Rectangular microstrip antenna analysis and design

Microstrip antennas are used in various applications and these are used extensively because of light weight, conformability and low cost. These antennas can be incorporated with printed strip-line feed networks and active devices. This is a relatively innovative field of antenna engineering. The radiation properties of micro strip structures have been recognized since the mid 1950’s. The application of this type of antennas started in early 1970’s when conformal antennas were needed for missiles in defense service. Rectangular and circular micro strip resonant patches have been used widely in different array configurations. A major contributing factor for recent advances of microstrip antennas is the current revolution in electronic circuit miniaturization brought about by developments in large scale integration. As conventional antennas are generally bulky and expensive part of an electronic system, the micro strip antennas based on photolithographic technology are light and cheap so it seen as an engineering breakthrough.

1. 1. 1 Introduction [11]

In its most elementary form, a Microstrip Patch antenna comprises a radiating patch on one side of a dielectric substrate which consist a ground plane on the other side as shown in Figure 2. 1. The patch is usually made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are generally photo etched on the dielectric substrate.

For analysis and prediction of performance, the patch is usually square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 1. 2. For a rectangular patch, the length L of the patch is usually 0. 3333Î» 0 < L < 0. 5 Î» 0, where Î» 0 is the free-space wavelength. The patch is chosen to be very thin such as t << Î» 0 (where t is the thickness of patch). The height h of the dielectric substrate is usually 0. 003 Î» 0â‰¤hâ‰¤0. 05 Î» 0. The dielectric constant of the substrate (Îµr) is typically in the range 2. 2 â‰¤ Îµrâ‰¤ 12.

Microstrip patch antennas radiate primarily due to the fringing fields between the patch edge and the ground plane. For excellent antenna performance, a thick dielectric substrate having a low dielectric constant is needed because this provides better efficiency, larger bandwidth and better radiation. However, by using this configuration the size of antenna becomes larger. To design a compact Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and have narrower bandwidth. Hence a trade-off must be recognized between the antenna dimensions and its performance.

1. 1. 2 Benefits and Drawbacks

Microstrip patch antennas are rising in popularity for use in wireless applications because of their low-profile structure. Therefore they have good compatibility for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The telemetry and communication antennas on missiles should to be thin and conformal and are often in the form of Microstrip patch antennas. In Satellite communication they have been used successfully.

1. 1. 2. 1 Advantages of Microstrip Patch Antenna [2]

Some of their principal advantages are given below:

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.

1. 1. 2. 2 Disadvantages of Microstrip Patch Antenna [2]

Microstrip patch antennas suffer from more drawbacks as compared to conventional antennas. Some of their major disadvantages are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.

1. 1. 3 Feeding Techniques [11]

Microstrip patch antennas can be fed by number of techniques. These techniques can be categorized as contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting method of feeding, electromagnetic field coupling is done to transfer the power between the microstrip line and radiating patch. The four most popular feed techniques that are used for feeding , these are microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

1. 1. 3. 1 Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch as shown in Figure 1. 3. The conducting strip is smaller in width as compared to the patch. This kind of feed arrangement has the benefit that the feed can be etched on the same substrate to provide a planar structure.

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is obtained by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides easy fabrication and simplicity in modeling and good impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which increases the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

1. 1. 3. 2 Coaxial Feed

Usually the Coaxial feed or probe feed is used for feeding the Microstrip patch antennas. As shown in the Figure 2. 4, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

The main benefit of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy in fabrication and has low spurious radiation. However, a major drawback is that it gives narrow bandwidth and difficulty in modeling since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates (h > 0. 02Î» 0). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which gives large bandwidth, the microstrip line feed and the coaxial feed suffer from several disadvantages as well. The non-contacting feed techniques can be used to solve these issues.

1. 2 RECTANGULAR PATCH ANTENNA [2]

Microstrip antennas are among the most widely used types of antennas in the microwave frequency range, and they are often used in the millimeter-wave frequency range (below approximately 1 GHz, the size of a microstrip antenna is usually too large to be practical, and other types of antennas such as wire antennas dominate). These are also known as patch antennas, microstrip patch antennas consist of a metallic patch of metal that is on top of a grounded dielectric substrate of thickness h, with relative permittivity and permeability Îµr and µr as shown in Figure 1. 5(a) (usually µr= 1). The metallic patch may be of different shapes, with rectangular and circular being the most common, as shown in Figure 1. 5(b) and Figure1. 5(c).

