Optimization of Microstrip Patch Antenna Parameters with Artificial Neural Networks

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Introduction

With the development of technology, it has become very important to transmit information from one point to another in an error-free and accurate manner, at low cost and by selecting the appropriate transmission medium. Antenna, which is very important in the transmission of information, is a circuit element that converts electrical signals into electromagnetic waves and transfers them to the transmission medium or converts electromagnetic waves from the transmission medium into field and electrical signals. It can be said that the microstrip antenna (MBA) is an element that provides these transformations at microwave frequencies.

Microstrip patch antennas are a geometrical structure consisting of a conductive metal patch that radiates on a metal-coated dielectric substrate called a ground plane (Garg at al., 1995). Microstrip patch antennas are one of the most popular types of antennas today due to their simple geometry, easy fabrication, low cost, light weight and ease of installation. Microstrip patch antennas have the potential for a wide range of applications over a wide frequency range. The widespread use of microstrip patch antennas in the industrial field means that they can be used in almost every field of communication and has brought significant contributions to the sector in terms of cost.

Today, the need for broadband and high data rate communication is increasing, especially in mobile communication systems. UHF band covers a part of satellite communication technology. It is evaluated that X/Ku/Ka band technologies can be used in the next generation over-the-horizon communication systems due to the low number of satellites with a transponder, also called UHF trasponder, and the high cost of circuit rental (Uğurlu, 2016).

In particular, developments in microwave technology have been driven by the advantages of antennas to be used in related devices such as large bandwidth, being as small as possible and easy to manufacture. Today, antenna designers direct their work by considering these factors.

Factors affecting the bandwidth of a microstrip patch antenna are generally the shape of the patch, the feeding method, the placement of the base and radiating patches and the parasitic elements. Various bandwidth enhancement methods have been used in the literature over the years to address these factors. The bandwidth of a microstrip patch antenna can be increased due to a low Q quality factor and well-excited multiple resonant modes. Another bandwidth enhancement method is the choice of a thick base with a low dielectric constant. The use of a parasitic patch is another bandwidth enhancement method (Panayi at al., 1999). The use of stack elements is another bandwidth enhancement method (Tong at al., 2000). Finally, changing the dimensions of the ground plane is another bandwidth enhancement method (Huynh & Stutzman 2003, Dilek Uzer at al., 2016).

As the studies on microstrip antennas have increased, the number of antennas with various geometric structures has also increased. Today, microstrip antennas are named according to the patch geometry. The study on rectangular microstrip patch antennas, which is considered as an important source of information in the literature, was done by Howell (Howell, 1972). Rectangular patches are the first and most widely used microstrip patch antenna geometry. It is larger in size than other patch geometries and therefore has a larger bandwidth.

The radiation pattern of a single element antenna is relatively broad, but the single element provides low gain. In order to meet the needs of long distance communication, it is necessary to design high gain antennas in most applications (Roy & Chakraborty, 2011). The gain of the antenna can be increased by increasing the electrical size of the antenna. However, the antenna gain can also be increased by placing the radiating element in a specific electrical and geometrical arrangement. This structure consisting of more than one radiating element is called an antenna array. Array antennas were first designed by Sanford as surface-matched array antennas for L Band applications (Sanford, 1974). The use of microstrip antennas as array antennas is quite common (Balanis, 1982). Antenna arrays are used to synthesize the required pattern that cannot be achieved with a single element, to improve directivity, beam scanning and other functions that are difficult to achieve with a single element.

Haeng Sook Noh, Jae Seung Yun, Jong Myen Kim, Soon-Ik Jeon (2004); In this study, a bidirectional high gain and broadband 1x8 rectangular cross-section microstrip patch antenna design for Ku band was realized and Rx/Tx feeds were formed for bidirectional communication. As a result, it was observed that the bandwidth increased by 10% in Rx feed and 11% in Tx feed.

Dowon Kim, Moonil Kim, Tanaka M., Matsugatani K. (2006); In this study, an array antenna with 12 patches in the shape of a hexagonal with smoothed corners was designed to increase the bandwidth. At 6.8 GHz, a material with a thickness of 1.27 mm and a dielectric constant of 9.8 was used, and the results showed that the bandwidth increased by 1.7% for each patch according to the measured values.

Shah, Suaidi, Aziz, Rose, Kadir, Ja'afar, Sidek, Rahim M.K.A., (2008); In this study, three (1x2, 1x4, 2x2) array antennas were designed. First, -45 and +45 degree inclined antennas were designed, then the same antenna was combined 2 times side by side and in the third design, 1x2 antennas were combined one below the other. FR4 material with dielectric constant (ε) 4 and h height 1.6 was used in the design. As a result of the measurements, it was observed that the gain of the 1x2 array antenna was 9.5 dB, while the gain of the 1x4 and 2x2 array antennas was approximately 20 dB. As a result, it is seen that antenna combinations will increase the gain.

Ang Yu, Xuexia Zhang (2002); In this study, a 2x1 rectangular patch antenna was first designed. Then 4x(2x1) patch antennas are combined to form a 1x8 combined patch antenna. Then, 8 interference patches with the same patch size were formed on the front side of the 1x8 array antenna. The parasitic patch antenna is compared with the formed patch antenna. Operating at 2.4 GHz resonant frequency, the antenna uses 2 mm thick dielectric material with a dielectric constant of 2.58. As a result, the gain of the 1x8 antenna with parasitic patch increases by 2.13 dB compared to the 1x8 patch antenna.

Such an antenna is recommended for wireless LAN networks.

Gültekin S.S. (2002); This study was conducted as a doctoral thesis and the parameters of rectangular, circular and triangular microstrip antennas were calculated by ANN and compared with the literature results. In this study, rectangular, circular and triangular geometric shapes are evaluated in a single geometric form and the results obtained are interpreted. Eleven different training algorithms were used in the ANN.

Türkmen M., Yıldız C., Sağıroğlu Ş. (2003); In this study, the characteristic impedance and effective dielectric constant of coplanar waveguides with an infinitely long dielectric base are calculated with a single Artificial Neural Network (ANN) model. The ANN structure was trained using five different learning algorithms and the algorithm performances were evaluated among themselves. It is observed that the obtained results are in good agreement with the existing results in the literature. Comparison of the results obtained from the presented ANN model with the results obtained with the Conformal Transformation Technique used in the literature for the analysis of such structures has led to the conclusion that ANNs can be used as a new alternative for solving such problems.

Ataş İ., Kurt MB., Ataş M. (2013); In this study, Open Coupled Microstrip Patch Antenna design based on ANN model for frequency values between 1 GHz and 3.5 GHz was carried out. A total of 500 patch antennas with different geometric structures were designed with the Electromagnetic Field Simulator software using the Finite Element Method and the resonant frequency value of each antenna was designed. The ANN model developed on the basis of the Levenberg Marquard learning algorithm was trained with the examples realized with the Electromagnetic Field Simulator and its accuracy was measured using the test data set that it did not see during the training period. The 5-fold crossover accuracy method was used to measure the success of the developed ANN model. As a result, in terms of time efficiency, the proposed method was found to work at least 100 times faster than the Electromagnetic Field Simulator software.

Microstrip Patch Antennas

Microstrip patch antennas that fulfill many wireless system requirements are widely used in handheld mobile devices and wireless communication systems. According to their advantages, these antennas find wider applications in mobile and satellite communications.

Advantages of microstrip patch antennas; light profile, low scattering interference, linear and circularly polarized radiation with small changes in feed position, easy construction of two or more frequency antennas, no need for cavity support, suitable mounting on planar and non-planar surfaces, simple and inexpensive to produce using modern printed circuit technology, mechanically strong when mounted on solid surfaces, compatible with MMIC (Monolithic Microwave Integrated Circuit Design) designs and regular conductor structures, solid state devices such as oscillators, amplifiers, variable attenuators, switches, modulators, mixers, phase shifters, etc. can be added to the substrate of microstrip antennas and composite systems can be developed, feeder lines and matching circuits can be manufactured at the same time with the antenna, and when modes are selected, compound systems can be developed. etc., solid state devices such as oscillators, amplifiers, variable attenuators, switches, modulators, mixers, phase shifters, etc. can be added to the substrate of microstrip antennas, feeder lines and matching circuits can be produced at the same time with the antenna, and when modes are selected; resonance frequency, polarization, pattern and impedance are versatile (Dundar, 2012).

