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A Type of Microstrip feed and the corresponding equivalent circuits, Microstrip feed at a radiating edge

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ABSTRACT

Microstrip Patch Antenna has radiation patterns that can be calculated easily. The source of the radiation of the electric field at the gap of the edge of the Microstrip element and the ground plane is the key factor to the accurate calculation of the pattern for the patch antenna [1]. This type of feed technique excitation of the antenna would be by the Microstrip line of the same substrate as the patch that is here can be considered as an extension to the Microstrip line, and these both can be fabricated simultaneously. This conducting strip is directly connected to the edge of the Micro strip patch, as known the conducting strip is smaller than that of the patch in width.

Keywords: Micro, Strips, Feed, Elements, Ratio, Transfer, Patch, Antenna.

1. INTRODUCTION

Microstrip patch antenna has various methods of feeding techniques. As these antennas having dielectric substrate on one side and the radiating element on the other. These feed techniques or methods are being put as two different categories contacting and non-contacting. Contacting feed technique is the one where the power is being fed directly to radiating patch through the connecting element i.e. through the Microstrip line. Non-contacting technique is the one where an electromagnetic magnetic coupling is done to transfer the power between the Microstrip line and the radiating patch. Even though there are many new methods of feed techniques the most popular or commonly used techniques are. [2]

1. *Microstrip line 2. Coaxial probe 3. Aperture coupling 4. Proximity coupling and 5. Co planar wave guide feed.*

1 and 2 being the contacting feed techniques and 3, 4 being non- contacting feed techniques. There are few factors which lead or involve in the selection of a particular type of feed technique. The first and the foremost factor is the efficient power transfer between the radiating structure and the feed structure, i.e. the impedance that is matching between the two. The minimization of the radiation and the effect of it's on the radiation pattern is one of the most important aspect for the evaluation of feed.

1.1. Microstrip Line feed

This type of feed technique excitation of the antenna would be by the Microstrip line of the same substrate as the patch that is here can be considered as an extension to the Microstrip line, and these both can be fabricated simultaneously. This conducting strip is directly connected to the edge of the Micro strip patch, as known the conducting strip is smaller than that of the patch in width [3]. This type of structure has actually an advantage of feeding the directly done to the same substrate to yield a planar structure as said above. The coupling between the Microstrip line and the patch is in the form of the edge or butt-in coupling as shown in the figure 1.

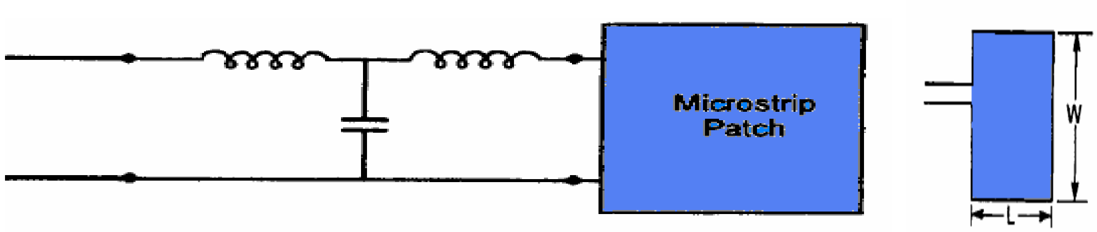
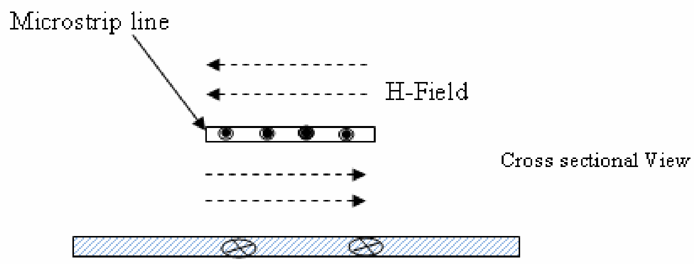


Figure 1: Microstrip feed at a radiating edge

There is an inset cut in the patch to match the impedance of the feed line to the patch without the need of additional matching element. This avoidance of the additional matching element can be done by the proper control of the inset position [4]. The surface waves and the spurious feed radiation increases as the thickness of the dielectric substrate increases which obviously hampers the bandwidth of the antenna. And this feed radiation which also leads to the undesired cross polarized radiation. As the description of the excitation of the patch by an edge coupled Microstrip line can be given in terms of the equivalent current density *Jz* associated with a magnetic field *Hy* of the Microstrip line at the junction place as in fig.



