A CIRCULAR MICROSTRIP ANTENNA

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ABSTRACT

A circular microstrip antenna is designed in order to obtain the required parameter responses from 2.4 GHz to 2.5 GHz by using CST software based on the method of cavity model due of simplicity and easier to analyze.

This circular patch is fed by microstrip line and FR-4 board is used with the specified information include the dielectric constant of substrate ($\epsilon_r = 4.7$), the resonant frequency ($f_r = 2.45$ GHz) and substrate height (h=1.6mm).

The main parameters concerned are return loss (S_{11}) and VSWR. A prototype of the circular microstrip antenna has been built and tested by Vector Network Analyzer (VNA). Then the measurement result obtained would be compared to the simulation result.

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ABSTRAK

Antena microstrip berbentuk bulat direka untuk beroperasi dari frekuensi 2.4GHz ke 2.5GHz menggunakan perisian CST. Analisis dibuat dengan menggunakan kaedah model kaviti kerana kaedah ini lebih mudah dianalisis.

Masukkan bagi antena adalah menggunakan jalur mikrostrip diatas papan FR-4. Papan ini diketahui memiliki nilai pemalar dielektrik ($\epsilon_r = 4.7$), frekuensi resonan adalah ($f_r = 2.45$ GHz) dan ketinggian papan FR-4 ialah (h=1.6mm).

Parameter yang akan diuji dalam kajian kali ini adalah nilai return loss, (S_{11}) dan VSWR bagi antena ini. Pengukuran nilai-nilai diatas adalah dibuat dengan menggunakan mesin Vector Network Analyzer (VNA). Seterusnya nilai-nilai dari proses pengukuran dibandingkan dengan nilai dari proses simulasi. Sekiranya terdapat sebarang perubahan nilai antara kedua-dua proses, langkah-langah mengurangkan berbezaan tersebut akan diambil dan akan di bincangkan di bahagian keputusan ujikaji.

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ABBREVIATION

VSWR	-	Voltage Standing Wave Ratio
CAD	-	Computer Aided Design
VNA	-	Vector Network Analyzer
SNA	-	Spectrum Network Analyzer
SMA	-	Sub-Miniature Version A
MoM	-	Method of Moments
FEM	-	Finite Element
FDTD	-	Finite Difference Time Domain
MIC	-	Microwave Integrated Circuits
GHz	-	Giga Hertz
Db	-	Decibel

CHAPTER 1

INTRODUCTION

1.1 Projects Background

In this circular microstrip antenna design, a circular microstrip antenna can only be analyzed conveniently via the cavity model and full-wave analysis. However, in this project the cavity model method is used. The cavity is composed of two perfect electric conductors at the top and bottom to represent the patch and ground plane, and by a cylindrical perfect magnetic conductor around the circular periphery of the cavity. The cavity model also provides the method that the normalized fields within the dielectric substrate can be found more accurately and it does not radiate any power. Besides that, the computed pattern, input impedance, return loss and VSWR at the resonant frequencies can be compared well with measurement by assuming the actual fields are approximate by the cavity model.

Besides that, the microstrip line feed is used in this project where a conducting strip is connected directly to the edge of the microstrip patch. This type of feeding provides the right impedance match between the patch and the feed line. In this case, the input impedance of the microstrip antenna is matched to the 50 Ω of feedline. This is important in order to ensure the maximum power can be transfer to the microstrip antenna and thus increasing the overall microstrip performance.

The objective of this project is:

Design a circular microstrip antenna at the range frequency of 2.4 GHz to 2.5 GHz pertaining to the return loss, VSWR and input impedance.

1.2 Scope of Works

In this project, this circular microstrip antenna is designed by using CST software. The simulation is carried out until the result obtained meets the required specifications. Then, the process continued by fabrication process before doing the measurement via Vector Network Analyzer. Finally, the comparison between the simulation and measurement results is investigated.

1.3 Problems Statement

i. Antenna is normally placed in higher place for less interference purposes thus conventional antenna is made of steel it is in fact a heavy substance. Due to the fact that microstrip antennas consist mainly of nonmetallic materials and due to the frequent use of foam materials as substrates, such antennas have an extremely low weight compared to conventional antennas.
ii. Conventional antenna is normally held for one unique excitation technique only. They are not compatible with many applications. However patches in microstrip antenna allow a lot of different excitation techniques to be used, compatible with any technology of the active circuitry and beam forming networks.

CHAPTER 2

MICROSTRIP ANTENNA THEORY

2.1 Introduction of Microstrip Antenna

A microstrip antenna is defined as an antenna which consists of radiating patch on one side of a dielectric slab and a ground plane on the other side. Figure 2.1 shows a basic configuration of the microstrip antenna.