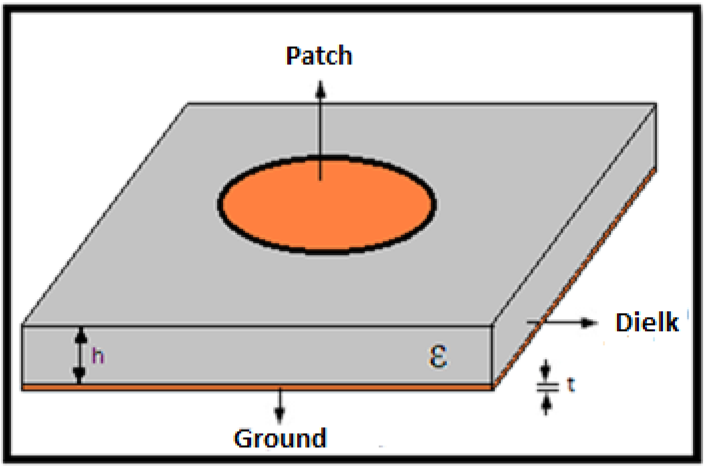
In addition, microstrip patch antennas have significant disadvantages. These include; very narrow bandwidth, low efficiency and low power, high Q (sometimes more than a hundred), insufficient polarization purity, insufficient scattering performance, spurious feed radiation, large physical dimensions of designs at low frequencies (Dundar, 2012).

The applications of microstrip patch antennas can be listed as wireless systems, satellite communications, defense industry systems, biomedical systems, environmental instrumentation and remote sensing systems, mobile communications, doppler and radars, guided missiles.

Physically, a microstrip patch antenna in its simplest form, as shown in Figure 1, consists of a metal patch radiating on a dielectric base covered with a metal called a ground plane. The metal parts are usually selected from a good conductive metal such as copper or gold. The thickness (t) of the ground and the patch varies between 50 µm and 200 µm. The thickness of the dielectric structure h varies between 0.25 mm and 25 mm.

Figure 1

Microstrip Patch Antenna Structure



The first step in microstrip antenna design is the selection of a suitable dielectric base. The dimensions and electrical properties of the dielectric base, which physically occupies the largest volume in the microstrip antenna, are very important for antenna performance. The dielectric base acts as a part of the transmission line that mechanically supports the circuit elements on the microstrip antenna by providing ease of assembly. Its dielectric permittivity and thickness determine the resonant frequency, resonant resistance and other electrical properties of the antenna (Sainati, 1996). Researchers have found that the most important parameters affecting the performance of microstrip antennas are the dielectric constant of the dielectric material and the tolerance values specified by the manufacturers for this dielectric. Therefore, materials with known dielectric constants are preferred in designs.

There are a large number of base materials used on the market. Their dielectric constant ranges from 1.7 to 25 (Traut, 1980; Olyphant & Nowicki, 1980). However, for high antenna performance, the dielectric constant εr should be less than 3 (Balanis 1982).

Microstrip Antenna Feed Type

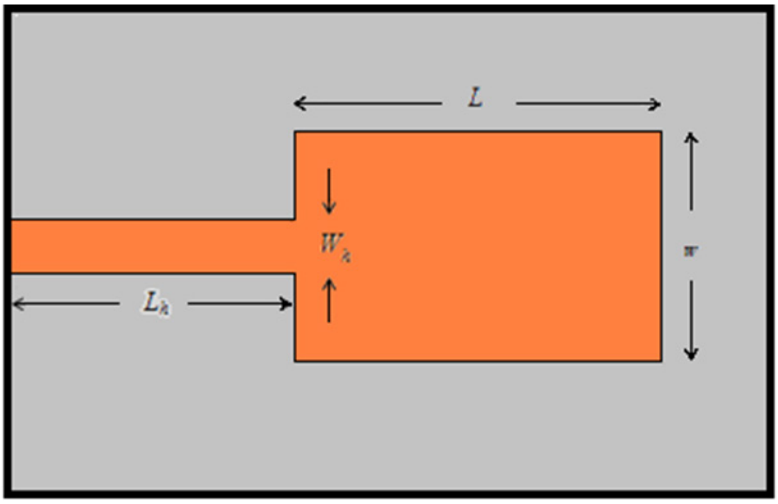
The most common techniques used for feeding microstrip patch antennas are microstrip line feed and coaxial line feed. Impedance matching is the most important factor to be considered for maximum power transfer in microstrip antennas. The feed line impedance is fixed and is 50 Ω. If the antenna impedance is different, a matcher must be installed between the feed line and the antenna to ensure impedance matching.

Microstrip Line Feed

One of the original excitation techniques for microstrip patch antennas is the edge feed or microstrip line feed technique (Munson 1974). As shown in Figure 2, a microstrip line of length Lh and width Wh is directly connected to a rectangular patch conductor of dimensions L and W using a printed circuit.

Figure 2

Edge-Fed Microstrip Patch Antenna Demonstration

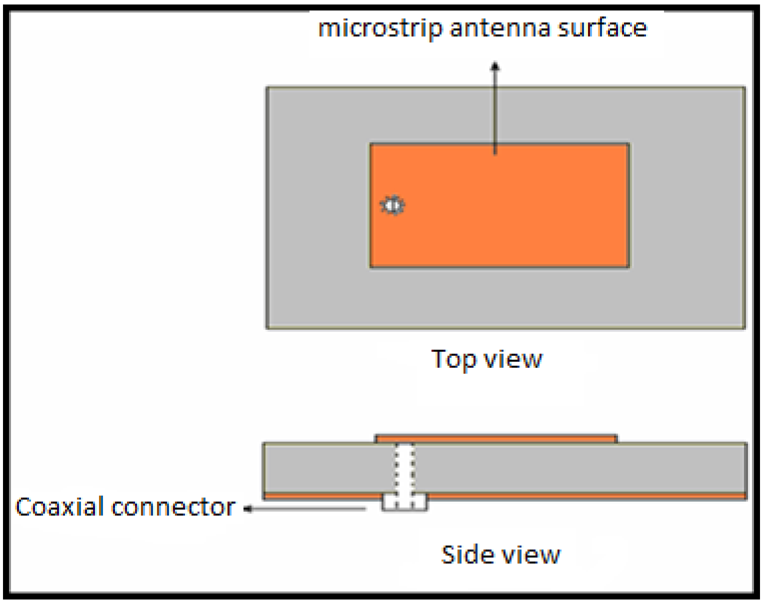


Coaxial Line Feed

Feeding a microstrip patch antenna with a coaxial coupler is another original form of excitation technique proposed in the 1970s. Coupling power through a coaxial coupler is one of the most fundamental mechanisms for microwave power transfer. A probe is usually used as a coaxial coupler. Figure 3 shows a coaxial line feed diagram fed by a coaxial coupler.

Figure 3

Microstrip Antenna With Coaxial Line Feed



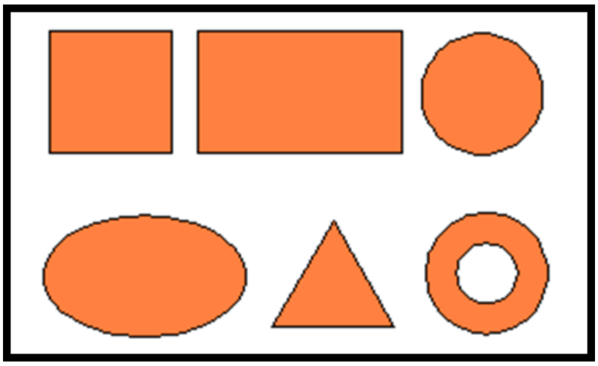
The coaxial feed pin is usually the inner conductor of a coaxial line. This is why probe feed is also known as coaxial feed. The coaxial conductor is connected from the ground side of the patch antenna, and the center conductor of the coax is soldered to the metal of the patch after passing the base.

Microstrip Antenna Patch Types

In microstrip antennas, the radiating part of the patch can be in different geometric shapes and sizes. As shown in Figure 4, there are patch antennas designed in square, rectangular, circle, triangular, etc. shapes.

