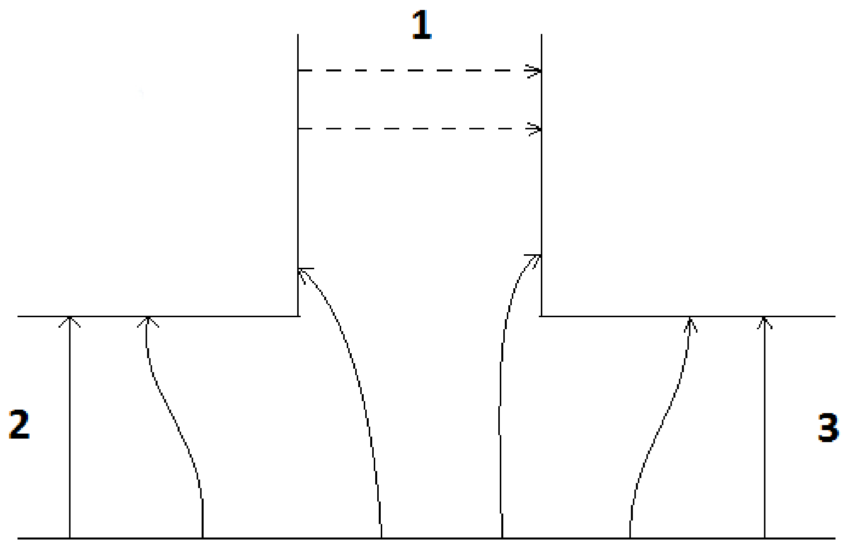


Figure 4.9.3(b). Electric field with input applied at port4.

In Figure 4.9.3(b), a side view at the junction of the hybrid-T is shown when the input signal is applied at $port_4$ in TE_{10} mode.

The reason for no coupling to $port_1$ is due to the reciprocity and the symmetry of the electric and magnetic field.

The signal divides equally to $port_2$ and $port_3$, but the phase is 180 degrees out of phase. Arm 1 is sometimes referred to as H-arm, because it is in the plane of the magnetic field.

Arm 4 is referred to as E-arm for the similar reason. Another place where the inputs can be applied to Arm 2 and Arm 3 at the same time. In this case the vector sum of the two inputs will appear at Arm 1.

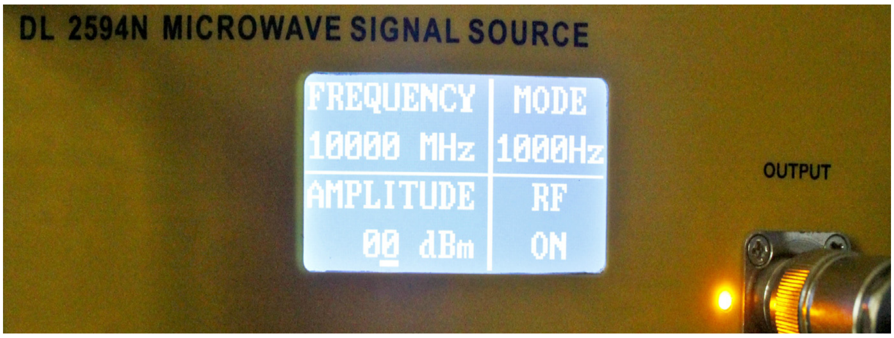
At Arm 4, the vector difference of the two inputs will appear.

2. Experiment Procedure

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapter 1.2.1 and 1.2.16.

a) Press to ON position the power button of the Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

For the Frequency Selective Amplifier (SWR) the following settings will be made:

d) Adjust the Gain Adjust Knob in the middle position.

e) Adjust the Frequency Tuning Knob in the middle position.

f) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales:1 ~ 4 and 3.2 ~ 10.

g) Gain selective switch: select the current coarse amplifier gain. The gain range is from 0 to 60 db, with a 10 db step.

h) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, the gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

i) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, the bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

j) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity.

k) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

1) Before using this equipment, you should read the instructions and operations in the user manual carefully!

2) The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument.

3) The instrument can work more stable after 30 minutes of preheating after initialization.

4) Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display.

A. Initial adjustments.

(1) Set up the equipment as shown in Figure 4.9.4 and/or Figure 4.9.5.

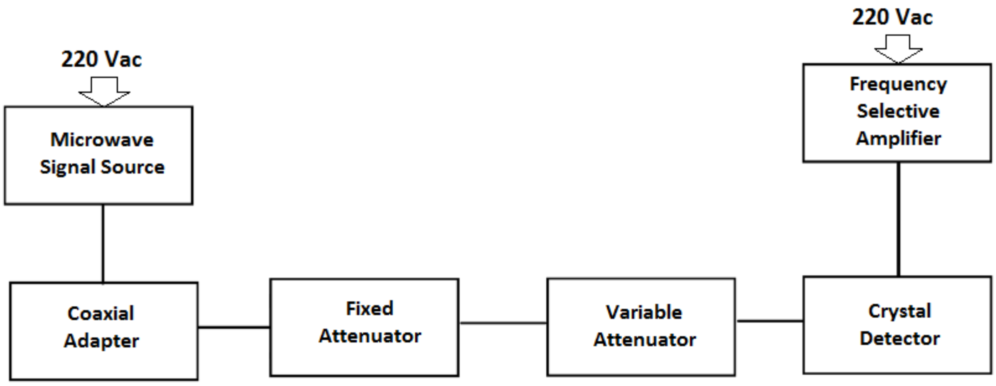


Figure 4.9.4. Initial setup diagram.

Figure 4.9.5. Real representation of the experiment.

(2) Adjust the SWR indicator gain for obtaining any convenient deflection.

(3) Power ON the Microwave Signal Source.