Most of the discussion in this section will be limited to the rectangular patch, although the basic principles are the same for the circular patch. (Many of the CAD formulas presented will apply approximately for the circular patch if the circular patch is modeled as a square patch of the same area.) Various methods may be used to feed the patch, as discussed below. One advantage of the

microstrip antenna is that it is usually low profile, in the sense that the substrate is fairly thin. If the substrate is thin enough, the antenna actually becomes “ conformal,” meaning that the substrate can be bent to conform to a curved surface (e. g., a cylindrical structure). A typical substrate thickness is about 0. 02 Î» 0. The metallic patch is usually fabricated by a photolithographic etching process or a mechanical milling process, making the construction relatively easy and inexpensive (the cost is mainly that of the substrate material). Other advantages include the fact that the microstrip antenna is usually lightweight (for thin substrates) and durable. Disadvantages of the microstrip antenna include the fact that it is usually narrowband, with bandwidths of a few percent being typical. Some methods for enhancing bandwidth are discussed later, however. Also, the radiation efficiency of the patch antenna tends to be lower than some other types of antennas, with efficiencies between 70% and 90% being typical.

1. 2. 1 Basic Principles of Operation

The metallic patch essentially creates a resonant cavity, where the patch is the top of the cavity, the ground plane is the bottom of the cavity, and the edges of the patch form the sides of the cavity. The edges of the patch act approximately as an open-circuit boundary condition. Hence, the patch acts approximately as a cavity with perfect electric conductor on the top and bottom surfaces, and a perfect “ magnetic conductor” on the sides. This point of view is very useful in analyzing the patch antenna, as well as in understanding its behavior. Inside the patch cavity the electric field is essentially z directed and independent of the z coordinate. Hence, the patch cavity modes are described by a double index (m, n). For the (m, n) cavity mode of the rectangular patch the electric field has the form

1. 1

Where L is the patch length and W is the patch width. The patch is usually operated in the (1, 0) mode, so that L is the resonant dimension, and the field is essentially constant in the y direction. The surface current on the bottom of the metal patch is then x directed, and is given by

1. 2

For this mode the patch may be regarded as a wide microstrip line of width W, having a resonant length L that is approximately one-half wavelength in the dielectric. The current is maximum at the centre of the patch, x = L/2, while the electric field is maximum at the two “ radiating” edges, x = 0 and x = L. The width W is usually chosen to be larger than the length (W = 1. 5 L is typical) to maximize the bandwidth, since the bandwidth is proportional to the width. (The width should be kept less than twice the length, however, to avoid excitation of the (0, 2) mode.) At first glance, it might appear that the microstrip antenna will not be an effective radiator when the substrate is electrically thin, since the patch current in (2) will be effectively shorted by the close proximity to the ground plane. If the modal amplitude A10 were constant, the strength of the radiated field would in fact be proportional to h. However, the Q of the cavity increases as h decreases (the radiation Q is inversely proportional to h). Hence, the amplitude A10 of the modal field at resonance is inversely proportional to h. Hence, the strength of the radiated field from a resonant patch is essentially independent of h, if losses are ignored. The resonant input resistance will likewise be nearly independent of h. This explains why a patch antenna can be an effective radiator even for very thin substrates, although the bandwidth will be small.

1. 2. 2 Resonant Frequency [2]

The resonance frequency for the (1, 0) mode is given by

1. 3

where c is the speed of light in vacuum. To account for the fringing of the cavity fields at the edges of the patch, the length, the effective length Le is chosen as Le= L + 2Î” L The Hammerstad formula for the fringing extension is

1. 4

where

1. 5

1. 3 Methods of Analysis [11]

There are different model for the parameter analysis of microstrip antenna which are listed below:

Approximate Model

Electromagnetic Simulation Model

Artificial Neural Network Model

Approximate model is based on based on numerical solution based on empirical formula (such as transmission line and cavity model). Electromagnetic simulation model is based on full wave such as method of moment and also with IE3d simulator. Artificial Neural Network Model uses neural model for the analysis.

The preferred models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model (which include primarily integral equations/Moment Method). The transmission line model is the simplest technique among all and it provides good physical insight but accuracy is lower. The cavity model is more accurate and gives good physical insight but have complexity with it. The full wave models are tremendously accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

1. 3. 1 Transmission Line Model [18]

This model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non-homogeneous line of two dielectrics, typically the substrate and air as shown in Figure1. 6.