Figure 4

Common Patch Shapes Used İn Microstrip Antennas



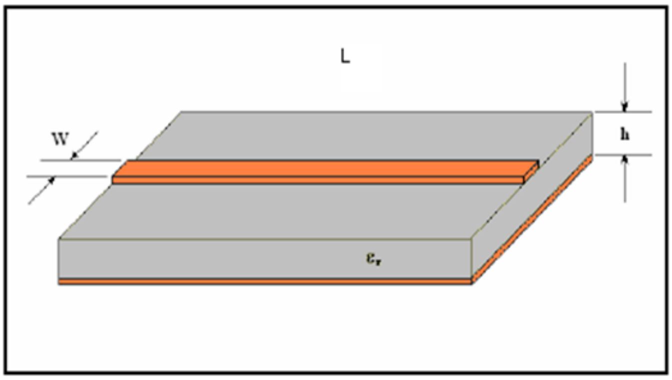
In microstrip patch antennas, studies have shown that the bandwidth is directly proportional to the patch volume. In other words, bandwidth can be increased by increasing the patch size. However, this can also lead to some disadvantages. For example, since the patch length is related to the wavelength of the designed frequency, the size can be increased by reducing the dielectric coefficient of the base. Considering that the feed line will emit more energy in this case, attention should be paid to the cross-polarization and side beam levels in the radiation. It should also be taken into account that increasing the patch width may lead to the excitation of higher order modes in the cavity. Increasing the base thickness increases the surface waves and losses at the surface. For these reasons, the addition of parasitic elements on the base is preferred rather than increasing the patch width (Yazgan 2006).

Rectangular Microstrip Patch Antenna Design

The rectangular microstrip patch antenna is the simplest microstrip patch structure. As shown in Figure 5, the basic antenna element is a conducting strip of dimensions (LxW) on a base of thickness h and dielectric constant εr, with the back side covered by the ground plane and the extension of the transmission line.

Figure 5

Basic Microstrip Patch Structure Used İn Microstrip Antennas



W Patch width can be found by the following formula (James 1989).

$$W = \frac{c}{2f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}} \tag{1}$$

In the formula c is the propagation speed of light in a vacuum, εr is the dielectric constant of the material and fr is the operating frequency.

L The patch length is obtained by subtracting the fringe field length (Δ) from the half-wavelength length.

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_e}} - 2\Delta l \tag{2}$$

In the formula εe is the effective dielectric constant and for (w/h) > 1;

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12t}{W}\right] \tag{3}$$

(Schneider, 1969). The value t in the equation is the microstrip line thickness.

The line expansion Δ is;

$$\Delta l = 0.412h \frac{(\varepsilon_e + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_e - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

is expressed as (Hammerstad & Bekkadal 1975).

In microstrip lines, the characteristic impedance depends on the width of the line and the thickness of the dielectric base. The formulas for the calculation of the effective dielectric coefficient and characteristic impedance are given in the following equations

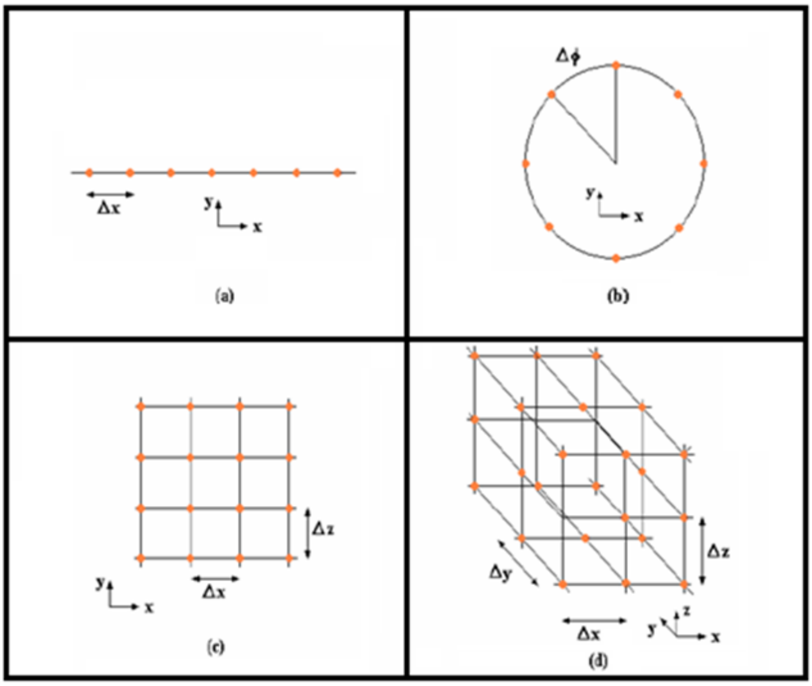
$$.\,\varepsilon_{eff} = \begin{cases} \dfrac{\varepsilon_r + 1}{2\left(1 - \dfrac{B}{C}\right)^2} & \dfrac{W}{h} < 1.3 \\[2ex] \dfrac{\varepsilon_r + 1}{2} + \left(\dfrac{\varepsilon_r - 1}{2}\right)\left(1 + \dfrac{10h}{W}\right)^{-\frac{1}{2}} & \dfrac{W}{h} \geq 1.3 \end{cases} \tag{5}$$

Array Antennas

The radiation pattern of a single element antenna is relatively broad, but the single element provides low gain. To meet the needs of long-distance communication, it is necessary to design high gain antennas for most applications. The gain of the antenna can be increased by increasing the electrical size of the antenna. However, the antenna gain can also be increased by placing the radiating element in a specific electrical and geometrical arrangement. This structure consisting of more than one radiating element is called an antenna array. The radiation pattern of an array of identical antenna elements depends on the geometrical shape of the array (linear, circular, spherical, etc.), the distance between the array elements, the amplitude and phase of the feed of the array elements, and the radiation pattern of the array elements alone (Balanis C. A., 1997).

Microstrip antenna arrays can be designed as one-dimensional, two-dimensional or three-dimensional, depending on the space dimensions in which radiation is desired. Figure 6 shows the array antenna geometries.

Figure 6
Microstrip Array Antenna Geometries, a) One Dimensional Uniform Linear Array, b) Circular Dimensional Array, c) Two Dimensional Array, d) Three Dimensional Array



The structure shown in Figure 6 a is a one-dimensional uniform linear array geometry for azimuthal beamforming in the horizontal plane only. These arrays are the most basic structures used for beamforming in azimuth. The structure shown in Figure 6 b is a circular array geometry representation, which is also used only for azimuthal beamforming in the horizontal plane. Figure 6 c shows a two-dimensional array antenna geometry that can be shaped in both azimuth and elevation angles. Figure 6 d shows a three-dimensional array antenna geometry that can be shaped in both azimuth and elevation angles. Two and three dimensional array antenna geometries are generally preferred in densely populated and indoor environments (Çakır G., 2004).

Artificial Neural Networks (ANNs)

Artificial neural networks have a theoretical structure inspired by the biological structure of the human nervous system. That is, artificial neural networks are composed of basic elements that function as neurons, which are nerve cells in the human nervous system. These elements are organized similar to the anatomy of the human brain. In addition to this great similarity, neural networks have many surprising features of the human brain.

Learning

Artificial neural networks can change their output behavior according to the inputs they receive from the environment. In the learning process, when a certain input is given to the network, the network has to modify itself in order to produce consistent responses. Various learning algorithms have been developed to train artificial neural networks. Each of these algorithms has its own strengths and weaknesses.

Generalization

A network that has been taught can be, to some extent, insensitive to small changes in the inputs given to it. That is, it always reacts in the same way. This ability is important in the real world to be able to recognize inputs that are slightly distorted by factors from the environment. This is a system that goes beyond the logic used in computers; it is a system developed to understand the imperfect world we live in. ANNs do generalization automatically because of their structure.

Summarization

Some artificial neural networks are capable of extracting the essence of a given set of input information. For example, a network may be given various distorted forms of the letter 'A' as input. After sufficient teaching, the network will be able to give a proper letter 'A' in response to a corrupted letter 'A'. In a sense, the network will have learned to produce something it has never seen or learned before. Here, the ability to create ideal prototypes is an important and useful human trait. Today, the use of this feature in ANNs is on the agenda. ANNs, of course, are not suitable for tasks such as calculating payrolls, which is what computers do. However, in the field of pattern-recognition, which is difficult or very limited for traditional computers, artificial neural networks have found a wide range of applications (Burr D.J., 1987).