(4) Apply the modulation voltage. Adjust the offset voltage and the pulse frequency of the square wave generator to obtain the maximum deflection on the SWR indicator.

a) In analog systems, full scale may be defined by the maximum voltage available, or the maximum deflection (full scale deflection or FSD) or indication of an analog instrument such as a moving coil meter or galvanometer.

b) Full scale deflection refers to the full range of motion of an analog 'needle' of an analog meter, or a galvanometer.

c) In the above meter, the amount that the needle moves away from 0 is called the deflection. Full scale deflection is, well, deflection that goes all the way to the end of the scale, in other words, full scale. Anything beyond this scale is not really measurable by this insturment, and so the term 'full scale' actually originates from the older term and concept of 'full scale deflection'. Be it an analog coil-actuated meter, a digital ADC, or even a DAC (though it is used to mean the output range available, not measurement), full scale is now used to mean the complete minimum to maximum range of something. We have mostly dropped the deflection part however, as deflection is rarely relevant anymore.

d) Note that it needs not be referring to voltage specifically. One could correctly say '0 to 100mA full scale' for example.

e) Full scale deflection has its history in analogue meters where the moving needle could "deflect" and that deflection was proportional to what it measured i.e. current, voltage or power. FSD is the maximum deflection the needle moved and, this represents the "full scale".

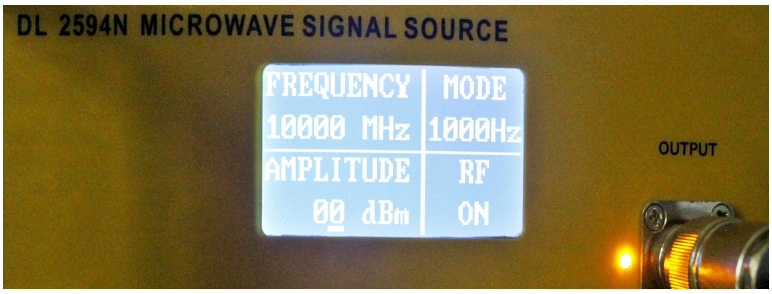
f) *Full scale is also a term that defines how much an output can rise or fall to i.e. the limits to which an output can be raised or lowered to. In a simple opamp circuit FS is usually a couple of volts inside the power rails. The terms are interchangeable generally and we have seen an output defined to have this or that full scale deflection (although strictly speaking it should be defined as full scale and not FSD).*

B. Measurement of decoupling between H-arm and E-arm.

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapter 1.2.1, 1.2.2 and 1.2.16.

a) *Press to ON position the power button of Microwave Signal Source and let it run for 30 minutes minimum.*

b) *The display will show the set of instances as in the figure below:*



c) *If RF is off, press the RF button.*

d) *Press to ON position the power button of the Power Meter and let it run for 30 minutes minimum.*

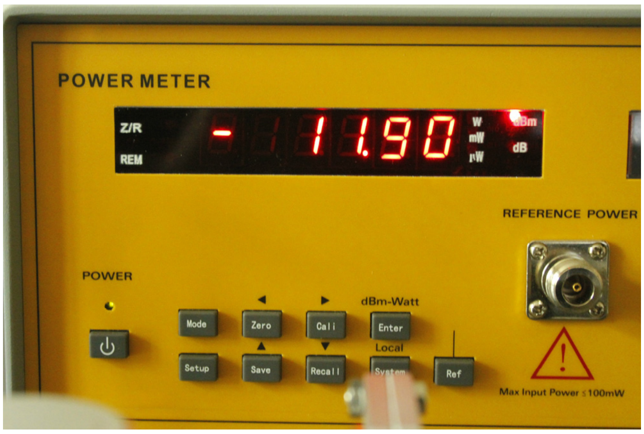
e) Press the Setup button once. The display will show the set of instances as in the figure below:

f) If the number displayed on the right of the display is not 10, press the Save button several times successively, which in this case is meant to increase the value of the number by one unit each time you press.

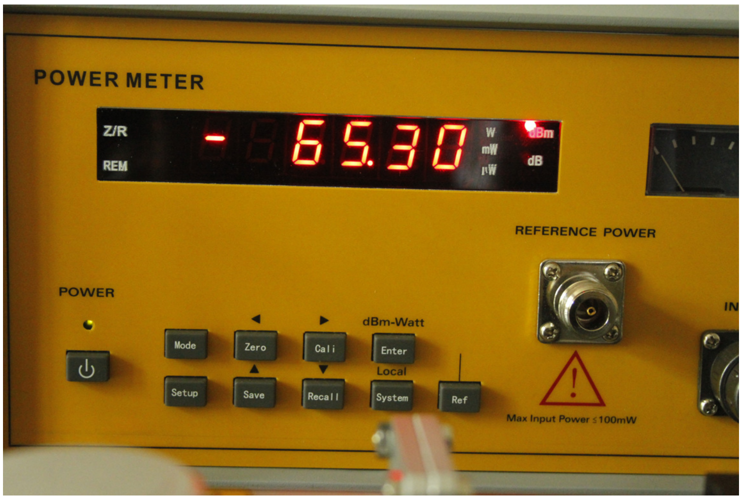
g) After the number is 10, press Setup button once again. The display will show the set of instances as in the figure below:

h) Do not modify anything at this setting.

i) Press Enter the button once. The display will show the set of instances as in the figure below:



j) If the Microwave Signal Source RF is OFF on the display, then the Power Meter display will show the information as in the picture below:



For the Frequency Selective Amplifier (SWR) the following settings will be made:

a) Adjust the Gain Adjust Knob in the middle position.

b) Adjust the Frequency Tuning Knob in the middle position.

c) The meter indicates SWR, attenuation and millivolt value. Millivolt scale is 0 ~ 1000 mV, attenuation scale is 0 ~ 10 db. SWR has two scales:1 ~ 4 and 3.2 ~ 10.

d) Gain selective switch: select the current coarse amplifier gain. The gain range is from 0 to 60 db, with a 10 db step.

e) Gain adjust knob: select the current fine amplifier gain. The range is 0 ~ 5 db continuously adjustable. With clockwise adjustment, the gain amplifier is increased; with anticlockwise adjustment, the gain is decreased.

f) Bandwidth adjust knob: adjust the bandwidth of current measurement. The range is 16 Hz to 40 Hz continuously adjustable. With clockwise adjustment, the bandwidth amplifier is increased; with anticlockwise adjustment, the bandwidth is decreased.

g) Frequency tuning knob: when there is input signal, this knob can be adjusted to get the maximum sensitivity.

h) If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.