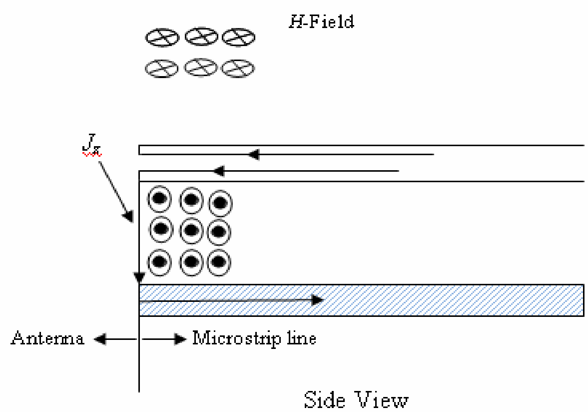


Figure 1: Representation of *H1*an at the interface between the patch antenna and the feed Microstrip line by an equivalent current density J_z – dotted lines signify H lines, solid lines are current lines.

The current *Jz* couples with the E_Z of the patch antenna and the coupling magnitude is being given by the equation

$$\text{Coupling} \approx \iiint E_Z Jz \, dv \approx \text{Cos}\,(\Pi x_0 / L) \text{ ---------------------- Eq. (1.1)}$$

1.2. Co Axial Feed Technique

This type of feed is the common technique used for the feeding of the Microstrip patch antennas. Coupling of the power through a probe is one of the basic studies that can be seen in the transfer of the microwave power.

It can be seen in the figure 2 below that the external or the outer conductor is connected to the ground plane and the inner conductor of the coaxial connector extends through the dielectric and is soldered to that of the radiating patch [5]. The coaxial probe in this feed would be an inner conductor of the coaxial line or this can be used as the power transfer from the strip line to the Microstrip antenna from the slot in the ground plane.

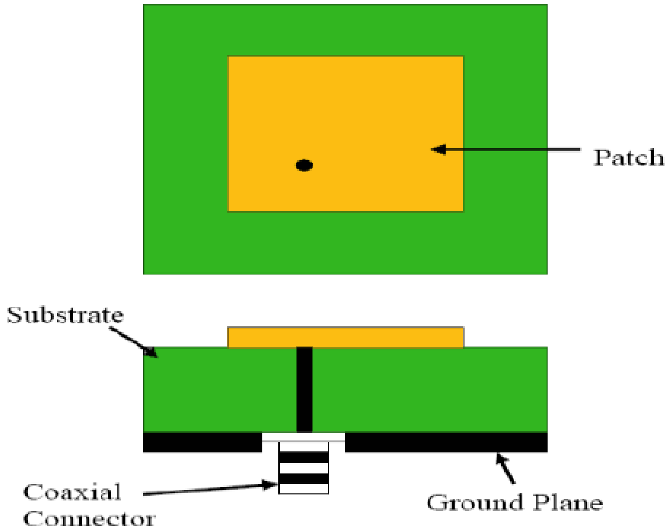


Figure 3: Probe Fed Rectangular Microstrip Patch Antenna

Unlike from the other feed techniques, here the advantage is that it has the flexibility to place the feed anywhere in the inside the patch in order to match the input impedance. This gives an easy way for the fabrication and it haw low spurious radiation. Of course there is a disadvantage as well from this type of feed as this gives a narrow bandwidth. And as the hole has to be put drill in the substrate there is a difficulty in the model [6]. With the connector extending out of the ground plane, this results in non planar surface to the substrates which are thick, i.e. having a height that is greater than 0.02λ. With the extended or the increase probe length the input impedance becomes more inductive, which leads to the matching problems of the impedance.

As discussed above about the feed point location, it is determined in order to have the best matching of the impedance. The excitation of the patch is mainly by the coupling of J_z (feed current) and E_z of the patch mode.

The coupling is given by the equation 1.2.

$$\iiint E_z J_z d_v \approx \cos(\Pi x_0 / L) \text{ ----------------- Eq. (1.2)}$$

- L is the resonate length

- X_0 offset of the feed point from the patch edge

The location of X_0 is at the radiating edge of the path $X_0 = 0$ or L

From the above discussion its is seen that the thick substrate, giving broad bandwidth Co axial Feed and the Microstrip line feed has disadvantages which are said to be the contacting feed techniques where as the non contacting feed techniques solve these problems which are discussed from below.

1.3. Aperture Couple Feed Technique

This type of feed technique comes under the non-contacting feed techniques and here the radiating patch and the micro strip feed line are being divided by the ground plane. The main features in this particular feed technique is that it has a wider bandwidth and the shielding of the radiating patch from the radiation gets from the structure. From the figure 4 below it can be seen that the configuration of this feed and as said above the radiating patch and Microstrip feed line are separated by the ground plane [7]. The coupling between the patch and the feed line is through aperture in the ground plane i.e. the line feed on the lower substrate of coupled electromagnetically to the patch through the aperture. The amount of coupling depends on the size, shape and also the location of the aperture. There is minimization of the spurious radiation as the ground plane separates the feed line and the patch; this can be achieved when there is a usage of thin, high dielectric material for the lower substrate and thick, low dielectric constant material for the upper substrate. The aperture slot can be of any size shape and these design parameters drive the bandwidth i.e. these parameters improve the bandwidth.