Biological Structure

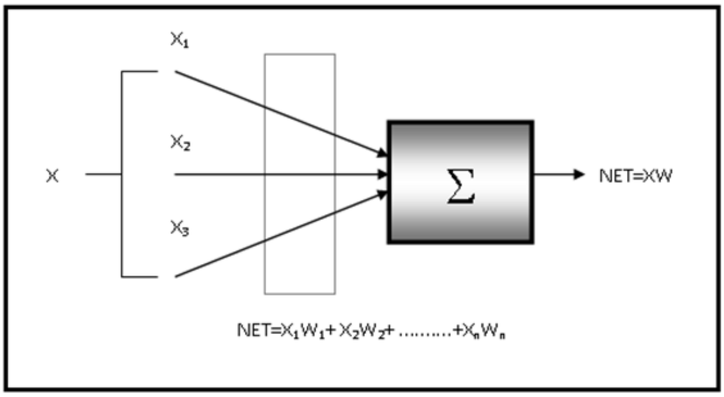
Artificial neural networks are inspired by biological neurons and researchers have studied the organization of the brain when thinking about the network shape and algorithm. However, knowledge about the brain's working system is very limited. The opportunity to guide those working on this subject is also very limited. In this respect, network design scientists have been forced to go beyond the existing biological knowledge and look for concepts that will help them find useful functions. In many cases this important change ignores biological facts, the brain becomes virtual, and networks cannot be organically applied to brain anatomy and function.

Despite this subtlety, comparisons between ANNs and the brain reveal similarities, even though they are not biologically very similar. ANN functions are reminiscent of human perception. For this reason, it is very difficult to avoid making analogies. The estimated 100 billion neurons in the brain have about 1 quadrillion connectors. Each neuron shares many common characteristics with other cells in the body. But the role of the neurons that make up the brain's communication system is to receive, process and transmit electrochemical signals in neural networks.

Artificial Neuron

The artificial neuron is designed to mimic the input, processing and output characteristics of a biological neuron. Here each input is multiplied by its own weight and all these multiplications are summed up. This sum can be likened to synaptic strength. This sum is used to determine the activation level of the neuron. Figure 7 shows this model.

Figure 7
Artificial Neuron

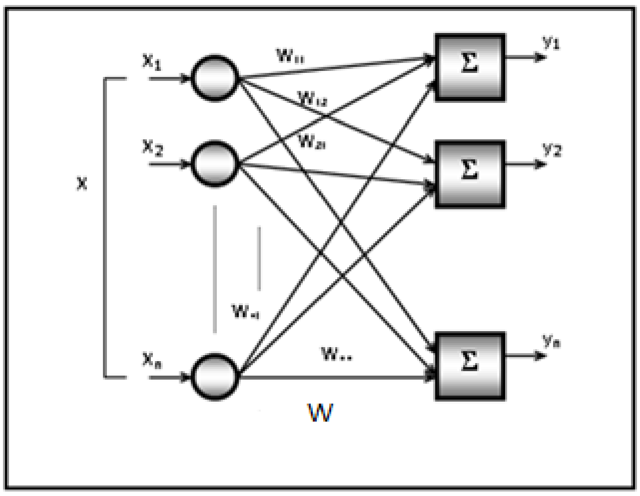


Although network sequences vary widely, most are based on the representation in Figure 7. Here the input set is represented as x1, x2, ..., xn and applied to the artificial nerve. These inputs are summed to form the vector X and sent as signals to the biological synapses. Each signal is multiplied by its associated weight value w1,w2,...,wn and transferred to the block denoted by Σ. Each weight represents the strength of a single biological synaptic connection. Here the sum of the set of weights forms a vector called W.

Single Layer ANN

The power and success of an ANN consisting of an artificial neuron and the interconnection of neurons will not be as perfect as that of a real nervous system. The simplest network structure is shown in Figure 8. Round representations only distribute the inputs to the neuron and do not perform any analysis. Therefore, in order to express the inputs differently from the neurons, it is necessary to represent them as round. Here, each element of X, the set of inputs, is connected to the ANN with a weight value. The first ANNs created were not so complex, with each neuron providing a weighted sum of the inputs to the network through a simple calculation. Artificial and biological neural networks may have some connections deleted, but complete connections are preferred to generalize the structure of the ANN. Where W is the weight matrix, m is the number of inputs and n is the number of neurons.

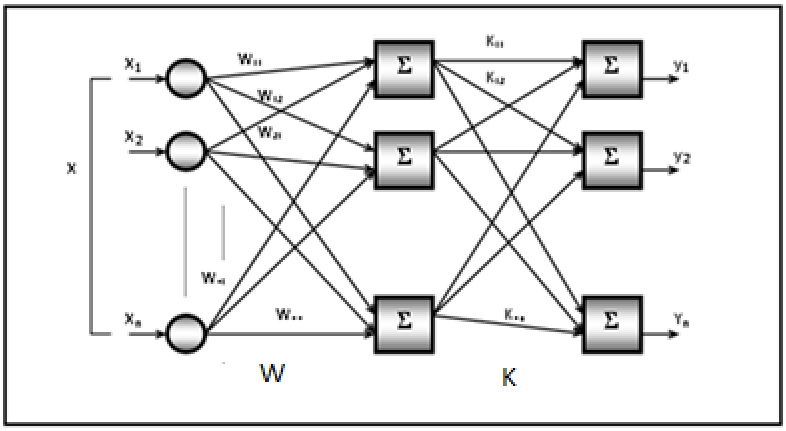
Figure 8
Single Layer Neural Networks



Multilayer ANN

Larger and more complex networks also need more computational capacity. ANNs are built to reflect a part of the brain. Multilayer networks have been proven to be better than single-layer networks and all studies have focused on them. Multilayer networks are a combination of single layer networks. Figure 9 shows the multilayer network structure.

Figure 9
Double Layer Neural Networks

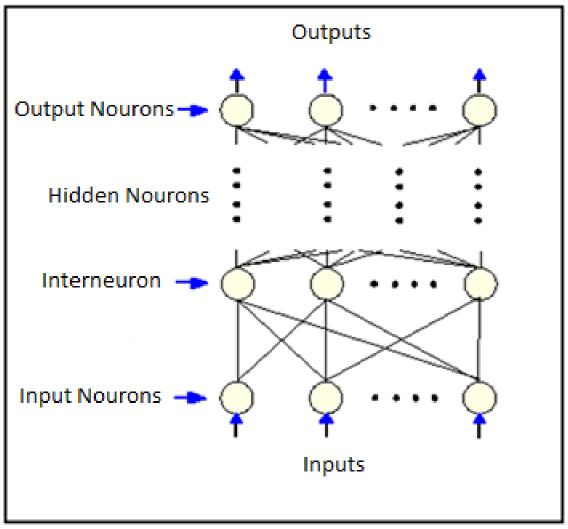


In multilayer networks, if a non-linear activation function is used, the computational power of these networks will not be perfect. If the activation function is linear, the output can be calculated as $(XW_1)W_2$ where X is the input vector, W_1 is the first weight matrix and W_2 is the second weight matrix. The terms are regrouped until the matrix product converges and written as $X(W_1W_2)$.

Multilayer Perseptron (MLP) ANN Structure

The MLP is a type of feed-forward ANN consisting of an input layer, one or more intermediate layers and an output layer, as shown in Figure 10. The processing elements in the input layer distribute the input signals to the processing elements in the intermediate layer. The processing elements in the intermediate layer sum the inputs from the input layer after multiplying them by the connection weights and pass them through a transfer function to the output layer. The processing elements in the output layer act like the intermediate layer elements and calculate the output value of the network.

Figure 10
A Common MLP Structure



In the so-called feed-forward neural network model, the information flow is forward and there is no feedback. The number of processing elements in the input layer depends on the number of inputs of the applied problem. The number of intermediate layers and the number of processing elements in the intermediate layers are found by trial and error.