1) Before using this equipment, you should read the instructions and operations in the user manual carefully!
2) The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument.
3) The instrument can work more stable after 30 minutes of preheating after initialization.
4) Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display.

(1) Set the equipment as shown in Figure 4.9.6 and/or Figure 4.9.7.

(2) Set the attenuator to 20 (A_1).

(3) Select a range on the SWR indicator which gives a reasonable deflection on the indicator. Adjust the gain control to a reference reading on the dB-scale of the indicator.

(4) Remove the detector and connect the variable attenuator to Arm 1.

(5) Connect matched terminations and power meters to Arm 2 and Arm 3 and connect the detector to Arm 4. Keep the Power Meter at the off position.

(6) Increase the sensitivity of the SWR indicator in 10 dB increment until the same reference as in (3) is obtained. The attenuation (A_1) of the Variable Attenuator may be reduced, if necessary.

(7) Record the results in Table 4.9-1.

Table 4.9-1. Decoupling between Arm 1 and Arm 4.

ATTENUATION OF THE VARIABLE ATTENUATIOR		Variations of the SWR Meter Gain	Decoupling
A_1 [dB]	A_2 [dB]	(in 10dB steps) n steps	$A_1 - A_2 + (n\times10)$ [dB]

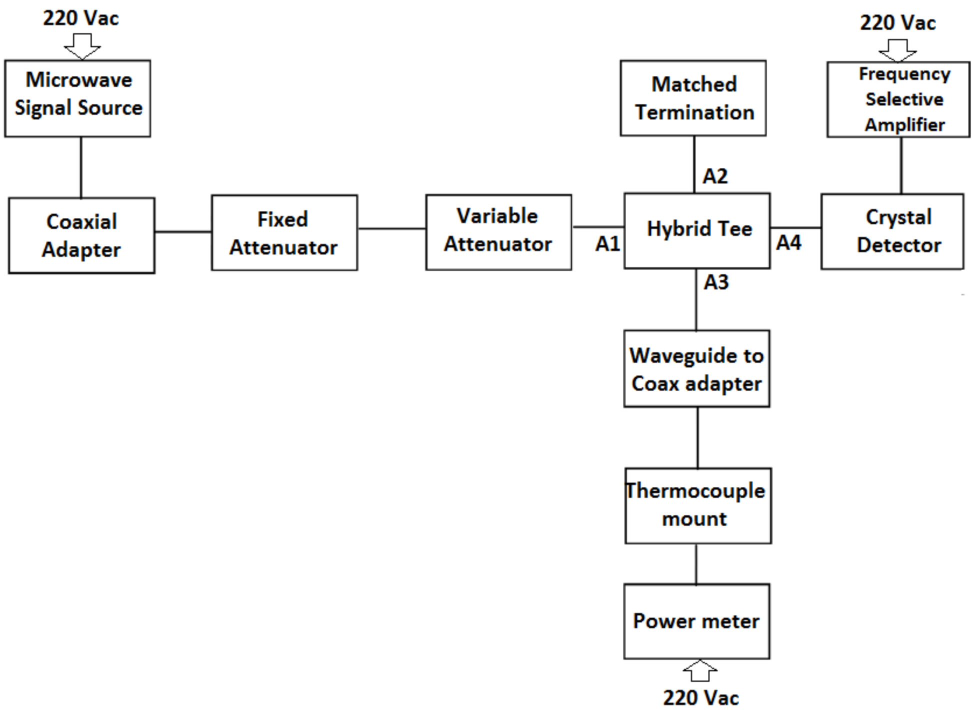


Figure 4.9.6. Setup diagram for measurement of decoupling between H Arm and E Arm.

Figure 4.9.7. Real representation of the experiment.

Figure 4.9.8. Detailed picture on connecting components to Hybrid-Tee.

D. Return loss measurement of the H-arm.

(1) Set up the equipment as shown in Figure 4.9.9 and/or Figure 4.9.10.

(2) Turn ON the Microwave Signal Source.

(3) Set the Variable Attenuator to 20 (A_5).

(4) Set up a reference point on the SWR indicator.

(5) Remove the Shorting Plate. Connect Arm 1 to the directional coupler as shown in Figure 4.9.11 and/or Figure 4.9.12. Connect a matched termination to Arm 3. Leave Arm 4 open (Arm 4 is the E-plane T. Since the decoupling to Arm 4 is almost 30-40 dB, leaving it open should not affect the accuracy).