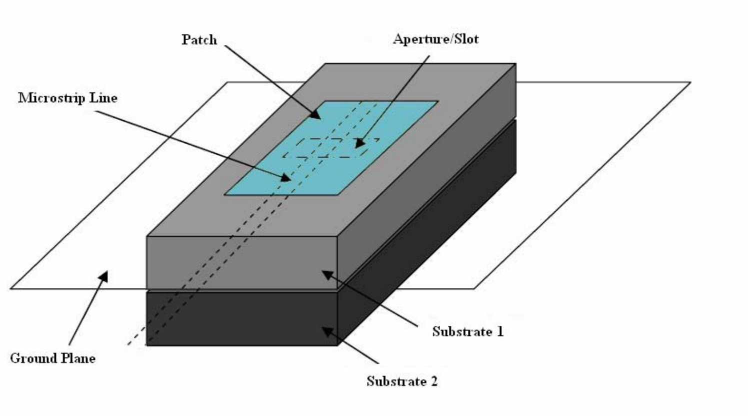


Figure 4: Aperture-couple feed technique general view

The lower and the upper substrate parameters are chosen separately to improve the bandwidth and for the optimization of the feed and radiation separately. So as said the patch's substrate is of thick and lower dielectric const and for the feed line it's thin and has a high dielectric const. In this feed technique there is a feature of improving the polarization purity. The black lobe radiation from the slot is typically 15 to 20db below the main beam of the coupling slot, is non resonant [8]. The position of the coupling slot is almost centered with respect to patch where there is a maximum magnetic field of patch to improve the magnetic coupling between the magnetic field of the patch and the magnetic current near the slot.

The coupling can be given by the expression.

$$\text{Coupling} = \iiint v HM.\ dv \approx \text{Sin}\ (\Pi\ X_0/L) \text{ -------------- Eq. (1.3)}$$

Where X_0 – offset of the slot from the edge.

In order to improve the bandwidth in this particular feed technique is by adjusting the location of the slot, its shape, length and the width of t he feed line and its stub length. There is obviously a disadvantage for the feed technique, it's difficult to fabricate as this has got multiple layers, due to this the thickness of the antenna increases.

1.4. Proximity Coupled Microstrip Feed

This is one of the non-contacting non coplanar Microstrip feed technique [9]. In this particular configuration, the patch antenna is on the upper layer substrate and the Microstrip feed line on the lower layer substrate as its uses 2 layers of substrate.

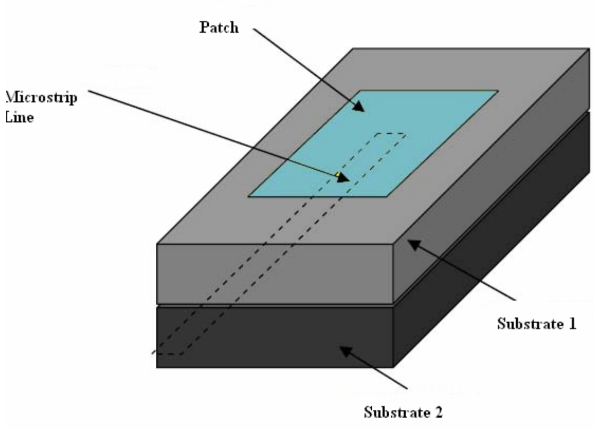


Figure 5: Proximity Coupled feed Technique

There is an open end to the feed line beneath the path. This feed technique is also known as electromagnetically the current coupled (proximity coupled Microstrip feed) feature of this differs from the other feed techniques i.e. the coupling capacitive in nature between the patch and the Microstrip.

The circuit that is shown below gives the configuration of this feed.

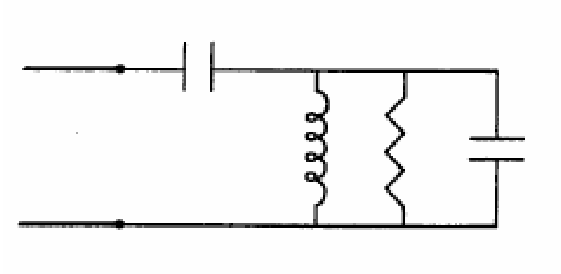


Figure 6: Proximity Coupled Microstrip Feed

In this the capacitor is also designed to get the impedance matching of the antenna and even for tuning the patch for the bandwidth. The advantage of this feed is the high bandwidth and the optimization of the spurious radiation.

As the terminology goes in order to improve the Bandwidth the open end of the line can be terminated in a substrate and the parameters are used for the improvement [10]. As in the previous feed technique the improvement of the Bandwidth and the optimization of the radiation can be done by the selection of the substrate and the open end of the Microstrip and the lower substrate is to be thin, the larger bandwidth is achieved by placing the radiating patch on the double layer.