ANN Learning Algorithms

There are many learning algorithms in the literature. These algorithms vary according to ANN structures. Some of them are Delta-Bar-Delta (DBD), Extended Delta-Bar-Delta (EDBD) and Levenberg-Marquardt (LM) learning algorithms.

The Delta-Bar-Delta training algorithm is a heuristic approach to increase the convergence rate of the weights in the MLP learning algorithm developed by Jacobs (1988). Experimental studies have shown that each dimension of the weight space can be very different in terms of error surfaces. In order to identify these differences in error surfaces, each weight of the network must have its own learning coefficient (Jacobs 1988). However, in this approach, the learning coefficient generated may be appropriate for a single weight but not for all weights. However, assigning a learning coefficient to each weight and allowing this learning coefficient to change over time will also provide more degrees of freedom to reduce the convergence time of the network.

The Extended Delta-Bar-Delta (EDBD) algorithm (Minai and Williams 1990) is an extension of the DBD algorithm (Jacobs 1988) and is based on the principle of reducing the training time of MLPs. The EDBD algorithm differs from the DBD algorithm in that it uses heuristic momentum, eliminates large jumps in the weight space, and is fast in avoiding large jumps that exceed the goal of geometric reduction. Levenberg-Marquardt (LM) learning algorithm, a highly successful optimization method, is one of the different learning techniques of the backpropagation algorithm used in learning. Based on the idea of a large number of neighbors, the LM algorithm is a least square estimation method (Levenberg 1944; Marquardt 1963).

Array Patch Antenna Design and Improvement of Antenna Parameters with Artificial Neural Networks

Antenna arrays can be used to increase antenna gain, directivity and bandwidth. Since it is simpler and more practical, identical array elements are chosen in many applications. However, array elements can also be selected in different structures (Özen B., Afacan E., 2014).

Design of 1x4 Rectangular Section Microstrip Patch Antenna at 2500 MHz Frequency

Today, the internet has entered every aspect of our lives and a life without the internet is unthinkable. WiMax (Wordwide Interoperability for Microwave Access), which is a worldwide interoperable microwave access, is an amplified wireless internet access (Wi-Fi) technology in the simplest terms. In this study, a rectangular 1x4 microstrip patch antenna design has been realized at 2500 MHz frequency for WiMax wireless high speed internet access. As in all microstrip antenna designs, material selection is the primary parameter in this design. The FR4 material properties selected for the design are given in Table 1.

Table 1

FR4 Base Material Properties

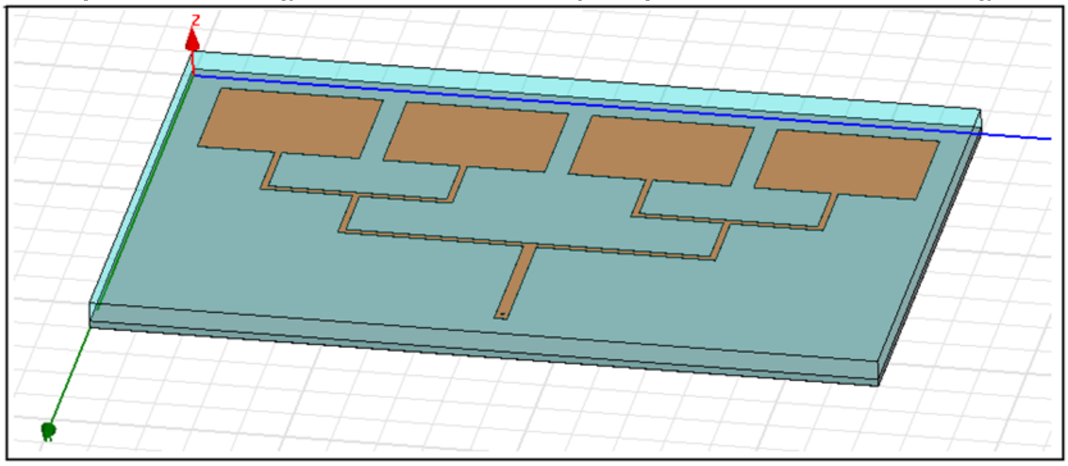
Material Properties	Value
Base	FR4
Dielectric Constant (εr)	4.9
Dielectric Thickness (h)	1.6 mm
Copper Thickness	0.035 mm

The first step in microstrip array antenna design is to create a basic array element that can radiate at 2500 MHz. In this design, the physical dimensions of the microstrip patch antenna are calculated using the design formulas given above.

This design forms the basis of the array antenna. In order to form an array, a half wavelength distance is left between two patches with the same physical properties. Thus, a 2x1 array antenna is formed. Two 2x1 array antennas are combined to form a 1x4 microstrip array antenna. Again, the distance between the patches is half a wavelength. The simulated 1x4 array antenna is given in Figure 11 (Dundar O, 2018).

Figure 11

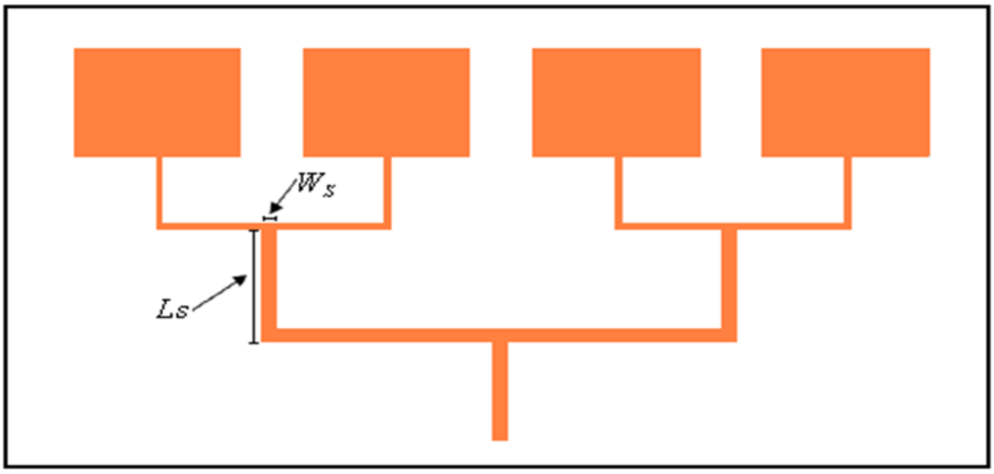
1x4 Array Antenna Designed at 2500 MHz Frequency in HFSS Simulation Program



After this stage, new array antennas were fabricated for refinement and optimization. The best optimization is achieved by ensuring impedance matching in the feed line between the patch and the feed point. For this purpose, the array antenna simulations were started by changing the dimensions of the feed line length Ls and width Ws. The 1x4 array antenna with Ls and Ws dimensions is shown in Figure 4.7. The 1x4 array antenna was designed in the HFSS simulation program by changing the Ls value between 13 mm and 16 mm at 0.5 mm intervals and the Ws value between 1 mm and 1.5 mm at 0.05 mm intervals. The feed path length Ls and feed path thickness Ws values were changed to form the basis of the antenna designed in Figure 12 (Dundar O, 2018).

Figure 12

Electrical Parameter Improvement of 1x4 Array Antenna with 2500 Mhz Resonant Frequency



In this way, 77 array antennas were designed in the HFSS simulation program and the results are given in Table 2.

Table 2

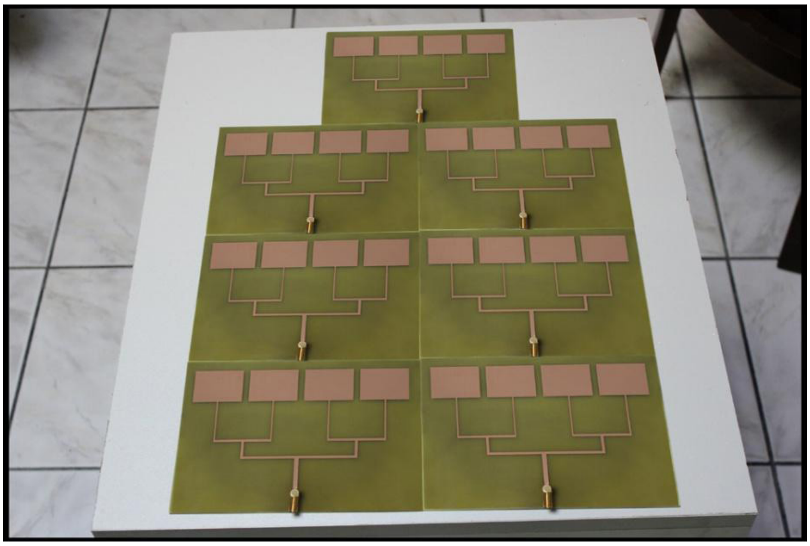
HFSS Result Outputs of 77 Array Antennas Designed (Dundar O, 2018).

