DESIGN & DEVELOPMENT OF RECTANGULAR WAVEGUIDE BANDPASS FILTER

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This report is submitted in partial fulfillment of the requirements for the award of Bachelor of Electronic (Computer Engineering) With Honours

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FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

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ABSTRACT

We all know how important are the communication in our live. So the good transmission lines can make our life much better and easier. The quality of transmission also important because we don't want the signal that we transfer or receive has a weakness such as losses. The waveguide is more useful elements in filter design as they generally have much higher Q factors than coaxial or other TEM resonators. Although, the waveguide has a distinct cut-off frequency above which electromagnetic energy will propagate and below which it is attenuated. The problem that why I proceed with this project is because the conventional planar filter like micro-strip filter producing several types of losses in transmission lines such as conductor, radiation, copper and dielectric losses. This project will demonstrate the characteristic of rectangular waveguide in producing a very high quality band-pass filter. The propose filter operate at X-band frequency (22.86mmX10.16mm) with 1GHz bandwidth. This high performance filter can be in mobile phone base-station such as use for the military.

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CHAPTER I

LITERATURE REVIEW

In this chapter, it will cover all about the theoretical and concept that related with the rectangular waveguide band-pass filter such as the introduction of waveguide, modes of propagation of rectangular waveguide, introduction of s-parameter and post as discontinuities in a waveguide.

1.0 Microwave Concept

Microwaves are electromagnetic waves with wavelengths ranging from as long as one meter to as short as one millimeter, or equivalently, with frequencies between 300MHz (0.3 GHz) and 300 GHz. This is an extremely broad definition including both

UHF and EHF (millimeter waves), and various sources use different boundaries. In all cases, microwave includes the entire SHF band (3 to 30GHz, or 10 to 1cm) at minimum, with RF engineering often putting the lower boundary at 1GHz (30cm), and the upper around 100GHz (3mm).

Apparatus and techniques may be described qualitatively as "microwave" when the wavelengths of signals are roughly the same as the dimensions of the equipment, so that lumped element circuit theory is inaccurate. As a consequence, practical microwave technique tends to move away from the discrete resistors, capacitors, and inductors used with lower frequency radio waves. Instead, distributed circuit elements and transmission-line theory are more useful methods for design and analysis. Open-wire and coaxial transmission lines give way to waveguides, and lumped-element tuned circuits are replaced by cavity resonators or resonant lines. Effects of reflection, polarization, scattering, diffraction and atmospheric absorption usually associated with visible light are of practical significance in the study of microwave propagation. The same equations of electromagnetic theory apply at all frequencies.

Electromagnetic waves longer (lower frequency) than microwaves are called "radio waves". Electromagnetic radiation with shorter wavelengths may be called "millimeter waves", terahertz radiation or even *T-rays*. Definitions differ for millimeter wave band, which the IEEE defines as 110 GHz to 300 GHz.

Above 300 GHz, the absorption of electromagnetic radiation by Earth's atmosphere is so great that it is effectively opaque, until the atmosphere becomes transparent again in the so-called infrared and optical window frequency ranges.

The microwave spectrum is usually defined as electromagnetic energy ranging from approximately 1 GHz to 100 GHz in frequency, but older usage includes lower frequencies. Most common applications are within the 1 to 40 GHz range. Microwave frequency bands, as defined by the Radio Society of Great Britain (RSGB), are shown in the table below:

Letter Designation	**Frequency Range (GHz)**
L band	1 to 2
S band	2 to 4
C band	4 to 8
X band	**8 to 12**
Ku band	12 to 18
K band	18 to 26.5
Ka band	26.5 to 40
Q band	30 to 50
U band	40 to 60
V band	50 to 75
E band	60 to 90
W band	75 to 110
F band	90 to 140
D band	110 to 170

Table 1: Microwave Frequency Band Range

Microwave frequency can be measured by either electronic or mechanical techniques. Frequency counters or high frequency heterodyne systems can be used. Here the unknown frequency is compared with harmonics of a known lower frequency by use of a low frequency generator, a harmonic generator and a mixer. Accuracy of the measurement is limited by the accuracy and stability of the reference source.