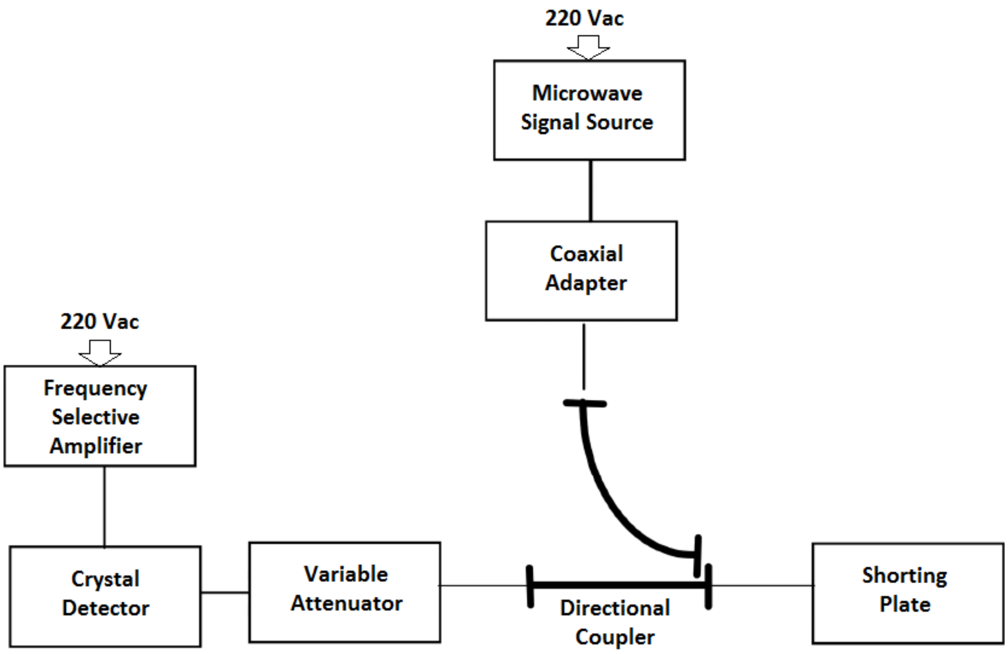


Figure 4.9.9. Initial setup for return loss measurement.

Figure 4.9.10. Real representation of the experiment.

(6) Increase the gain of the SWR indicator in 10dB increment. Decrease the attenuation (A5) until the same level as in (4) is obtained. Record the results in Table 4.9-3.

Figure 4.9.11. Real representation of the D (5) experiment.