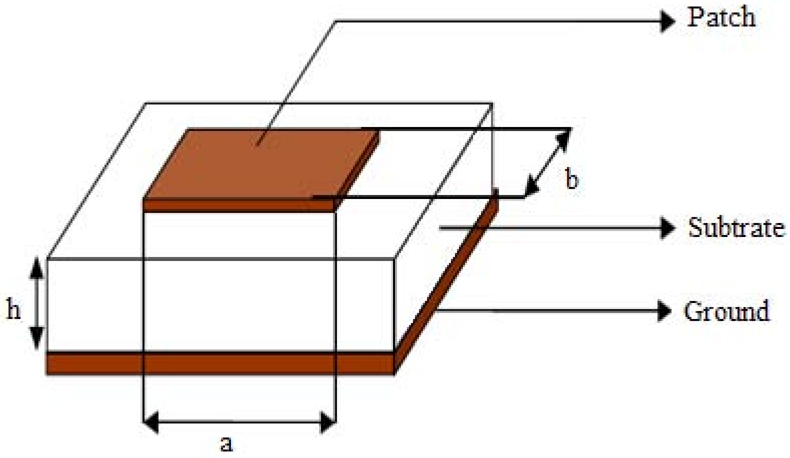

Figure 2.1: Basic microstrip antenna configuration [1].

Microstrip antennas are used in a broad range of applications from communication systems such as radars, telemetry and navigation field due to their simplicity, conformability, low manufacturing cost, and very versatile in terms of resonant frequency, polarization, pattern and impedance at the particular patch shape and model [1].

Microstrip antennas have been used in various configurations such as square, rectangular, circular, triangular, trapezoidal, eliptical etc. In microstrip antenna designs, it is depends strongly on the dimensions of the patch, the location of the feed point, the excitation frequency, the permittivity of the substrate and its thickness.

Microstrip antennas radiate due to the fringing fields between the patch and the ground plane. Figure 2.2 shows the fringing fields in a microstrip patch antenna [1].

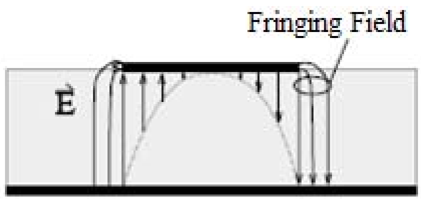

Figure 2.2: Fringing fields within the microstrip antenna

The fields at the end of the patch can be splitted into tangential and normal components with respect to the ground plane. The normal field components are out of phase because the length of the patch is approximately $\lambda/2$. Therefore their contribution to the far field in broadside direction cancels each other. The tangential field components, which are in phase, combine to give the maximum radiated field normal to the surface of the patch [2].

Due to the fringing fields between the patch and the ground plane, the effective dimensions of the antenna are greater than the actual dimensions. For example the radius effective of the patch is greater than the physical radius. In this case fringing effect makes the radius effective look larger due to the fact that some of the waves travel in the substrate and some in the air. Besides that, if the frequency of the wave is at a resonant point then the electric fields around the edges have the maximum amplitude. Thus, the radiated electric fields will be at a maximum at resonant frequencies.

2.2 Basic Characteristic of Microstrip Antenna

Basically, the microstrip antenna consists of a very thin metallic patch ($t \ll \lambda_\circ$ where $\lambda_\circ$ is the free space wavelength) placed a small fraction of a wavelength ($h \ll \lambda_o$, Usually $0.003\lambda_o \leq h \leq 0.05\lambda_o$) above a ground plane. The microstrip patch is designed so its pattern maximum is normal to the patch. This is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch [1].

There are several substrates that can be used in this microstrip antenna design and the dielectric constants are usually in the range of $2.2 \leq \epsilon_r \leq 12$. By referring this fact, the ones that are most desirable for antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space but at the expense of larger element size [3].

Thin substrates with higher dielectric constants are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling and lead to smaller element size. However, because of their greater losses then they are can be classified as less efficient and have relatively smaller bandwidths. Since the microstrip antennas are often integrated with other microwave circuitry then a compromise has to be reached between good antenna performance and circuit design.

2.3 Basic Microstrip Antenna Properties

In microstrip antenna, there several important properties that need to be considered including quality factor, resonance frequency, bandwidth, input impedance, radiation pattern, return loss and polarization.