Matching does depend on the length of the feed line and the width/line ratio of the patch. The disadvantage is as it's difficult to fabricate due to the two substrate layers which require accurate alignment which directly or indirectly increases the thickness of the antenna.

2. Model Analysis of Microstrip Antenna

In the previous text we had discussed about the types, applications, feed techniques etc about the Microstrip antennas, feed techniques etc about the Microstrip antennas. There is a lot of importance in analyzing the models of antennas which [11].

- Takes us on to a platform of antennas performance advantages and also their limitations.
- The correct design process will help us reduce the cost, in fact having a cost analysis as well as to get the best design at the lowest cost possible with a better performance.
- Analyzing the models and their performance gives an idea to use the best combinations in practice and also to update the older designs to the newer specifications.

For every task we do irrespective of where ever and whatever there are always some main objectives to have the concentration on. In the same way here in the analysis of Microstrip antennas the objective is to calculate the radiation characteristics of the Microstrip antenna in order to have an edge over the failures. The following are calculated during the analysis.

- Radiation patterns
- Polarization
- Gain

In addition to these the near field characteristics are also analyzed during the analysis such as. [5]

- Impedance Bandwidth,
- Input Impedance,
- Antenna efficiency,
- Mutual coupling.

Analysis of Microstrip antennas are not that easy as it is thought there are many complicated issues involved in it such as the narrow frequency band characteristics, it has wide range of feed techniques, substrate characteristics, configurations and of course the patch shape and size which is the most important aspect [12]. Not all characterizes are taken in to consideration for the final analysis are it is very difficult to manage every aspect, so it is often happens to put some under the mat, antenna with a good performance are said to have the following characteristics:

- The antenna is to be as simple as it can be when it provides the near field characteristics and the radiation characteristics.
- It should be useful enough to calculate the radiation characteristics and near field characteristics.
- The results are to be as accurate it can give for the required purpose.

2.1. Transmission Line Model

In this model we can see the Microstrip Antenna in 2 slots with the design of height '*h*', and width '*w*' and are separated by the transmission line 'L'. We can see the same in the figures below.

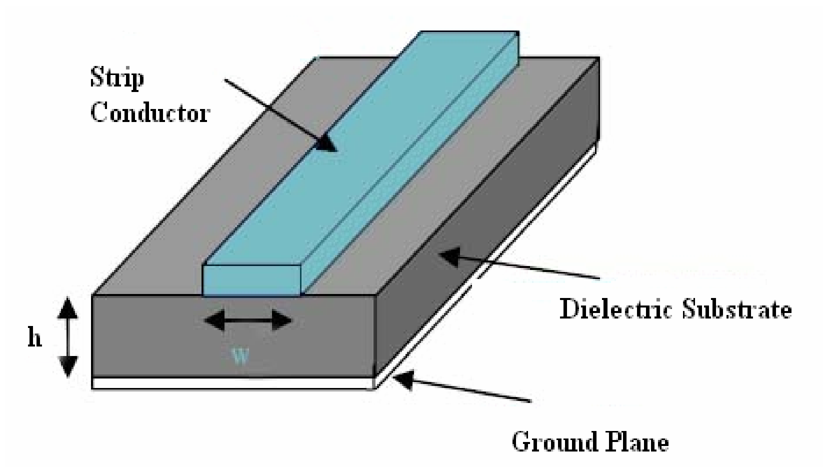


Figure 7: Microstrip Line

The electric field lines in the antenna mostly move in the substrate and even a bit out of the substrate in to the air. Due to this the transmission lines are not able to support the pure transverse electric magnetic (TEM) mode of transmission because the lines in the substrate and lines in the air have different phase velocities [13]. In order to have a notice of wave propagation and the fringing in the line the ε_{reff} – the effective dielectric constant has to be calculated. The value of ε_{reff} is slightly less than that of ε_r as we can see that the fringing fields are not confined only in the substrate but some are out in the air.

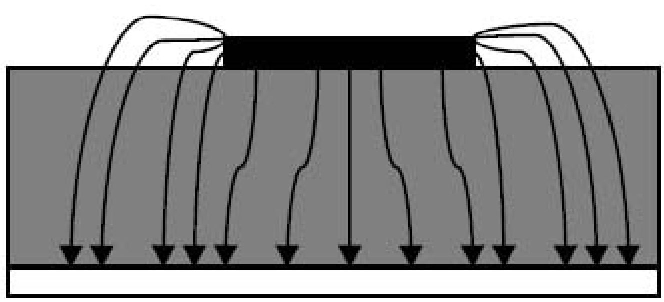


Figure 8: Microstrip Line

The parameters are given on the co-ordinate axis such as Width on y axis height on z direction and length on x direction. For the analysis of the antenna it has to be operated in the basic mode i.e. TM_{10} and for this the length of the patch should be less than λ/2 where λ – the wavelength in the dielectric medium and should be equal to λ0/ √ (ε_{reff}) where λ_0 – free space wavelength [14]. In TM_{10} mode the field varies by one λ/2 cycle. There variation along the width of the patch. The Microstrip patch antenna is represented by 2 slots, which are separated by the transmission line has said previously with a length L and it is open circuited on the two ends. The width of the structure has a maximum voltage and minimum current as it is an open ended circuit. The tangential and the normal components of the fields at the edges are resolved with respect to the ground.