Hence, as seen from Figure 1. 7, most of the electric field lines reside in the substrate and parts of some lines in air. Therefore this transmission line cannot support pure transverse-electric magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead of it, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (Îµreff) must be got in order to account for the fringing and the wave propagation in the line. The value of Îµreff is slightly lesser than Îµr because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 1. 6 above. The expression for Îµreff is given by Balanis[2] as:

1. 6

where

Îµreff= Effective dielectric constant

Îµr = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

It is shown in the Figure 1. 8 that the normal components of the electric field at the two edges

along the width kept in opposite directions and thus out of phase since the patch is Î»/2 long and hence they cancel each other in the broadside direction. The tangential components (seen in Figure 1. 9), which are in phase, it means that the resulting fields combine to give maximum radiated field which is normal to the surface of the structure. Hence the edges along the width can be given as two radiating slots, which are Î»/2 apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots. Electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance Î” L, which is given empirically by Hammerstad[3] as:

1. 7

The effective length of the patch Leff now becomes:

1. 8

The effective length for a given resonance frequency f0 is given by:

1. 9

For a rectangular Microstrip patch antenna, the resonance frequency fo for any TMmn mode is given by James and Hall [14] as:

1. 10

where m and n are modes along length L and width W respectively.

For efficient radiation, the width W is given by Bahl and Bhartia [15] as:

1. 11

1. 3. 1. 1 Limitation of Transmission Line Model:

The basic limitation of transmission line model is it yields the least accurate results and it lacks the versatility. However, it does shed some physical insight. It also ignores field variations along the radiating edges.

1. 3. 2 Cavity Model [20]

Although the transmission line model is easy to use in practical approach but it has some inherent disadvantages as well. Specifically, it is useful for rectangular design patches and it ignores field variations along the radiating edges. By using the cavity model these disadvantages can be overcome. A brief overview of this model is given below. In this model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom.

The basis for this assumption is the following observations for thin substrates (h << Î»).

- Since the substrate is thin, the fields in the interior region do not vary much in the z direction, i. e. normal to the patch.
- The electric field is z directed only, and the magnetic field has only the transverse components Hx and Hy in the region bounded by the patch metallization and the ground plane.

This observation provides for the electric walls at the top and the bottom.

Consider Figure 1. 10 shown above. When the power is provided to microstrip patch, a charge distribution is observed on the upper and lower surfaces of the patch and at the bottom of the ground plane. This charge distribution is controlled by two mechanisms as an attractive mechanism and a repulsive mechanism are discussed by Richards. The attractive mechanism is between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentration intact at the bottom of the patch. The repulsive mechanism is between the same charges on the bottom surface of the patch, it causes pushing of some charges from the bottom, to the top of the patch. Because of this charge movement, currents flow at the top and bottom surface of the patch. The cavity model assumes that the height to width ratio (i. e. height of substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface.

1. 12

QT is total antenna quality factor and has been expressed by:

1. 13

Qd represents the quality factor of the dielectric and given as:

1. 14

where

denotes the angular resonant frequency.

WT denotes the total energy stored in the patch at resonance.

Pd denotes the dielectric loss.

tan Î´ denotes the loss tangent of the dielectric.

Qc represents the quality factor of the conductor and is given as:

1. 15

where

Pc denotes the conductor loss.

Î" denotes the skin depth of the conductor.

h denotes the height of the substrate

Qr represents the quality factor for radiation and given as:

1. 16

where

Pr denotes the power radiated from the patch.

Substituting equation (1. 13),(1. 14),(1. 15) and (1. 16) in equation (1. 12), we get

1. 17

1. 3. 3 Electromagnetic Simulation Model [22]

Electromagnetic simulation model is based on full wave analysis such as method of moment and also with IE3d simulator. Electromagnetic simulation model give more accurate analysis of microwave patch antenna parameters – such as S-parameters, radiation patterns, etc. -compared to the approximate models, such as transmission line model, cavity model but suffer from the drawback of time-consuming intensive computations compared to the approximate models which are less accurate but faster.

CHAPTER 2: ARTIFICIAL NEURAL NETWORK

This chapter deals with Artificial Neural Network and their various types, back propagation algorithm, working principle of back propagation and different types of training used by back propagation.