2.3.1 Quality Factor

Generally, there are four main loss mechanisms that need to be considered in a microstrip antenna that are radiation loss (Q_{rad}), surface-wave loss (Q_{sw}), dielectric loss (Q_d) and metallization loss (Q_c). Radiation loss represents the loss due to radiation into space waves. For surface-wave loss, it is represents the amount of power coupled into surface waves loss which needs to be minimized for a typical design. In addition that, surface-wave effects can reduce the overall efficiency of the microstrip antenna. These two loss mechanisms have the usual definitions used in general microstrip circuits. Therefore, the total quality factor of the antenna can be given by [4, 5]:

$$\frac{1}{Q} = \frac{1}{Q_{rad}} + \frac{1}{Q_{sw}} + \frac{1}{Q_d} + \frac{1}{Q_c} \tag{1-1}$$

2.3.2 Resonance Frequency

Resonance frequency for a microstrip antenna is defined as the frequency where input impedance has no reactive part. At this frequency, the input impedance of the antenna is approximately equal to the radiation resistance provided that all other loss mechanism (e.g., conductor and dielectric) are relatively small.

Note that this definition assumes that the antenna can be represented by a simple parallel RLC tank-circuit near the resonance; thus, the reference plane of the antenna input impedance is important. Due to this fact, the effect of higher of higher order modes can also be approximated using an inductive shift near resonance affecting the actual resonance frequency.

2.3.3 Bandwidth

The bandwidth of the patch is defined as the frequency range over which it is matched with that of the feed line within specified limits. In other words, the bandwidth of an antenna is usually defined by the acceptable standing wave ratio (SWR) value over the concerned frequency range. There are basically three definitions for bandwidth of a microstrip patch antenna or an array that are impedance bandwidth, pattern bandwidth and polarization bandwidth.

In a microstrip antenna, one way to increase the impedance bandwidth is to increase the thickness of the dielectric substrate. However, as the thickness of the substrate increases, the impedance locus of the antenna become inductive which makes matching the antenna difficult and the surface wave excitation becomes higher which cause spurious radiation.

Another alternative technique that are widely used to increase the impedance bandwidth are by using a matching network to match the feed to the antenna over a broadband, using multiple resonators that are tuned to slightly different frequencies and modifying the feed configuration of the antenna.

On the other hand, the bandwidth also can be defined for a given voltage standing wave ratio (VSWR) at the lower and upper band-edge frequencies [6]:

$$BW = \frac{1}{Q}\frac{VSWR-1}{\sqrt{VSWR}} \qquad (1\text{-}2)$$

where Q is the quality factor of the antenna. Therefore the bandwidth of the microstrip antenna is typically given for a VSWR of 1:2.

2.3.4 Input Impedance

Generally, the antenna is fed by a transmission line having a characteristic impedance Z_c and behaves as a complex impedance, $Z_a = R_a + jX_a$ that connected to the transmission line. The input resistance R_a is related to the power absorbed by the antenna and the input reactance X_a is related to the electromagnetic energy stored in the vicinity of the antenna [7]. For the calculation of input impedance, the method of moments give results of better accuracy compared to the cavity method.

The input impedance of the antenna depends on many factors including its geometry (rectangular, circular and etc.), its method of excitation and its proximity to surrounding objects [1]. However, the impedance match between the antenna and the transmission line is usually expressed in terms of the standing wave ratio (SWR) or the reflection coefficient of the antenna when connected to a transmission line of given impedance.

2.3.5 Radiation Pattern

Radiation pattern can be defined as mathematical function or graphical representation of the radiation properties of the antenna as a function of space coordinates. There are fundamentally two ways of obtaining the radiation pattern of a microstrip patch antenna [8]. In the first method, the radiation pattern is directly obtained from the currents flowing on the patch surface which are calculated Green's function of the medium. In the second method, the equivalence principle is applied to a surface surrounding the patch and substrate below the patch by assuming the patch cavity has perfect magnetic walls.

Generally the radiation patterns can be plotted in terms of field strength, power density, or decibels. They can be absolute or relative to some reference level, with the peak of the beam often chosen as the reference. Radiation patterns can be displayed in rectangular or polar format as functions of the spherical coordinates θ and $\emptyset$.

2.3.6 Return Loss

Return loss can be defined as reflection coefficient expressed in decibels (dB). Return loss measures the power loss due to the load mismatch that occurs when some of the power does not return as reflection. In this case, not all the available power from the generator is delivered to the load. Return loss is related by the following equation:

$$\text{Return Loss} = -20\log_{10}|\Gamma| \qquad (1\text{-}3)$$

This return loss is expressed in dB where Γ is the voltage reflection coefficient. In practical design, the return loss is related to the input impedance Zin and the characteristic impedance Zo of the connecting feed line.