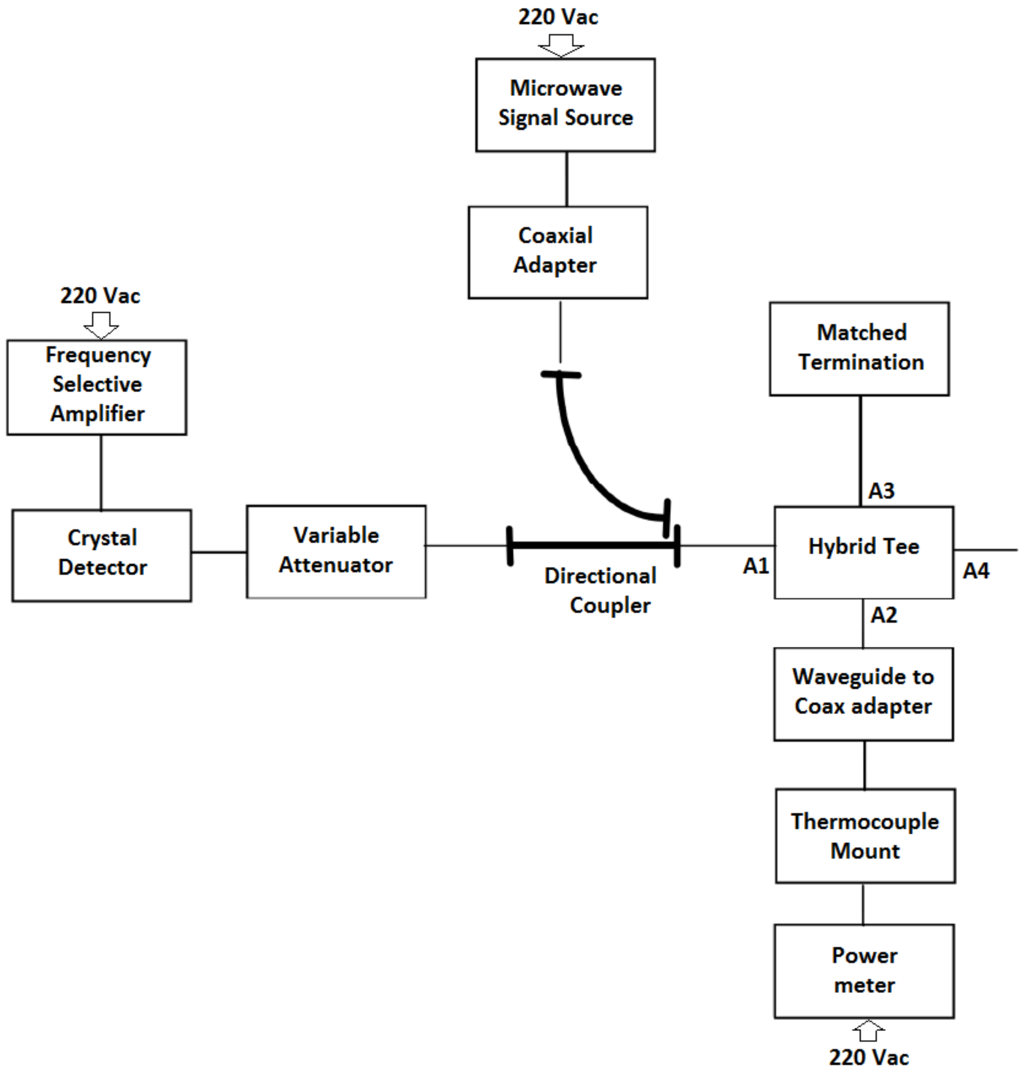


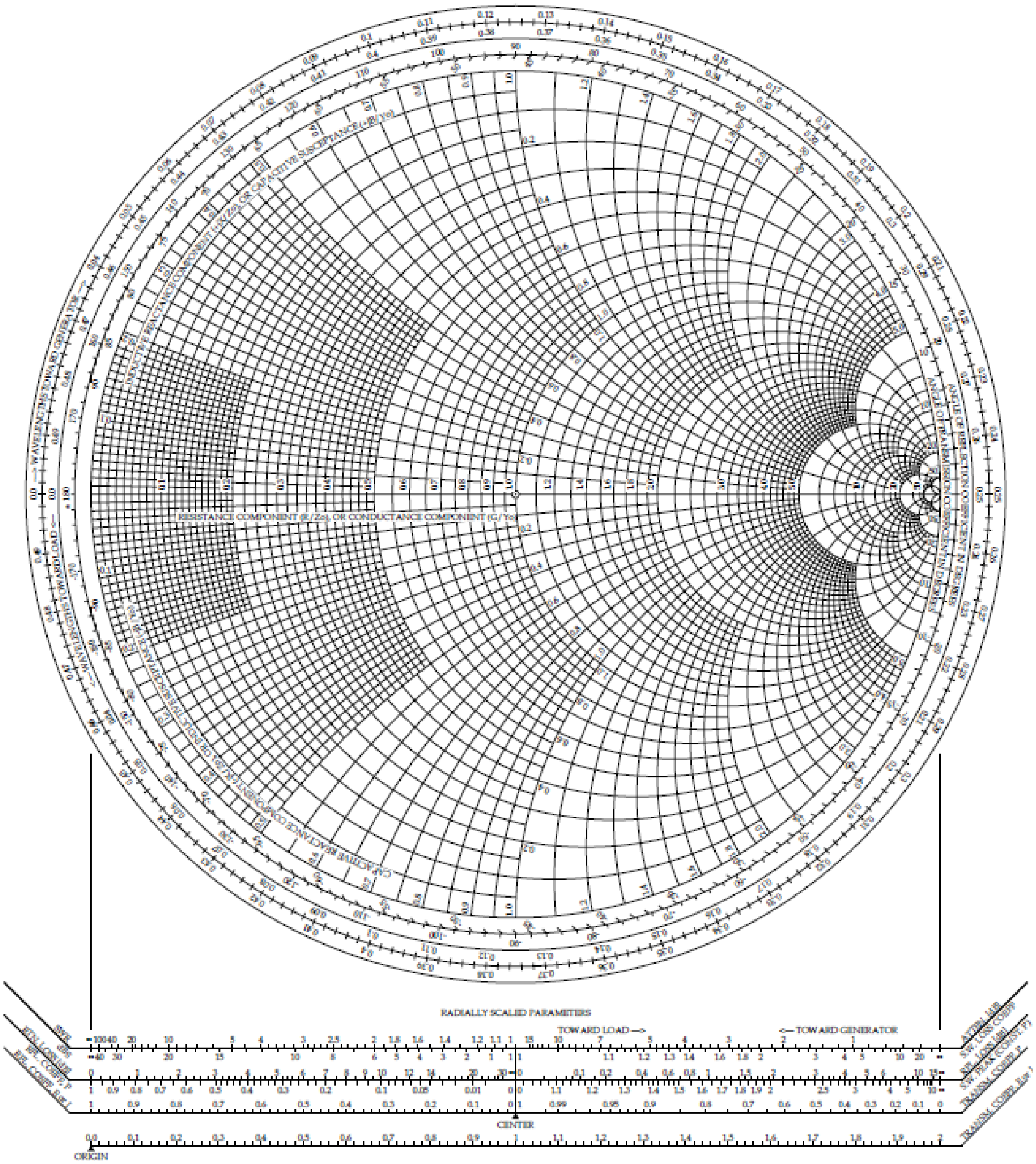
Figure 4.9.12. Return loss measurement setup. The D (5) experiment.

Table 4.9-3. Return loss measurement data.

Object	Attenuation		Gain increase of the SWR meter in 10dB steps A_6-A_5+(n×10)	Return loss	
	A_5 dB	A_6 dB		dB	Absolute value
Arm 1					
Arm 4					

Smith Chart

Impedance or Admittance coordinates



4.10. Experiment 10: Emission and reception using Horn antennas

Objectives

- To learn the uniform plane wave solution to the wave equation.
- To learn microwave propagation in the free space.

1. Theory:

Horn antennas are very popular at UHF (300 MHz-3 GHz) and higher frequencies (we have heard of horn antennas operating as high as 140 GHz). Horn antennas often have a directional radiation pattern with a high antenna gain, which can range up to 25 dB in some cases, with 10-20 dB being typical. Horn antennas have a wide impedance bandwidth, implying that the input impedance is slowly varying over a wide frequency range (which also implies low values for S11 or VSWR). The bandwidth for practical horn antennas can be in the order of 20:1 (for instance, operating from 1 GHz - 20 GHz), with a 10:1 bandwidth not being uncommon.

The gain of horn antennas often increases (and the beam width decreases) as the frequency of operation is increased. This is because the size of the horn aperture is always measured in wavelengths; at higher frequencies, the horn antenna is "electrically larger"; this is because a higher frequency has a smaller wavelength. Since the horn antenna has a fixed physical size (say, a square aperture of 20 cm across, for instance), the aperture is more wavelengths across at higher frequencies. Moreover, a recurring theme in antenna theory is that larger antennas (in terms of wavelengths in size) have higher directivities.

Horn antennas have very little losses, so the directivity of a horn is roughly equal to its gain.

Popular versions of the horn antenna include the E-plane horn, shown in Figure 4.10.1. This horn antenna is flared in the E-plane, giving the name. The horizontal dimension is constant at w.

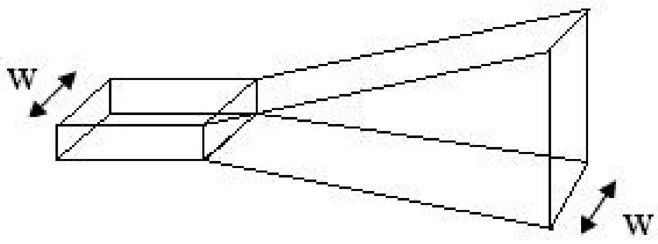


Figure 4.10.1. E-plane Horn Antenna.