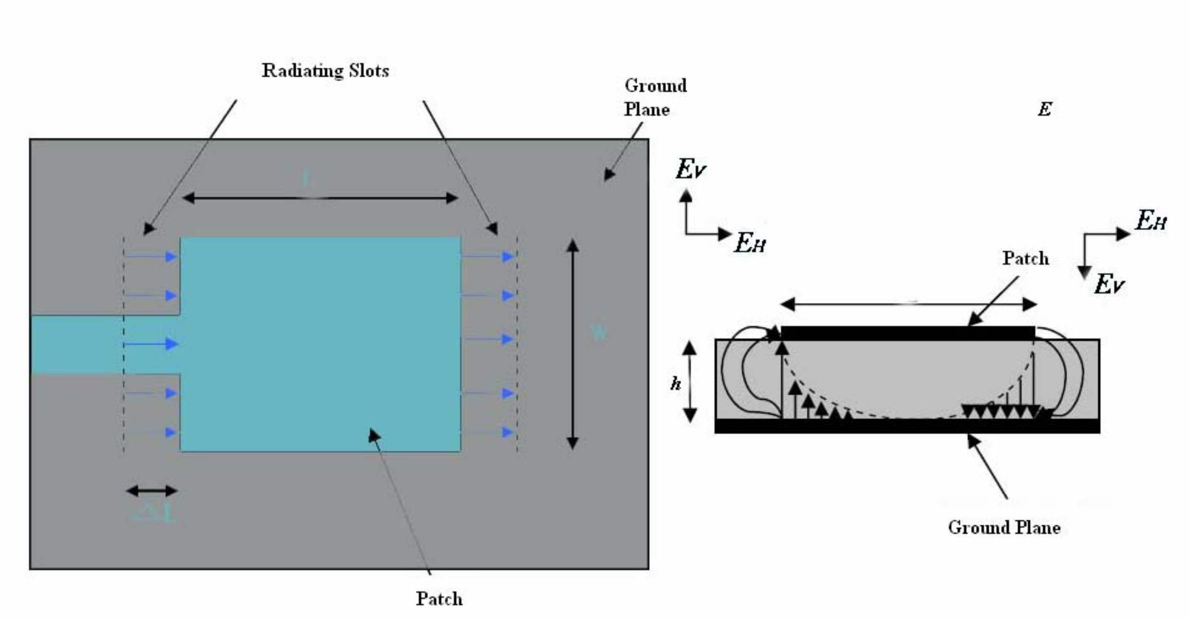


Figure 9: The top and the side views of the antenna

The field lines, some reside in the substrate and some are spread in to the air, the normal components are towards the width and opposite in direction, i.e. they are not in phase as the patch is λ/2 long. So they are cancelled as they are opposite in direction [15]. The tangential components are in phase which makes the resulting fields to combine for a maximum radiating field to the surface of the structure. The fringing fields along the width of the structure are taken as radiating slots and the patch of the antenna electrically seen to be a bit larger than usual design. So the dimensions are changed and extended a bit for a better performance i.e. it is been extended by ΔL, E_H.

ΔL is calculated as below:

L_{eff} the effective length of the patch is given by:

$$L_{eff} = L + 2\Delta L \text{ ------------------- Eq. (1.4)}$$

2.3. Cavity Model

The transmission line model was impressive and was good at usage, robust and easy – even after having disadvantages, like ignorance of the field variations on the radiating edges of the patch. To overcome these types of disadvantages we have another model – cavity model – this is preferred the most to analyze the Microstrip antenna. The structure of the model goes this way – the inner region of the patch is filled as a cavity, bounded by the electric walls on both ways i.e. on top and bottom, it has a magnetic wall thorough the periphery [16]. Few observations have been made for the thin substrates taking $h << \lambda_0$ in to consideration.

- As the thin substrate is considered the interior fields doesn't vary with 'z' i.e. $d/dz \approx 0$.
- As the thin substrate is considered the interior fields doesn't vary with 'z' i.e. $d/dz \approx 0$.
- The electric field is towards the 'z' direction and the magnetic field components H_x & H_y in the region that is bounded by the patch metallization & the ground plane.
- There is no component for the electric current which is normal to the patch edge, saying that the tangential components of the magnetic field is negligible, i.e. $\delta E_z / \delta_n = 0$ for the magnetic wall to be placed along the periphery.
- The operation goes as follows, we can see the charge distribution on the upper and the lower surfaces of the patch and even at the bottom of the ground plane, this happens when there is a power given to the Microstrip patch .