In a laboratory setting, Lecher lines can be used to directly measure the wavelength on a transmission line made of parallel wires, the frequency can then be calculated. A similar technique is to use a slotted waveguide or slotted coaxial line to directly measure the wavelength. These devices consist of a probe introduced into the line through a longitudinal slot, so that the probe is free to travel up and down the line. Slotted lines are primarily intended for measurement of the voltage standing wave ratio on the line. However, provided a standing wave is present, they may also be used to measure the distance between the nodes; which is equal to half the wavelength. Precision of this method is limited by the determination of the nodal locations. [1]

1.1 Introduction to waveguide

A waveguide is a hollow conductive tube or metallic pipes usually rectangular, circular or elliptical with uniform cross-section. The dimension of the cross section will directs the propagation of an electromagnetic within the interior of the guide by confining the wave's energy.

Waveguide technology is still widely employed in the frequency range from 1 to 100GHz. Waveguide resonators are very useful elements when designing a filter where it have much higher Q factors, low loss and very high power capability than coaxial cable or other TEM resonator.

This project are design and develop of the band-pass filters because waveguide filters are typically band-pass filters due to the intrinsic high-pass behavior of a waveguide. [2]

The dimensions of the cross section are selected such that electromagnetic waves can propagate within the interior of the waveguide. A waveguide does not conduct current in the true sense but rather serves as boundary that confines electromagnetic energy.

The walls of the waveguide are conductors and, therefore, reflect electromagnetic energy from their surface. If the wall of the waveguide is a good conductor and very thin, little current flows in the interior walls; and consequently, very little power is dissipated. Electromagnetic energy propagates down the waveguide by reflecting back and forth in a zigzag pattern. The cross-sectional area of a waveguide must be on the same order as the waveguide of the signal it is propagating. Therefore, waveguides are generally restricted to frequencies above 1GHz. [3]

These are distinct differences between waveguide and TEM transmission lines. A transmission line has a minimum of two conductors and supports the TEM mode of propagation, which has zero cut-off frequency. There is no minimum size for the cross-section of a TEM line in order for signal propagation to occur, other than that determined by dissipation losses. On the other hand, a waveguide has only one conductor consisting of the boundary of the pipe. The waveguide has a distinct cut-off frequency above which electromagnetic energy will propagate and below which it is attenuated. The cut-off frequency of the waveguide is determined by its cross-sectional dimensions. For example, a rectangular cross-section waveguide must have a width at least greater than one-half of the free space wavelength for propagation to occur at particular frequency.

Furthermore, propagation in waveguides occurs with distinct field patterns, or modes. Any waveguide can support an infinite number modes each of which have their-own cutoff frequency. Also, both the characteristic impedance and the propagation constant of a waveguide are function of frequency.

The advantage of waveguides, waveguides is the most efficient way to transfer electromagnetic energy. Waveguide are essentially coaxial lines without center conductors. They are constructed from conductive material and may be rectangular, circular, or elliptical in shape, as shown in figure 1.1.

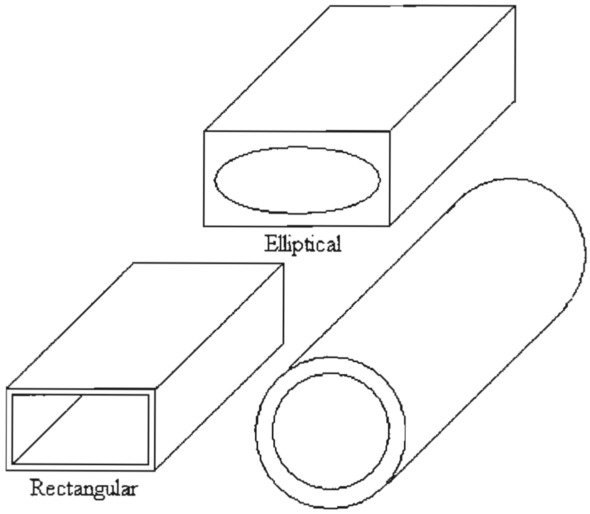


Figure 1.1: various geometries of waveguide

The rectangular waveguide designs based on the specification that have been standardize. The waveguide size chart shown in table 2.