Another example of a horn antenna is the H-plane horn, shown in Figure 4.10.2. This horn is flared in the H-plane, with a constant height for the waveguide and horn of h.

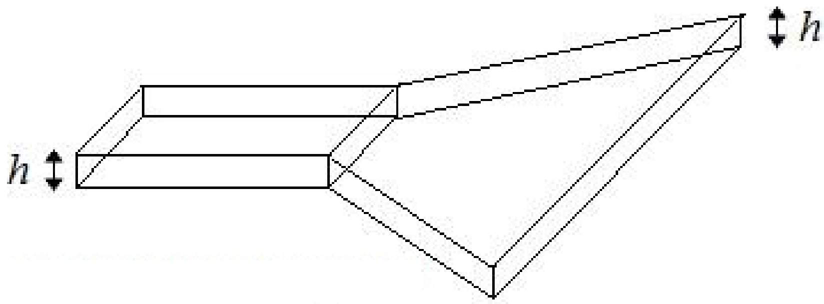


Figure 4.10.2. H-Plane Horn Antenna.

The most popular horn antenna is flared in both planes as shown in Figure 4.10.3. This is a pyramidal horn and has a width B and a height A at the end of the horn.

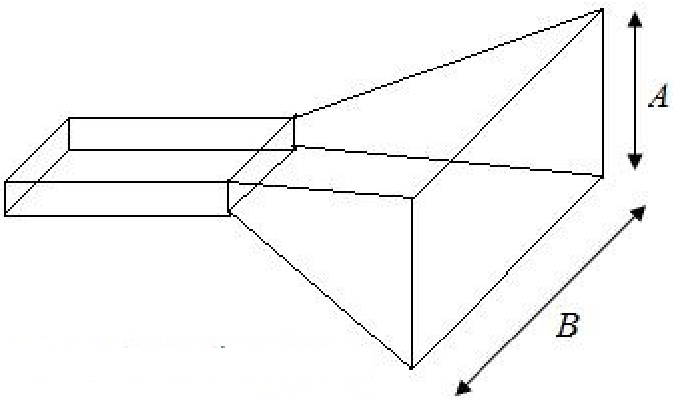


Figure 4.10.3. Pyramidal Horn Antenna.

Horn antennas are typically fed by a section of a waveguide, as shown in Figure 4.10.4. The waveguide itself is often fed with a short dipole, which is shown in red in Figure 4.10.4.

A waveguide is simply a hollow, metal cavity (see the waveguide tutorial). Waveguides are used to guide electromagnetic energy from one place to another. The waveguide in Figure 4.10.4 is a rectangular waveguide of width b and height a, with b>a. The E-field distribution for the dominant mode is shown in the lower part of Figure 4.10.1

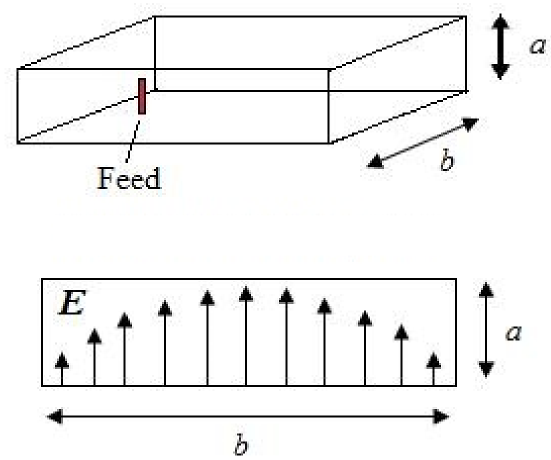


Figure 4.10.4. Waveguide used as a feed to Horn Antennas.

Antenna texts typically derive very complicated functions for the radiation patterns of horn antennas. To do this, first the E-field across the aperture of the horn antenna is assumed to be known and the far-field radiation pattern is calculated using the radiation equations. While this is conceptually straight forward, the resulting field functions end up being extremely complex, and personally we do not feel to add a whole lot of value. The E-field distribution across the aperture of the horn antenna is what is responsible for the radiation.

The radiation pattern of a horn antenna will depend on B and A (the dimensions of the horn at the opening) and R (the length of the horn, which also affects the flare angles of the horn), along with b and a (the dimensions of the waveguide). These parameters are optimized in order to taylor the performance of the horn antenna and are illustrated in the Figure 4.10.5. and Figure 4.10.6.

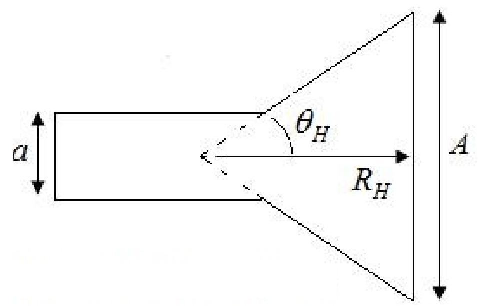


Figure 4.10.5. Cross section of waveguide cut in the H-plane.

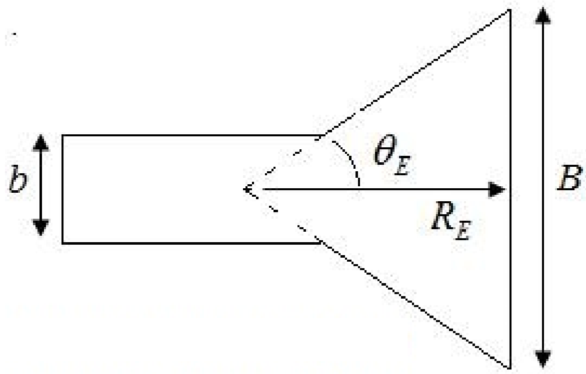


Figure 4.10.6. Cross section of waveguide cut in the E-plane.