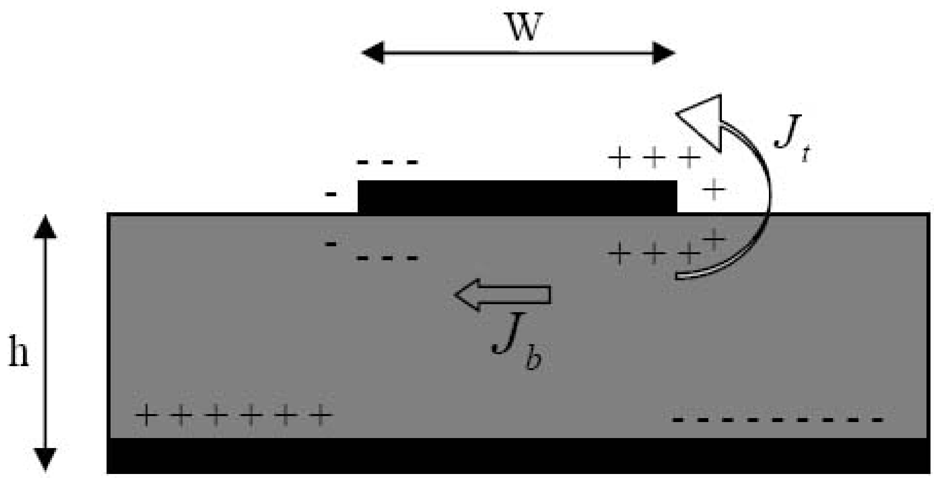


Figure 10: Charge distribution and the current density creation on the Microstrip patch

There exists two mechanisms in order to control the charge distribution those are – attractive mechanism and the repulsive mechanism, there are opposite charges at the bottom side of the patch and on the ground plane here the former mechanism is used. This helps in controlling the charge distribution and has the concentration on the bottom of the patch. The latter mechanism is used when there are same charges at the bottom of the patch; these charges normally cause the pushing of the charge from the bottom of the patch to the surface [17]. The currents floe from top to the bottom of the patch due to the charge movement and due to the height to width ratio of the cavity model is less this results in the domination of the attractive mechanism causing the charge and even the current to move down to the bottom surface of the patch. The flow of current on the top reduces gradually as the height to width ratio still goes down resulting cause the pushing of the charge from the bottom of the patch to the surface. The currents floe from top to the bottom of the patch due to the charge movement and due to the height to width ratio of the cavity model is less this results in the domination of the attractive mechanism causing the charge and even the current to move down to the bottom surface of the patch. Tangential magnetic field components through the patch edges. That is the reason why the walls are being designed as the magnetic conducting surfaces. This creates a free flow and the operation for the electric and magnetic fields below the patch. In practice there is a chance of not making the width to height ratio very less which can give a way to create the tangential magnetic fields, but as the components being very small the walls would be operating perfectly i.e. magnetic conducting [18].

In order to have the radiation and the loss mechanism there is a need of having a radiation resistance R_r and loss resistance R_L.

The lossy cavity represents the antenna and the loss is taken in to consideration by – effective loss tangent δ_{eff}

Where $\delta_{eff} = 1/Q_T$ ------------------- Eq. (1.5)

Q_T -- total antenna quality factor.

Q_d -- quality factor of the dielectric [11]

ω_r - angular resonant frequency.

W_r - total energy stored in the patch at the resonant freq.

P_d - dielectric loss.

3. Antenna Parameters

From here we discuss the overview of the patch antenna design parameters of the rectangular patch antenna:

In a simple way we can say that "an antenna is the transitional radio b/w free space and a guiding device. For designing a perfect antenna there are certain parameters that are to be considered that define the configuration of the antenna.

3.1. Return Loss

This is the best and convenient method to calculate the input and output of the signal sources. It can be said that when the load is mismatched the whole power is not delivered to the load there is a return of the power and that is called loss, and this loss that is returned is called the 'Return loss'.

This Return Loss is determined in dB as follows:

$$RL = -20\log|\Gamma| \text{ (dB) ------------------- Eq. (1.6)}$$

During the process of the design of the rectangular patch antenna there is a response taken from the magnitude of S_{11} Vs the frequency (this is known as the *return loss*), as shown in the figure, just as the verification of the design [19].