2. 1 INTRODUCTION TO ARTIFICIAL NEURAL NETWORK [13]

Neural network has been motivated from the human brain because the brain is a highly complex, nonlinear, and parallel computer. It is estimated that there are approximately 10 billion neurons in the human brain. Neurons (basic constituents of brain) are organized in such a manner that our brain performs certain tasks many times faster than the fastest digital computer in existence today. At birth, a brain has great structure and the ability to build up its own rules through what we usually refer to as " experience". A neural network is made up of simple processing units, which has a natural tendency for storing experiential knowledge and making it available for use. It resembles the brain in two respects. Knowledge is acquired by the network from its environment through a learning process. Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.

2. 2 NETWORK ARCHITECTURES

The manner in which the neurons of a neural network are structured is intimately linked with the learning algorithm used to train the network. We may therefore speak of learning algorithms (rules) used in the design of neural networks as being structured.

In general, we may identify two fundamentally different classes of network architectures:

2. 2. 1 Single-Layer Feedforward Networks [13]

In a layered neural network the neurons are organized in the form of layers. In the simplest form of a layered network, we have an input layer of source nodes that projects onto an output layer of neurons (computation nodes), but not vice versa as shown in Figure2. 1. Such a network is called a single-layer network, with the designation " single-layer" referring to the output layer of computation nodes (neurons).

Input layer Output layer

of source nodes of neurons

2. 2. 2 Multilayer Feedforward Networks [13]

The second class of a feedforward neural network distinguishes itself by the presence of one or more hidden layers, whose computation nodes are correspondingly called hidden neurons or hidden units, The function of hidden neurons is to intervene between the external input and the network output in some useful manner, By adding one or more hidden layers, the network is enabled to extract higher-order statistics as shown in Figure 2. 2. The source nodes in the input layer of the network supply respective elements of the activation pattern (input vector), which constitute the input signals applied to the neurons (computation nodes) in the second layer (i. e., the first hidden layer). The output signals of the second layer are used as inputs to the third layer, and so on for the rest of the network. Typically the neurons in each layer of the network have as their inputs the output signals of the preceding layer only. The set of output signals of the neurons in the output (final) layer of the network constitutes the overall response of the network to the activation pattern supplied by the source nodes in the input (first) layer.

Input layer of Layer of Layer of source nodes hidden neurons output neurons

2. 2. 3 Multilayer Perceptrons[13]

Multilayer feed forward networks are an important class of neural networks. The network consists of a set of sensory units (source nodes) that constitute the input layer, one or more hidden layers of computation nodes, and an output layer of computation nodes. The input signal propagates through the network in a forward direction, on a layer-by-layer basis. These neural networks are commonly referred to as multilayer perceptrons (MLPs), which represent a generalization of the single-layer perceptron, shown in Figure 2. 3.

Multilayer perceptrons have been applied successfully to solve some difficult and diverse problems by training them in a supervised manner with a highly popular algorithm known as the back-propagation algorithm.

A multilayer perceptron has three distinctive characteristics:

The model of each neuron in the network includes a nonlinear activation function.

The network contains one or more layers of hidden neurons that are not part of the input or output of the network. These hidden neurons enable the network to learn complex tasks by extracting progressively more meaningful features from the input patterns (vectors).

The network exhibits high degrees of connectivity, determined by the synapses of the network. A change in the connectivity of the network requires a change in the population of synaptic connections or their weights.

Input layer First hidden layer Second hidden layer Output layer

2. 3 The Backpropagation Algorithm [13]

The backpropagation algorithm is used in layered feed-forward ANNs. This means that the artificial neurons are organized in layers, and send their signals “ forward”, and then the errors are propagated backwards. The network receives inputs by neurons in the input layer, and the output of the network is given by the neurons on an output layer. There may be one or more intermediate hidden layers. The backpropagation algorithm uses supervised learning, which means that we provide the algorithm with examples of the inputs and outputs we want the network to compute, and then the error (difference between actual and expected results) is calculated. The idea of the backpropagation algorithm is to reduce this error, until the ANN learns the training data. The training begins with random weights, and the goal is to adjust them so that the error will be minimal.