2.3.7 Polarization

Polarization can be defined as wave radiated by the antenna in that particular direction. This is usually dependant on the feeding technique. When the direction is not specified, it is in the direction of maximum radiation [9]. The two most widely used polarization types are linear polarization and circular polarization. Basically, linear polarization can be obtained by using various feed arrangements with no modification and circular polarization can be obtained by similar procedure but slight modifications made to the elements [1].

i. Linear Polarization

Linear polarization can be either vertical or horizontal depending on the orientation of the patch. An antenna is vertically linear polarized when its electric field is perpendicular to the Earth's surface. Whereas horizontally linear polarized antennas have their electric field parallel to the Earth's surface. Figure 2.3 illustrates the operations of a linearly polarized wave radiating perpendicular to the patch plane. In order to obtain a linear polarization, the time-phase difference between the two components must be

$$\Delta\emptyset = \emptyset_y - \emptyset_x = n\pi , \qquad n = 0, 1, 2, 3,\ldots$$

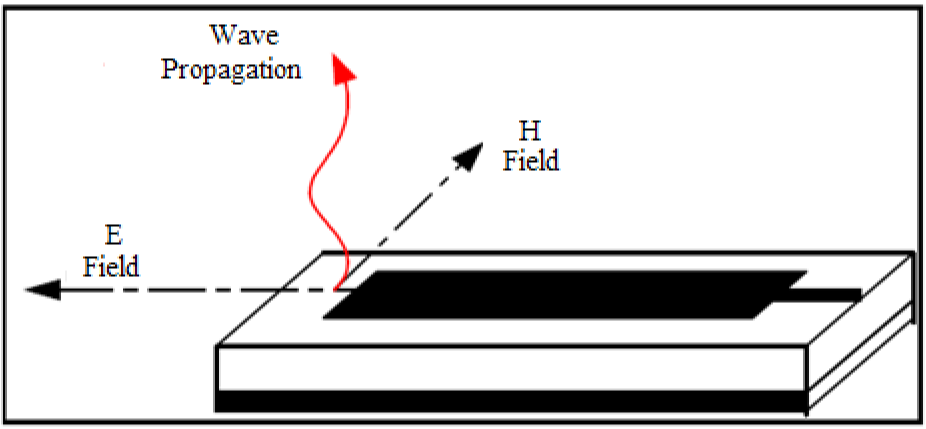

Figure 2.3: Linear polarization

In linear polarization, the quality of the polarization is often inadequate for application because of the asymmetry of the feed and the radiating element. However, this purity can be improved by making the arrangement of patches and feed symmetrical. Examples of antenna radiating with linear polarization using square patch as follow as [7]:

a) Coaxial feed in the middle of one side
b) Direct feed by microstrip line at the middle of one side
c) Feed by a microstrip line across a slot in the ground plane
d) Coaxial feed on one diagonal of the square
e) Direct feed by microstrip line at one corner of the square
f) Feed by a microstrip line across the diagonal slot in the ground plane

ii. Circular Polarization

Circular polarization can result in left hand circularly polarized (LHCP) where the wave is rotating anticlockwise, or right hand circularly polarized (RHCP) which denotes a clockwise rotation. In order to obtain a circular polarization, the magnitudes of the two components are the same and the time- phase difference between them is odd multiples of $\pi/2$. That is

$$\Delta\emptyset = \emptyset_y - \emptyset_x = \begin{cases} +\left(\frac{1}{2}+2n\right)\pi, n=0,1,2,\ldots \text{ for CW} \\ -\left(\frac{1}{2}+2n\right)\pi, n=0,1,2,\ldots \text{ for CCW} \end{cases}$$

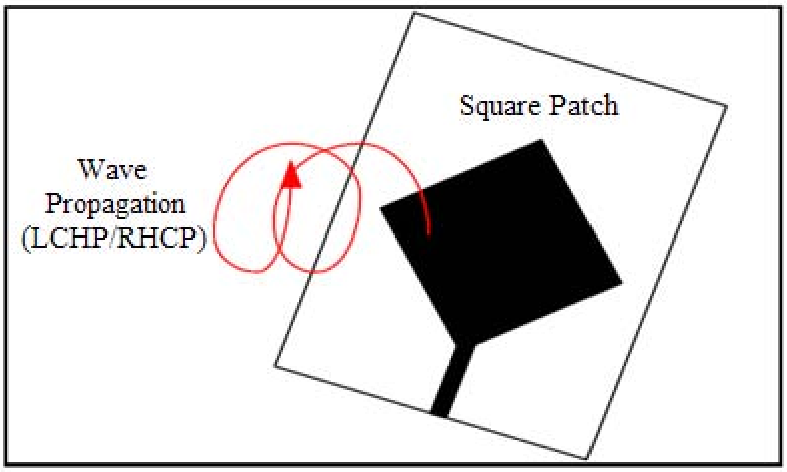

Figure 2.4: Circular polarization