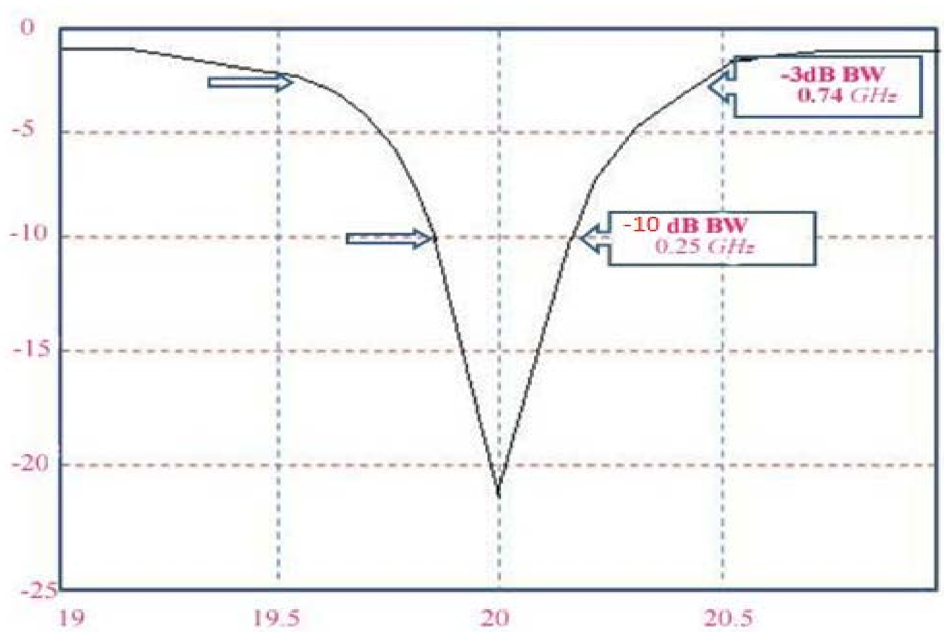


Figure 11: S11 (return loss) for 20GHz rectangular patch antenna

In the figure above it shows that the rectangular patch antenna resonating at 20GHz having a return loss of -21.5dB and those -3dB and -10dB bandwidths are 0.74GHz and 0.25GHz, due to the reason that the radio amplifier reduces the output power, can be more worse and can become unstable if the VSWR is large. To have a perfect matching between the antenna and the transmitter, Γ=0 and RL = ∞, this indicates that there is no power that is returned or reflected but when

Γ=0 and RL = 0dB, this indicated that the power that is sent is all reflected back. It this is said that for the practical applications *VSWR*=2 is acceptable as the return loss would be -9.54dB.

3.2. Radiation Pattern

Microstrip Patch Antenna has radiation patterns that can be calculated easily. The source of the radiation of the electric field at the gap of the edge of the Microstrip element and the ground plane is the key factor to the accurate calculation of the pattern for the patch antenna [20]. Simply it can be said that the power radiated or received by the antenna is the function of angular position and radial distribution from the antenna. In the figure 12 below we can see the side view of the rectangular Microstrip element associated with source, and also the radiating of E field.

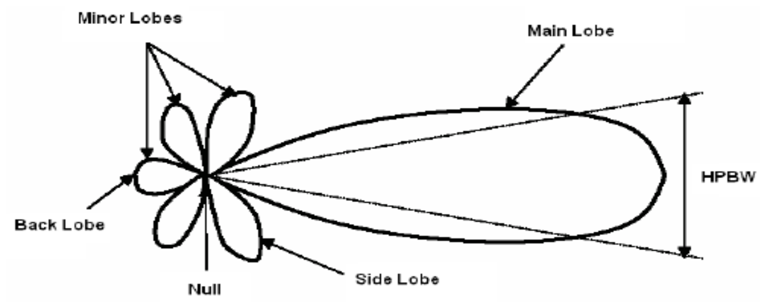


Figure 12: Radiation Pattern of a generic dimensional antenna

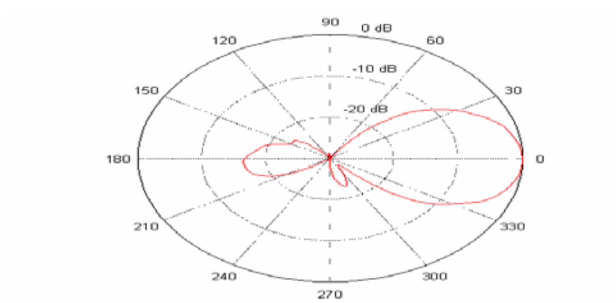


Figure 13: A general radiation pattern for a Microstrip antenna

3.3. Gain

The gain of the antenna is the quantity which describes the performance of the antenna or the capability to concentrate energy through a direction to give a better picture of the radiation performance. This is expressed in dB, in a simple way we can say that this refers to the direction of the maximum radiation [21].

The expression for the maximum gain of an antenna is as follows:

$$G = \eta \times D \text{ ------------------- Eq. (1.7)}$$

η – The efficiency of the antenna

D – Directivity

In order to receive or transmit the power it can be chosen to maximize the radiation pattern of the response of the antenna in a particular direction.