Order	L_S (mm)	W_S (mm)	f_{rs} (MHz)	S_{11} (dB)	BW (MHz)	Directivite	Gain	Efficiency
1	16.0	1.50	2650	-31.74	68	7.5153	3.2344	0,7271
2	16.0	1.45	2640	-31.87	74	7.3728	3.1841	0,7341
3	16.0	1.40	2640	-32.88	72	7.4663	3.2627	0,7476
4	16.0	1.35	2640	-35.99	72	7.4630	3.2367	0,7497
5	16.0	1.30	2640	-37.40	73	7.3092	3.1873	0,7480
6	16.0	1.25	2640	-38.00	75	7.4033	3.2067	0,7524
7	16.0	1.20	2640	-30.73	73	7.2396	3.1315	0,7385
8	16.0	1.15	2630	-37.53	77	7.4609	3.2235	0,7698
9	16.0	1.10	2640	-28.15	75	7.4385	3.2654	0,7945
10	16.0	1.05	2630	-26.64	79	7.4316	3.2525	0,7951
11	16.0	1.00	2630	-25.00	75	7.4697	3.2119	0,7866
12	15.5	1.50	2650	-36.27	67	7.6181	3.2937	0,7637
13	15.5	1.45	2650	-29.09	73	7.5078	3.2443	0,7589
14	15.5	1.40	2650	-25.39	71	7.4988	3.2437	0,7492
15	15.5	1.35	2650	-32.63	73	7.2856	3.1436	0,7390
16	15.5	1.30	2650	-25.79	75	7.4862	3.2703	0,7758
17	15.5	1.25	2620	-22.91	72	6.6886	2.7548	0,7375
18	15.5	1.20	2640	-26.83	75	7.4380	3.2086	0,7582
19	15.5	1.15	2640	-26.83	78	7.4514	3.2540	0,7922
20	15.5	1.10	2520	-33.00	62	7.5152	3.3923	0,7966
21	15.5	1.05	2540	-38.92	63	7.6296	3.4057	0,8045
22	15.5	1.00	2540	-49.28	62	7.7745	3.4221	0,8129
23	15.0	1.50	2660	-32.37	72	7.6498	3.3426	0,7864
24	15.0	1.45	2660	-29.00	71	7.6539	3.3376	0,7852
25	15.0	1.40	2650	-29.00	73	7.5870	3.3082	0,7967
26	15.0	1.35	2650	-29.29	73	7.5870	3.3082	0,7967
27	15.0	1.30	2660	-7.80	0	3.6200	0.9268	0,4414

28	15.0	1.25	2650	-25.00	75	7.4741	3.2930	0,8032
29	15.0	1.20	2650	-23.22	78	7.6520	3.3704	0,8117
30	15.0	1.15	2640	-21.41	75	7.5954	3.3265	0,8095
31	15.0	1.10	2640	-23.14	78	7.5468	3.3189	0,8350
32	15.0	1.05	2630	-19.33	76	7.2822	3.1730	0,7964
33	15.0	1.00	2640	-20.00	84	7.6627	3.4056	0,8988
34	14.5	1.50	2665	-21.13	80	7.4787	3.2557	0,7874
35	14.5	1.45	2660	-22.20	73	7.5482	3.2723	0,7909
36	14.5	1.40	2660	-23.38	74	7.7271	3.4170	0,8506
37	14.5	1.35	2660	-23.62	72	7.7271	3.4170	0,8506
38	14.5	1.30	2640	-18.70	75	7.4014	3.2330	0,7972
39	14.5	1.25	2640	-18.89	73	7.4014	3.2330	0,7972
40	14.5	1.20	2650	-20.47	75	7.5349	3.3116	0,8362
41	14.5	1.15	2640	-20.00	77	7.4690	3.2604	0,8199
42	14.5	1.10	2640	-18.39	77	7.4248	3.3014	0,8699
43	14.5	1.05	2650	-18.64	78	7.6282	3.3860	0,8802
44	14.5	1.00	2650	-18.76	79	7.6282	3.3860	0,8802
45	14.0	1.50	2660	-21.09	71	7.2584	3.1177	0,8526
46	14.0	1.45	2610	-32.24	67	5.9829	2.3855	0,8863
47	14.0	1.40	2660	-25.94	71	7.5764	3.3668	0,9050
48	14.0	1.35	2660	-20.70	75	7.5813	3.3094	0,8309
49	14.0	1.30	2660	-18.39	76	7.5015	3.2870	0,8499
50	14.0	1.25	2660	-18.33	76	7.5015	3.2870	0,8499
51	14.0	1.20	2660	-15.12	78	7.6573	3.3986	0,9224
52	14.0	1.15	2650	-17.25	76	7.5107	3.3138	0,8665
53	14.0	1.10	2650	-17.82	80	7.5764	3.3668	0,9050
54	14.0	1.05	2650	-16.56	79	7.6219	3.3970	0,9061
55	14.0	1.00	2650	-16.81	79	7.6219	3.3970	0,9061
56	13.5	1.50	2580	-21.00	52	6.0839	2.3205	0,7784
57	13.5	1.45	2670	-18.45	74	7.4940	3.2724	0,8196
58	13.5	1.40	2670	-18.33	73	7.5766	3.3097	0,8479
59	13.5	1.35	2670	-18.26	74	7.5766	3.3097	0,8479
60	13.5	1.30	2660	-18.20	75	7.7134	3.4283	0,8947
61	13.5	1.25	2660	-18.26	75	7.7134	3.4283	0,8947
62	13.5	1.20	2660	-14.74	73	7.4830	3.3280	0,8945
63	13.5	1.15	2650	-16.31	78	7.5178	3.3165	0,8878
64	13.5	1.10	2660	-15.93	78	7.6350	3.4326	0,9441
65	13.5	1.05	2650	-15.93	79	7.6763	3.4368	0,9557
66	13.5	1.00	2650	-15.87	81	7.6763	3.4368	0,9557
67	13.0	1.50	2660	-17.56	73	7.6337	3.3814	0,8635
68	13.0	1.45	2670	-17.44	73	7.6671	3.3817	0,8859
69	13.0	1.40	2670	-17.38	74	7.6123	3.3755	0,9091
70	13.0	1.35	2670	-16.69	74	7.6123	3.3755	0,9091
71	13.0	1.30	2670	-15.26	74	7.6566	3.4170	0,9284
72	13.0	1.25	2670	-15.32	73	7.6566	3.4170	0,9284
73	13.0	1.20	2660	-12.57	65	7.3898	3.2466	0,9085
74	13.0	1.15	2660	-14.95	73	7.5886	3.3882	0,9228
75	13.0	1.10	2530	-16.76	54	7.9852	3.4213	0,9622
76	13.0	1.05	2660	-14.38	75	7.6643	3.4162	0,9576
77	13.0	1.00	2660	-14.45	76	7.6643	3.4162	0,9576

When these designs are examined, it is seen that each data is different. Within these data, the array designs with the best data results for each Ls were taken and the manufacturing process was started. The array antennas with the lowest return response numbers 6, 22, 23, 37, 46, 56 and 67 in the Table were selected for manufacturing. For 7 different Ls values, the array antennas with the best result data were fabricated. The fabricated array antenna with row number 6, which performed well, is shown in Figure 4.8. The other array antennas are collectively given in Figure 13 (Dundar O, 2018).

Figure 13
Manufacturing of 7 1x4 Microstrip Array Antennas



Measurements of the array antennas were performed with VNA. The values obtained as a result of the measurements are given in Table 3.