Observe that the flare angles (θ_E and θ_H) depend on the height, width and length of the horn antenna.

Given the coordinate system of Figure 4.10.7 (which is centered at the opening of the horn), the radiation will be maximum in the +z-direction (out of the screen).

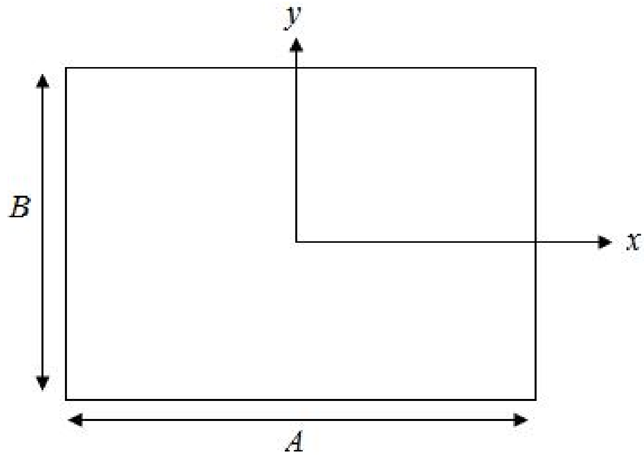


Figure 4.10.7. Coordinate system used, centered on the Horn Antenna opening.

The E-field distribution across the opening of the horn antenna can be approximated by:

$$\mathbf{E}_A = \hat{\mathbf{y}} E_0 \cos\left(\frac{\pi x}{A}\right) e^{-j\frac{k}{2}\left(\frac{x^2}{R_H} + \frac{y^2}{R_E}\right)} \quad (4.10\text{-}1)$$

The E-field in the far-field will be linearly polarized and the magnitude will be given by:

$$|\mathbf{E}| = \frac{k}{4\pi r}(1+\cos\theta) \int_{-B/2}^{B/2} \int_{-A/2}^{A/2} E_A(x,y) e^{jk(x\sin\theta\cos\phi + y\sin\theta\sin\phi)} dxdy \quad (4.10\text{-}2)$$

The horn antenna geometry affects its antenna gain. However, this optimal geometry is only valid at a single frequency. Since horn antennas are to operate over a wide frequency band, they are often designed to have optimal gain at the lowest frequency in the band.

At higher frequencies, the geometry is no longer optimal, so the E-field across the aperture is not optimal. However, the horn's aperture becomes electrically larger at higher frequencies (the aperture is more wavelengths long as the frequency increases or the wavelength decreases). Consequently, the loss of an optimal aperture field is offset by an electrically larger horn and the antenna gain actually increases as the frequency increases.

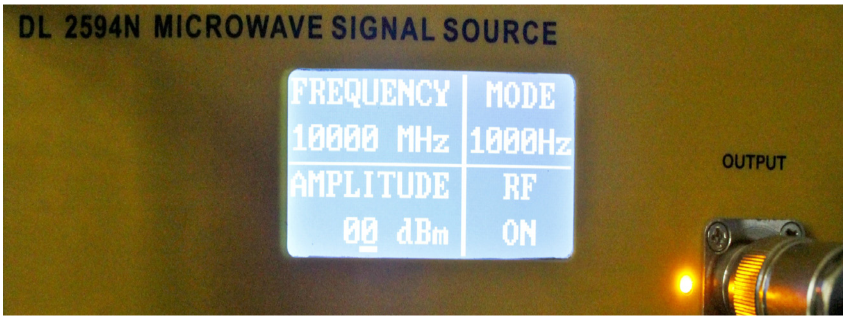
2. Experiment Procedure

Note

In the text and images in the following figures are presented the manual action modes for preparing the devices so they are stable in operation and calibrated according to the instructions in subchapter 1.2.1 and 1.2.2.

a) Press to ON position the power button of Microwave Signal Source and let it run for 30 minutes minimum.

b) The display will show the set of instances as in the figure below:



c) If RF is off, press the RF button.

d) Press to ON position the power button of the Power Meter and let it run for 30 minutes minimum.

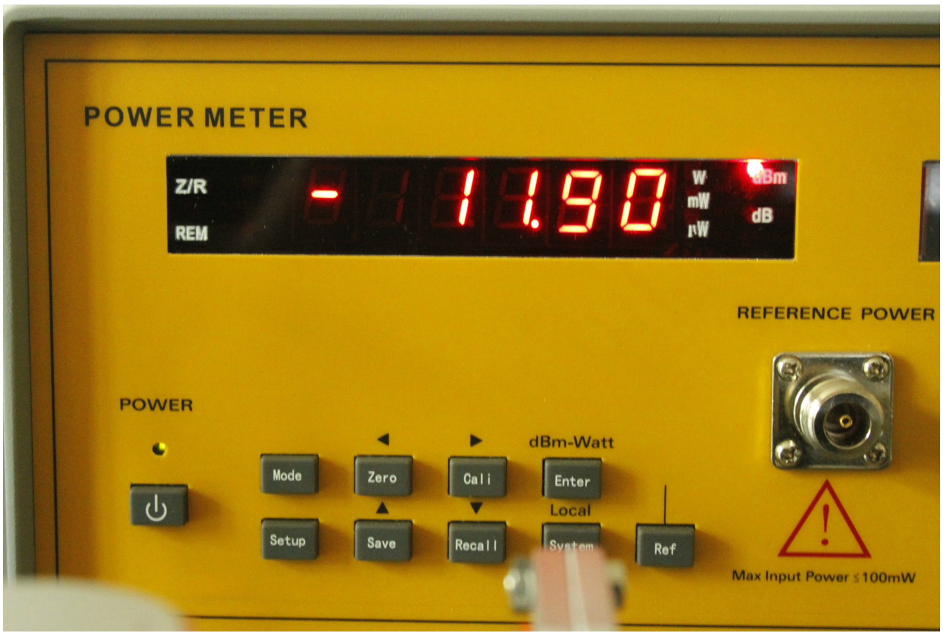
e) Press the Setup button once. The display will show the set of instances as in the figure below:

f) If the number displayed on the right of the display is not 10, press the Save button several times successively, which in this case is meant to increase the value of the number by one unit each time you press.