Waveguide	Band	Frequency Range (GHz)	Inner Cross Dimension (mm)	Outer Cross Dimension (mm)
WR-204	S	2.60 – 3.95	72.14 X 34.04	76.20 X 38.01
WR-229	C	3.95 – 5.85	58.17 X 29.083	61.42 X 32.33
WR-137	J	5.85 – 8.20	34.85 X 15.799	38.10 X 19.05
WR-90	**X**	**8.20 – 12.40**	**22.86 X 10.16**	**25.40 X 12.70**
WR-62	Ku	12.40 – 18.00	15.79 X 7.89	17.83 X 9.93
WR-42	K	18.00 – 26.50	10.68 X 4.31	12.70 X 6.35
WR-28	Ka	26.4 – 40.1	7.11 X 3.55	9.14 X 5.59

Table 2: Waveguide Size Chart

1.2 Modes of Propagation in Rectangular Waveguide

Rectangular waveguide dominant with TE and TM modes but cannot exist in the TEM modes. This because in general, if solution of the wave equation subject to the boundary conditions is obtained for any one of the field components. The possible field solutions are typically classified in term of TE or TM modes.

Electromagnetic waves travel down a waveguide in different configuration called propagation modes. In 1955, the Institute of Radio Engineers published a set of standards. These standards designated the modes for rectangular waveguides as $TE_{m,n}$ for transverse-electric waves and $TM_{m,n}$ for transverse-magnetic waves.

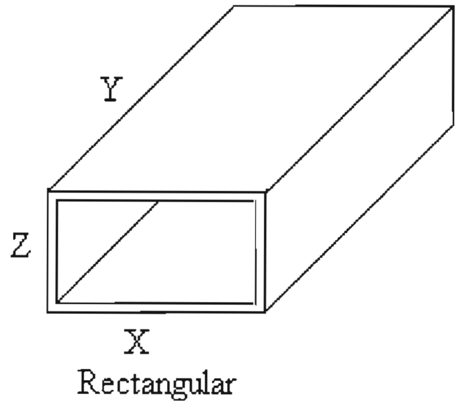


Figure 1.2: Rectangular Waveguide

In both cases, *m* and *n* are integers designating the number of half-wavelengths of intensity (electric and magnetic) that exist between each pair of walls. *m* is measured along the X-axis on the waveguide (the same axis the dimension *a* is measured on), and *n* is measured along the Z-axis (the same as dimension *b*).