The directivity of an antenna can be defined as – the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged in all the directions. And the gain can be known as the ratio between the amounts of energy propagated in these directions to the energy that would be propagated if there is an Omni-directional antenna.

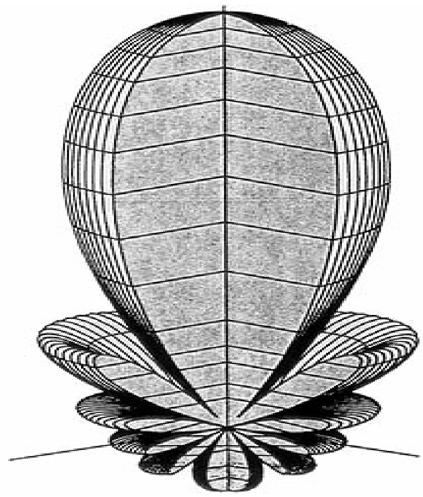


Figure 14: Directivity of an antenna

The directivity of the antenna depends on the shape of the radiation pattern. The measurement is done taking a reference of isotropic point source from the response. The quantitative measure of this response is known as the directive gain for the antenna on a given direction.

3.4. Polarization

The polarization of the electric field vector of the radiated wave or from source Vs time the observation of the orientation of the electric fields does also refer to the polarization. It is defined as the property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric filed vector [22].

The direction or position of the electric field the ground gives the wave polarization. The common types of the polarization are circular and linear the former includes horizontal and vertical and the latter includes right hand polarization and left hand polarization.

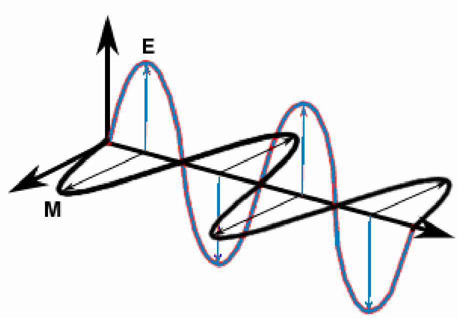


Figure 15: A linearly polarized wave

It is said to be linearly polarized when the path of the electric field vector is back and forth along the line.

3.5. Reflection Coefficient |Γ| and Character Impedance (Z_0)

There is a reflection that occurs in the transmission line when we take the higher frequencies in to consideration. There is a resistance that is associated with each transmission line which comes with the construction of the transmission line. This is called as character impedance (***Z_0***). The standard value of this impedance is 50ohm. Always the every transmission line is being terminated with an arbitrary load Z_L and this is not equivalent to the impedance i.e. Z_0. Here occurs the reflected wave [23].

The degree of impedance mismatch is represented by the reflection coefficient at that load. We can observe here that the reflection coefficient for the shorted load Z_L=0, there is a match in the load $Z_L=Z_0$ and an open load $Z_L = \infty$ are -1, 0, +1.

Hence we can say that the reflection coefficient ranges from 0 to +1.

3.6. Voltage Standing Wave Ratio (VSWR)

There should be a maximum power transfer between the transmitter and the antenna for the antenna to perform efficiently. This happens only when the impedance Z_{in} is matched to the transmitter impedance, Z_s.

In the process of achieving this particular configuration for an antenna to perform efficiently there is always a reflection of the power which leads to the standing waves, which is characterized by the Voltage Standing Wave Ratio (*VSWR*).

VSWR = V_{max} / V_{min} = 1+S11/ 1- S11

As the reflection coefficient ranges from 0 to 1, the *VSWR* ranges from 1 to ∞.

3.7. Input Impedance

This is the ratio of the voltage to current at the pair of terminals or the ratio of the appropriate components of the electric fields to the magnetic fields at a point. Or in other words we can say it is the impedance presented by the antenna at the input terminal.

$$Z_{in} = (R_{in} + jX_{in}) \text{ ------------------- Eq. (1.8)}$$

R_{in} – the real part, representing the power dissipated though heat or through radiation losses.

X_{in} = imaginary part, representing the reactance of the antenna & the power stored in the near field of the antenna. [36]

3.8. Bandwidth

Bandwidth can be said as the frequencies on both the sides of the centre frequency in which the characteristics of antenna such as the input impedance, polarization, beam width, radiation pattern etc are almost close to that of this value. As the definition goes "the range of suitable frequencies within which the performance of the antenna, some characteristic, conforms to a specific standard".

The bandwidth is the ratio of the upper and lower frequencies of an operation. According to the bandwidth can be obtained as:

$$BW\ broadband = f_L/f_H \text{ ------------------- Eq. (1.9)}$$

BW narrowband (%) = [f_H- f_L/ f_C]X 100

When the ratio $f_L f_H$= 2 the antenna is said to be broadband. We can judge the antenna's performance by operating the antenna at a high frequency by observing *VSWR*, when *VSWR*≤2 (R_L≥-9.5dB) the antenna is said to have performed well.

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