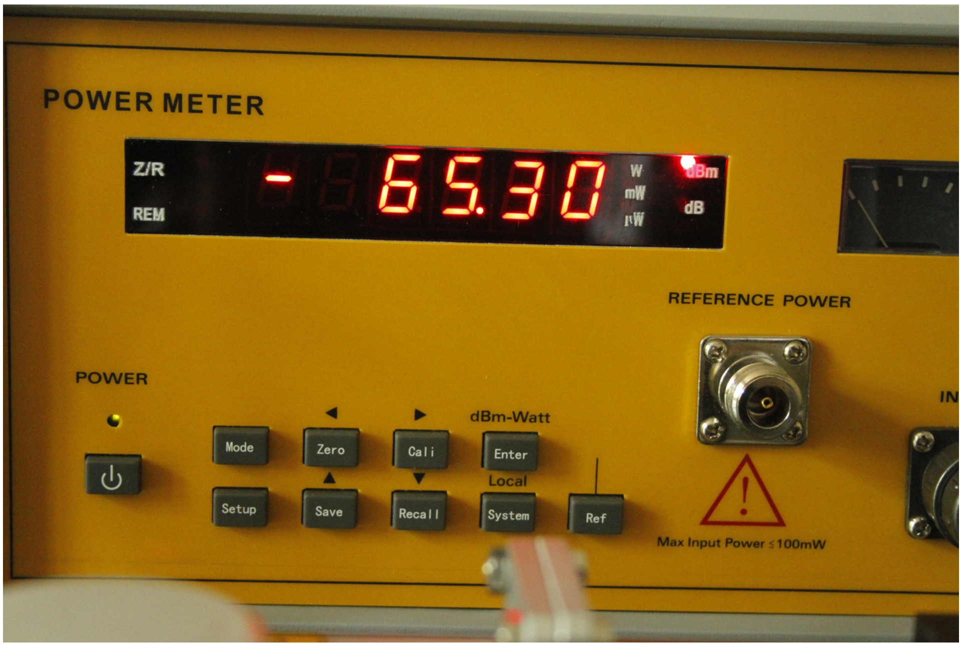
g) After the number is 10, press the Setup button once again. The display will show the set of instances as in the figure below:

h) Do not modify anything at this setting.

i) *Press the Enter button once. The display will show the set of instances as in the figure below:*



j) *If the Microwave Signal Source RF is OFF on the display, then the Power Meter display will show the information as in the picture below:*



k) *If RF is ON for the Microwave Signal Source and the device has been running for at least 30 minutes, under these conditions you can start measuring.*

Warning!

1) *Before using this equipment, you should read the instructions and operations in the user manual carefully!*
2) *The power supply voltage range is AC 110V~220V, 50Hz/60Hz. Over-voltage may cause damage to the internal components of this instrument;.*
3) *The instrument can work more stable after 30 minutes of preheating after initialization.*
4) *Any structural modification of the experiment (component removal, component replacement, etc.) will only be done after the RF has the OFF status on the Microwave Signal Source display.*

(1) Set up the equipment as shown in Figure 4.10.8 and/or Figure 4.10.9.

(2) Turn ON the Microwave Signal Source.

(3) Set the Variable Attenuator to 20.

(4) Position the Horn antennas 1 cm apart in front of the other.

(5) Turn ON the Power Meter.

(6) Record in the Table 4.10-1 the first value of the power level shown by the Power Meter.

(7) Repeat the records in Table 4.10-1 by changing the distance between the antennas at 2 cm, 3 cm, 4, cm, 5 cm, 10 cm, 15 cm, 30 cm and 60 cm.

(8) Represent graphically in P coordinates and d the values recorded in Table 4.10-1.

Note

Draw a straight line on a sheet of paper, place the antenna holder on the paper sheet and try placing the antenna Stand Base so that the line is in the middle of the width of the Stand Base.

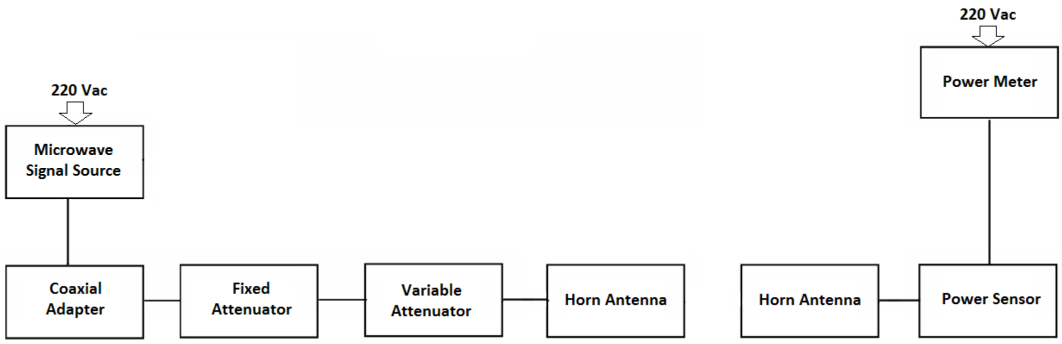


Figure 4.10.8. Setup diagram for measurement of microwave propagation between Horn antennas.

Figure 4.10.9. Real representation of the experiment.

Table 4.10-1.

Power indicator (dB)									
Distance (cm)	**1**	**2**	**3**	**4**	**5**	**10**	**15**	**30**	**60**

5. References

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