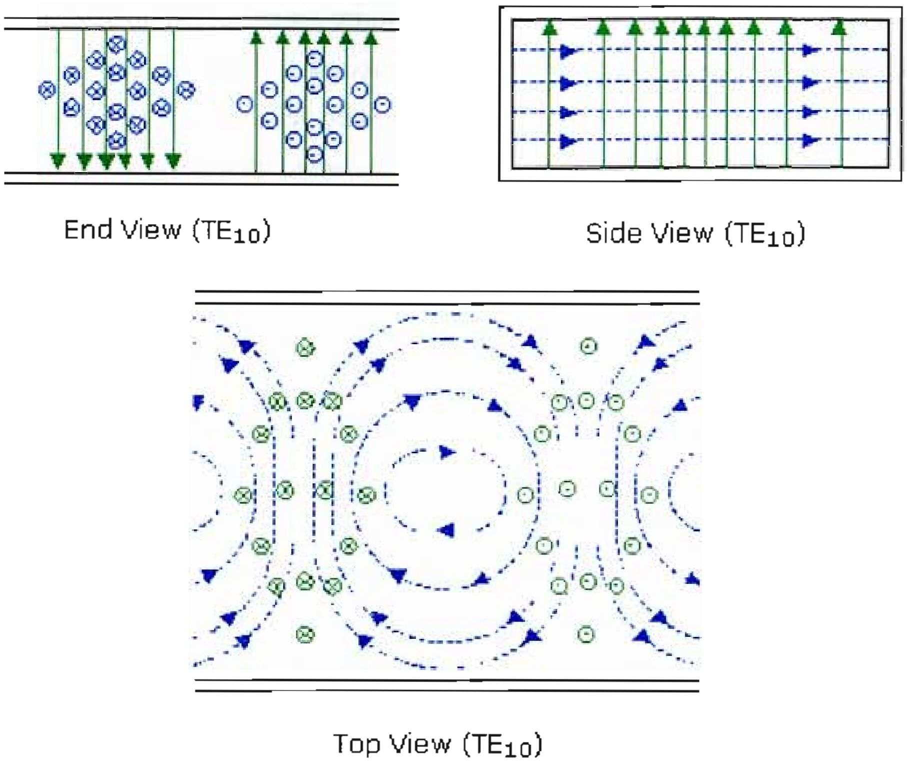


Figure 1.3: E field and H field in the rectangular waveguide for TE modes

Figure 1.3 shows the electromagnetic field pattern for a TE_{10} mode wave. The TE_{10} mode is sometimes called the dominant mode because it is most "natural" mode. A waveguide acts as a high-pass filter in that it passes only those frequency above the minimum or cut-off frequency.

At frequency above the cut-off frequency, higher-order TE modes of propagation, with more complicated field configurations, are possible. It is undesirable to operate a waveguide at a frequency at which these higher modes can propagate. The TE_{10} mode desired because it allows for the smallest possible size waveguide for a given frequency of operation. From figure 3, we can see that the electric field or E field vectors are parallel to each other and perpendicular to the wide face of the guide. [4]

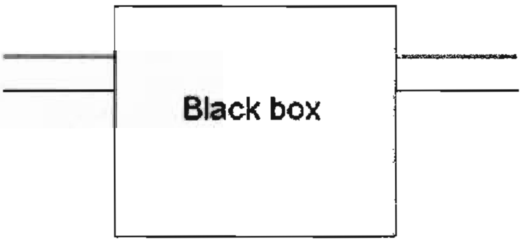
The amplitude is greatest midway between the narrow walls and decreases to zero at the walls, in a cosines fashion. The magnetic field or H field vectors (dashed lines) are also parallel to each other and perpendicular to the electric vectors. The magnetic intensity is constant in the vertical direction across the guide section. Form the view, we can see that the wave propagate in the longitude direction of the waveguide, perpendicular to the E and H vectors.

1.3 Basic Concept of S-parameter

Scattering Parameters, or s-parameters, are the reflection and transmission coefficients between the incident and reflection waves. They describe completely the behavior of a device under linear conditions at microwave frequency range. Each parameter is typically characterized by magnitude, decibel and phase. The expression in decibel is 20log(S) because s-parameters are voltage ratios of the waves. [4] The advantage of s-parameters does not only lie in the complete description of the device performance at microwave frequencies but also the ability to convert to other parameters such as hybrid (H) or admittance (Y) parameters. To more understand of the S-parameter concept let's look at this example.

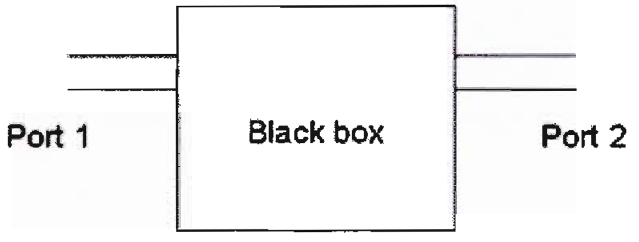
1.3.1 S-parameters are a useful method for representing a circuit as a "black box"

The external behaviour of this black box can be predicted without any regard for the contents of the black box. This black box could contain anything such as a resistor, transmission line or an integrated circuit.