The activation function of the artificial neurons in ANNs implementing the i backpropagation algorithm is a weighted sum (the sum of the inputs x multiplied by their ji respective weights w)

2. 1

If the output function would be the identity (output= activation), then the neuron would be called linear. But these have severe limitations. The most common output function is the sigmoidal function:

2. 2

The sigmoidal function is very close to one for large positive numbers, 0. 5 at zero, and very close to zero for large negative numbers. This allows a smooth transition between the low and high output of the neuron.

The goal of the training process is to obtain a desired output when certain inputs are given. Since the error is the difference between the actual and the desired output, the error depends on the weights, and we need to adjust the weights in order to minimize the error. We can define the error function for the output of each neuron:

2. 3

We take the square of the difference between the output and the desired target because it will be always positive, and because it will be greater if the difference is big, and lesser if the difference is small. The error of the network will simply be the sum of the errors of all the neurons in the output layer:

2. 4

The backpropagation algorithm now calculates how the error depends on the output, inputs, and weights. After we find this, we can adjust the weights using the method of gradient descendent:

2. 5

This formula can be interpreted in the following way: the adjustment of each weight (w) will be the negative of a constant eta multiplied by the dependence of the previous weight on the error of the network, which is the derivative of E in respect to w. The size of the adjustment will depend on eta, and on the contribution of the weight to the error of the function. This is, if the weight contributes a lot to the error, the adjustment will be greater than if it contributes in a smaller amount. is used until we find appropriate weights (the error is minimal). If you do not know derivatives, don’t worry, you can see them now as functions that we will replace right away with algebraic expressions. If you understand derivatives, derive the expressions yourself and compare your results with the ones presented here. If you are searching for a mathematical proof of the backpropagation algorithm, you are advised to check it in the suggested reading, since this is out of the scope of this material.

So, we “ only” need to find the derivative of E in respect to w. This is the goal of the backpropagation algorithm, since we need to achieve this backwards. First, we need to calculate how much the error depends on the output, which is the derivative of E in respect to O.

2. 6

And then, how much the output depends on the activation, which in turn depends on the weights.

2. 7

By using above equations-

2. 8

And so, the adjustment to each weight will be

2. 9

This equation is used for training an ANN with two layers.

For training the network with one more layer we need to make some considerations. If we want to adjust ik the weights of a previous layer, we need first to calculate how the error depends not on the weight, but in the input from the previous layer.

2. 10

where:

2. 11

And, assuming that there are inputs u into the neuron with v

2. 12

If we want to add yet another layer, we can do the same, calculating how the error depends on the inputs and weights of the first layer.

2. 3. 1 Different Training Models for Back propagation Algorithm

There are several back propagation training model which are listed below and categorized under three different section based on their training speed.

Gradient Descent back propagation

Gradient Descent with momentum back propagation

Variable Learning Rate back propagation

Resilient back propagation

Scale Conjugate Gradient back propagation

Quasi Newton back propagation

Levenberg Marquardt back propagation

The first two training models are come in category of slow training model which are too slow for the practical problems. The last four training models come in category of fast training model which are further divided in two section one is based on heuristic techniques, which were developed from an analysis of the performance of the standard steepest descent algorithm (Variable Learning Rate and Resilient back propagation) while the second uses standard numerical optimization techniques (Scale Conjugate Gradient, Quasi Newton and Levenberg Marquardt back propagation).

In our thesis, we basically deal with fast training models which use the standard numerical optimization techniques.

2. 3. 1. 1 Scale Conjugate Gradient Training

The basic back propagation algorithm adjusts the weights in the steepest drop direction (negative of the gradient), the direction in which the performance function is decreasing most quickly. It turns out that, although the function decreases most quickly along the negative of the gradient, this does not essentially produce the best ever convergence. In the conjugate gradient algorithms a search is perform along conjugate directions, which gives generally faster convergence than steepest descent directions.

In most of training models a learning rate is used to decide the length of the weight update (step size). In most of the conjugate gradient algorithms, the step size is adjusted at each iteration. A search is done alongside the conjugate gradient direction to determine the step size that minimizes the performance function along that line.

2. 3. 1. 2 Basic step of Scale Conjugate Gradient

All the conjugate gradient algorithms start by searching in the steepest decent direction (negative to gradient) on first iteration.

A line search is then performed to determine the optimal distance to move along the current search direction as:

2. 13

Then the next search direction is determined so that it is conjugate to earlier search directions. descent direction with the prior search d