Table 3
Simulation and Measurement Results of Fabricated Array Antennas

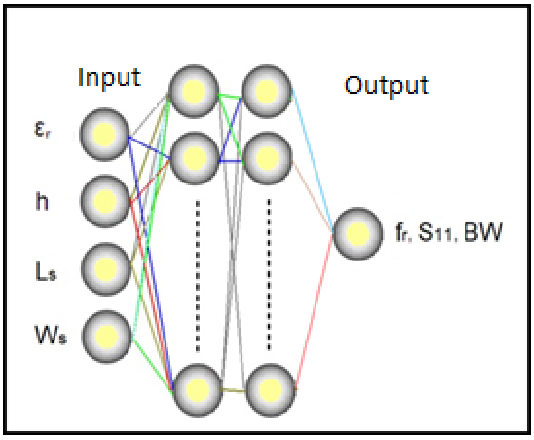
Order	Sequence Number in Table 2	L_S (mm)	W_S (mm)	Simulation Results			Measurement Results		
				S_{11} (dB)	f_r (MHz)	BW (MHz)	S_{11} (dB)	f_r (MHz)	BW (MHz)
1	6	16,0	1,25	-38.00	2640	75	-15,2	2580	85
2	22	15,5	1.00	-49,28	2540	62	-14.0	2612	77
3	23	15.0	1,50	-32,37	2660	72	-15.0	2609	85
4	37	14,5	1,35	-23,62	2660	72	-25.0	2594	86
5	46	14,0	1,45	-32,24	2610	67	-22.0	2610	92
6	56	13,5	1,50	-21.00	2580	52	-26.0	2599	82
7	67	13,0	1,50	-17,56	2660	73	-22,5	2600	178

Calculation of Return Response, Frequency and Bandwidth of 1x4 Rectangular Section Microstrip Patch Antenna at 2500 MHz Frequency Using ANN

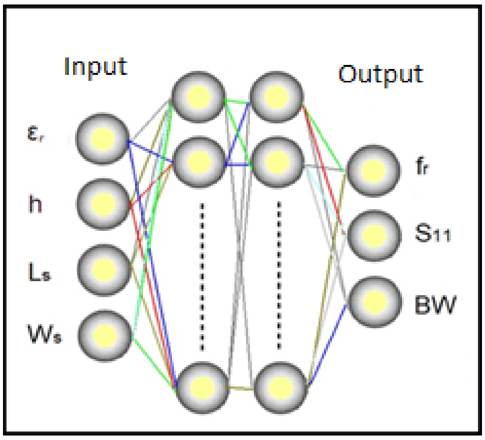
In this section, the return response, frequency and bandwidth of a 1x4 rectangular microstrip patch antenna at 2500 MHz are calculated by ANN. The simulation results of 77 array antennas given in Table 4.3 are used to train the ANN structure and 7 measurement results given in Table 4.4 are used to test the ANN structure. The calculations were performed using the "Multilayer Perseptron" (MLP)-ANN network structure. In addition, two network structures were used separately. The first is a single output network structure (Figure 14a) and the second is a two-layer three output network structure (Figure 14b). Four input parameters were used in both structures. The input parameters are dielectric constant (εr), dielectric base thickness (h), feed line length (LS) and feed width (WS). The output parameters are resonance frequency (frs), return response (S11) and bandwidth (BW). Levenberg-Marquardt was used as the training algorithm in both ANN network structures (Dundar O, 2018).

Figure 14

2500 Mhz MLP-ANN Network Structures a) Single Output Network Structure, b) Three Output Network Structure



a)



b)

Table 4 shows the input output test set and ANN test results for the single output network structure for the calculation of the resonant frequency (fr). The differences obtained from the results are indicated. Table 5 shows the input output test set and ANN test results of the single output network structure for the calculation of the return response (S_{11}). The differences obtained from the results are indicated. Table 6 shows the input output test set and ANN test results for the single output network structure for bandwidth (BW) calculation. The differences obtained from the results are indicated. Table 7 shows the input output test set and ANN test results of the three output network structure for the calculation of resonant frequency (fr), return response (S_{11}) and bandwidth (BW). The differences obtained from the results are indicated. Table 8 shows the number of inputs, outputs, iterations and intermediate layers for the single output and three output network MLP-ANN structure (Dundar O, 2018).

Table 4

Input Output Test Set and ANN Test Results of Single Output Network Structure for Calculation of Resonant Frequency (fr)

Inputs				Out f_r (GHz)	ANN f_r (GHz)	Difference Absolute Error (GHz)
ε_r	h (mm)	Ls (mm)	Ws (mm)			
4.900	1.600	16.000	1.250	2.6400	2.6399	0.0001
4.900	1.600	15.500	1.000	2.5400	2.5400	0.0000
4.900	1.600	15.000	1.500	2.6600	2.6611	0.0011
4.900	1.600	14.500	1.350	2.6600	2.6588	0.0012
4.900	1.600	14.000	1.450	2.6100	2.6100	0.0000
4.900	1.600	13.500	1.500	2.5800	2.5800	0.0000
4.900	1.600	13.000	1.500	2.6600	2.6600	0.0000
Total Test Absolute Error Average						**0.000343**

Table 5

Input Output Test Set and ANN Test Results of Single Output Network Structure for Calculation of Return Response (S_{11})

Inputs				Out S_{11} (dB)	ANN S_{11} (dB)	Difference Absolute Error (dB)
ε_r	h (mm)	Ls (mm)	Ws (mm)			
4.900	1.600	16.000	1.250	-38.0000	-38.0000	0.0000
4.900	1.600	15.500	1.000	-49.2800	-49.2800	0.0000
4.900	1.600	15.000	1.500	-32.3700	-32.3716	0.0016
4.900	1.600	14.500	1.350	-23.6200	-23.6187	0.0013
4.900	1.600	14.000	1.450	-32.2400	-32.2396	0.0004
4.900	1.600	13.500	1.500	-21.0000	-21.0002	0.0002
4.900	1.600	13.000	1.500	-17.5600	-17.5663	0.0063
Total Test Absolute Error Average						**0.00140**

Table 6

Input Output Test Set and ANN Test Results for Single Output Network Structure for Bandwidth (BW) Calculation

Inputs				Out BW (MHz)	ANN BW (MHz)	Difference Absolute Error (MHz)
ε_r	h (mm)	Ls (mm)	Ws (mm)			
4.900	1.600	16.000	1.250	75.00	75.00	0.00
4.900	1.600	15.500	1.000	62.00	62.00	0.00
4.900	1.600	15.000	1.500	72.00	72.00	0.00
4.900	1.600	14.500	1.350	72.00	72.10	0.10
4.900	1.600	14.000	1.450	67.00	67.00	0.00
4.900	1.600	13.500	1.500	52.00	52.00	0.00
4.900	1.600	13.000	1.500	73.00	73.00	0.00
Total Test Absolute Error Average						**0.01428**

Table 7

Input Output Test Set and ANN Test Results of Three Output Network Structure for Calculation of Resonance Frequency (fr), Return Response (S_{11}) and Bandwidth (BW)

Inputs				Outputs			ANN Outputs			Difference Absolute Error		
ε_r	h (mm)	Ls (mm)	Ws (mm)	f_r (GHz)	S_{11} (dB)	BW (MHz)	f_r (GHz)	S_{11} (dB)	BW (MHz)	f_r (GHz)	S_{11} (dB)	BW (MHz)
4.900	1.600	16.000	1.250	2.6400	-38.0000	75.0000	2.6350	-38.0000	71.6000	0.0050	0.0000	3.4000
4.900	1.600	15.500	1.000	2.5400	-49.2800	62.0000	2.5390	-49.2800	61.5000	0.0010	0.0000	0.5000
4.900	1.600	15.000	1.500	2.6600	-32.3700	72.0000	2.6614	-32.3700	74.0000	0.0014	0.0000	2.0000
4.900	1.600	14.500	1.350	2.6600	-23.6200	72.0000	2.6535	-23.6200	71.7000	0.0065	0.0000	0.3000
4.900	1.600	14.000	1.450	2.6100	-32.2400	67.0000	2.6382	-32.2401	69.8000	0.0282	0.0001	2.8000
4.900	1.600	13.500	1.500	2.5800	-21.0000	52.0000	2.5787	-21.0000	59.0000	0.0013	0.0000	7.0000