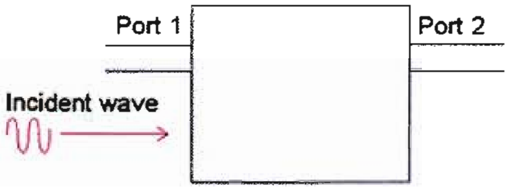
1.3.2 A "black box" or network may have any number of ports.

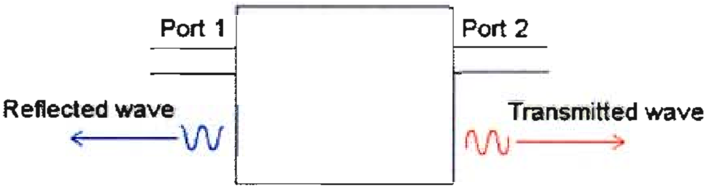
This diagram shows a simple network with just 2 ports. A port is a terminal pair of lines.



1.3.3 S-parameters are measured by sending a *single* frequency signal into the network or "black box" and detecting what waves exit from each port.

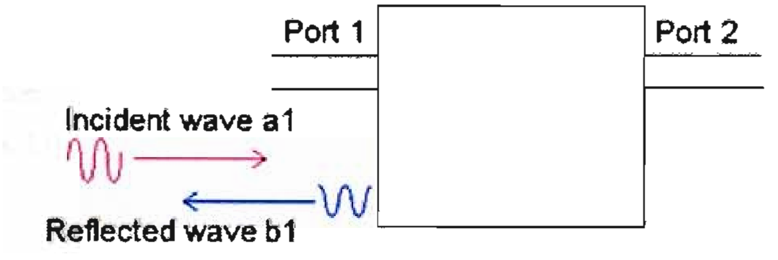
Power voltage and current can be considered to be in the form of waves travelling in both directions. For a wave incident on Port 1 some part of this signal reflects back out of that port and some portion of the signal exits other ports.



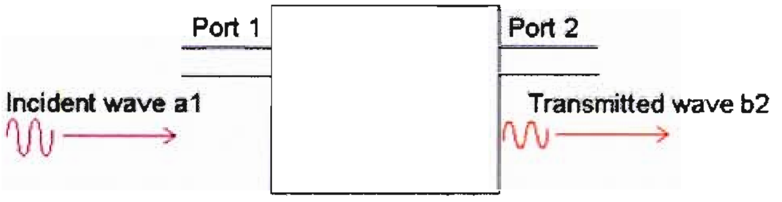


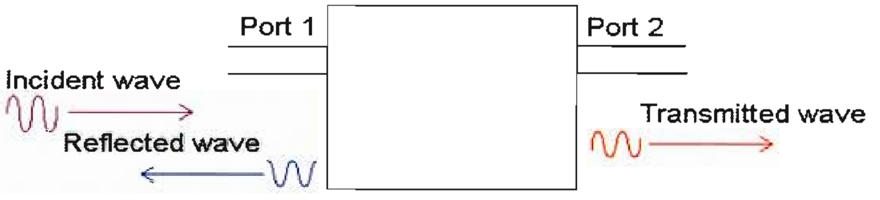
1.3.4 S-parameters described as S_{11} and S_{21}.

First let's look at S_{11}, S_{11} is refers to the signal reflected a Port 1 for the signal incident at Port 1. Scattering parameter S_{11} is the ration of the two wave's b1/a1.



Now let's look at S_{21}, S_{21} is refers to the signal exiting at Port 2 for the signal incident at Port 1. Scattering parameter S_{21} is the ratio of the two wave's b2/a1.





The transmitted and reflected wave will have changed in amplitude and phase from incident wave. Generally, the transmitted and reflected wave will be at the same frequency as the incident wave. We can conclude that S-parameters are a powerful way to describe an electrical network. S-parameters change with frequency / load impedance / source impedance / network. S_{11} is the reflection coefficient. S_{21} describes the forward transmission coefficient (responding port 1^{st}!). S-parameters have both magnitude and phase information. Sometimes the gain (or loss) is more important than the phase shift and the phase information may be ignored and S-parameters may describe large and complex networks. [5]