4.900	1.600	13.000	1.500	2.6600	-17.5600	73.0000	2.6601	-17.5600	73.0000	0.0001	0.0000	0.0000
Total Test Absolute Error Average										**0.00621**	**0.000014**	**2.2857**

Table 8

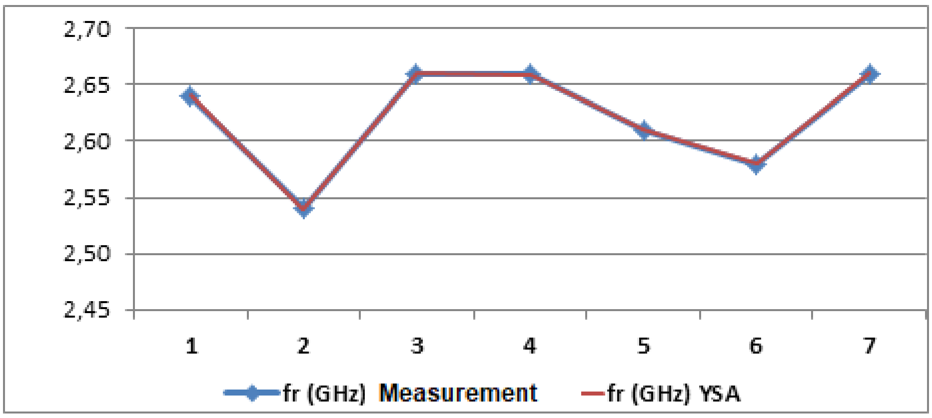
Three Output ANN Network Structure of frs, S11 and BW Output Parameters for 2500 Mhz Operating Frequency

ANN Network Structure	Inputs	Outputs	Interlayer Neuron Numbers		Number of Training Iterations
Single output structure	ε_r, h, L_S, W_S, $f_{rç}$	f_{rs}	8	6	3000
	ε_r, h, L_S, W_S, $f_{rç}$	S_{11}	8	7	2000
	ε_r, h, L_S, W_S, $f_{rç}$	BW	8	8	400
Three output structure	ε_r, h, L_S, W_S, $f_{rç}$	f_{rs}, S_{11}, BW	10	9	2000

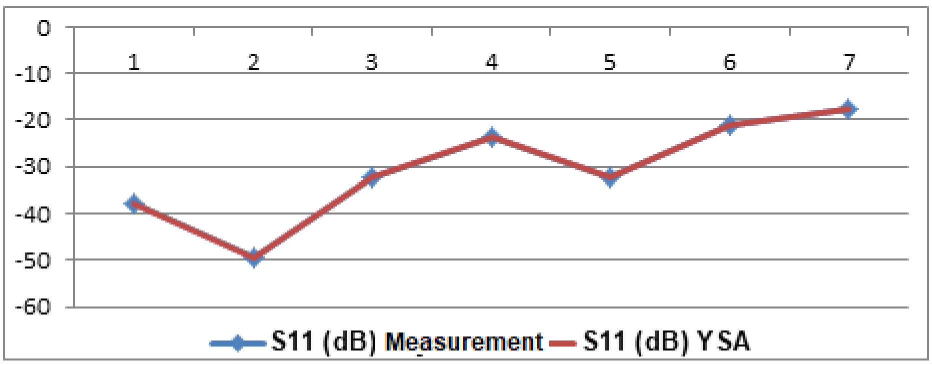
Figure 15 (a, b, c) shows 7 measurements and ANN test curves obtained from a single output network structure and Figure 16 (a, b, c) shows a three output network structure (Dundar O, 2018).

Figure 15

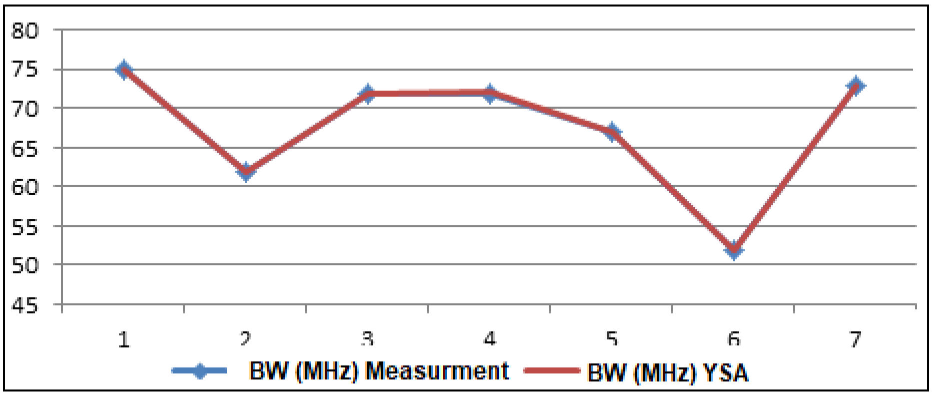
Measurement and ANN Test Curves Obtained with Single Output CCP-ANN Network Structure, a) fr, b) S_{11}, c) BW



a)



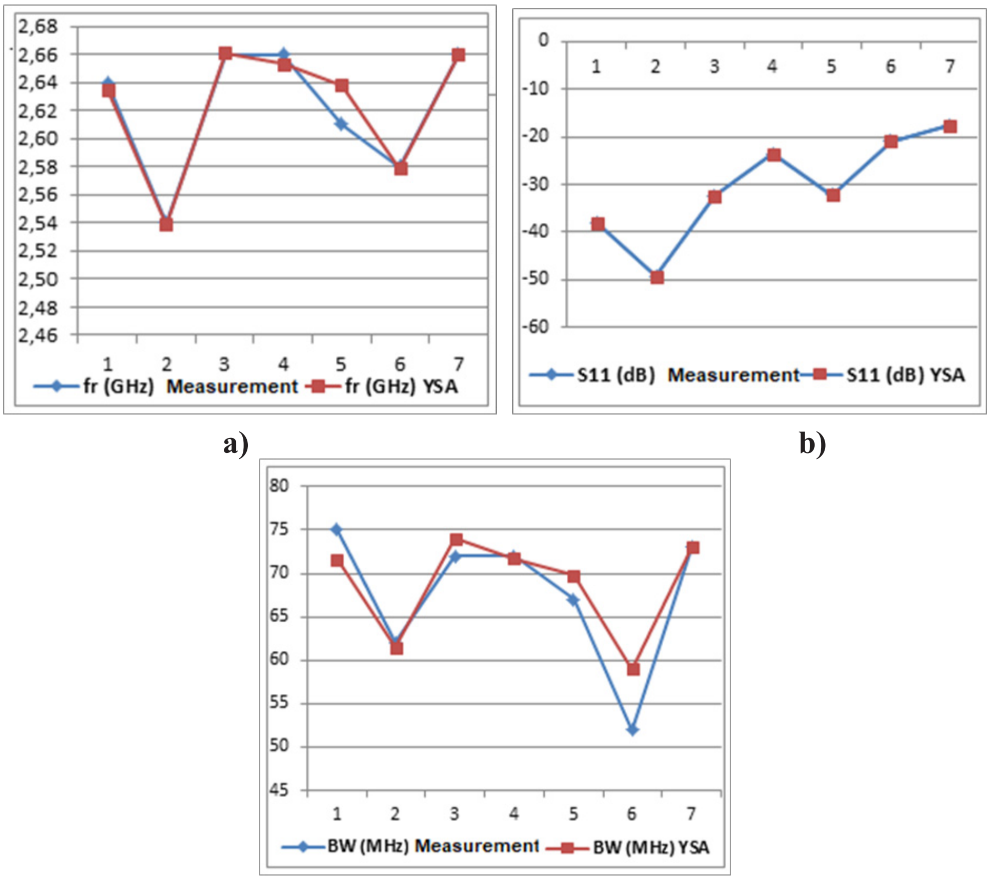
b)



c)

Figure 16

Measurement and ANN Test Curves Obtained with Three Output MLP-ANN Network Structure, a) fr, b) S_{11}, c) BW



a) b)

c)

Conclusion

As can be seen from the tables and graphs, the return response, frequency and bandwidth of the 1x4 rectangular section microstrip patch antenna at 2500 MHz frequency trained with the Levenberg-Marquardt training algorithm in single output and three output MLP-ANN network structure were calculated and very good results were obtained. The results show that ANN can calculate these parameters.

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