APPLICATION OF ARTIFICIAL NEURAL NETWORKS IN DESIGNING MICROSTRIP ANTENNA AND FILTER

Presented By:-
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Microstrip Antenna & FSS

- The field communication is marching ahead with tremendous speed. Presently we are in the arena of mobile and satellite communication. The role of Microstrip Antenna in mobile communication and that of Frequency Selective Surface (FSS) in satellite communication has ushered in a new era. The developments include (i) Size reduction (ii) Enhancement of bandwidth (iii) Multi-Frequency operation (iv) Gain Enhancement.

- Similarly the study on Frequency Selective Surface has been started mainly in 1990. In this field we are still trying heart and soul for further development of the FSS. The developments include (i) To increase separation between transmission and reflection bands (ii) Size reduction (iii) Bandwidth enhancement and (iv) Multi-Frequency operation.
What is Artificial Neural Network?

- An artificial neural network is a system, based on the operation of biological neural networks, in other words, is an emulation of biological neural system.
Why do we require Artificial Neural Network?

• Normal Computation is performed using sets of fixed rules. So the requirement here is a set of fixed rules.

• In cases where fixed rules are not available the computation has to be performed by developing the rules just like a biological brain does for a totally new object. This is where Artificial Neural Network comes in.
Biological inspiration

• Animals are able to react adaptively to changes in their external and internal environment, and they use their nervous system to perform these behaviours.

• An appropriate model/simulation of the nervous system should be able to produce similar responses and behaviours in artificial systems.

• The nervous system is built by simple units, the neurons, so copying their behavior and functionality should be the solution.
Biological inspiration

Dendrites

Soma (cell body)

Axon
Biological inspiration

The information transmission happens at the synapses.
Biological inspiration

• The spikes travelling along the axon of the pre-synaptic neuron trigger the release of neurotransmitter substances at the synapse.

• The neurotransmitters cause excitation or inhibition in the dendrite of the post-synaptic neuron.

• The integration of the excitatory and inhibitory signals may produce spikes in the post-synaptic neuron.

• The contribution of the signals depends on the strength of the synaptic connection.
• Three Layer Neural Network with Two Inputs and One Output
• First unit adds products of weights coefficients and input signals
• Second unit realise nonlinear function, called neuron activation function
\[ y_1 = f_1(w_{(x1)}x_1 + w_{(x2)}x_2) \]
\[ y_2 = f_2(w_{(x1)2}x_1 + w_{(x2)2}x_2) \]
\[ y_3 = f_3(w_{(x1)3}x_1 + w_{(x2)3}x_2) \]
- Propagation of signals through the hidden layer
• Propagation of signals through the hidden layer
• Propagation of signals through the output layer.

\[ y = f_6(w_{46}y_4 + w_{56}y_5) \]
The output signal of the network $y$ is compared with the desired output value (the target).

The difference is called error signal $\delta$ of output layer neuron.
The idea is to propagate $\delta$ (computed in single teaching step) back to all neurons
\[ \delta_5 = w_{56} \delta \]
- The weights' coefficients $w_{mn}$ used to propagate errors back are equal to this used during computing output value. Only the direction of data flow is changed.
\[ \delta_2 = w_{24} \delta_4 + w_{25} \delta_5 \]
\[ \delta_3 = w_{34} \delta_4 + w_{35} \delta_5 \]
When the error signal for each neuron is computed, the weights coefficients of each neuron input node may be modified. In formulas below, $\frac{df(e)}{de}$ represents derivative of neuron activation function (which weights are modified).
• Coefficient $\eta$ affects network teaching speed

\[ w'_{(x1)2} = w_{(x1)2} + \eta \delta_{2} \frac{df_{2}(e)}{de} x_{1} \]

\[ w'_{(x2)2} = w_{(x2)2} + \eta \delta_{2} \frac{df_{2}(e)}{de} x_{2} \]
\[ w'_{(x1)_3} = w_{(x1)_3} + \eta \delta_3 \frac{df_3(e)}{de} x_1 \]

\[ w'_{(x2)_3} = w_{(x2)_3} + \eta \delta_3 \frac{df_3(e)}{de} x_2 \]
\[ w'_{14} = w_{14} + \eta \delta_4 \frac{df_4(e)}{de} y_1 \]

\[ w'_{24} = w_{24} + \eta \delta_4 \frac{df_4(e)}{de} y_2 \]

\[ w'_{34} = w_{34} + \eta \delta_4 \frac{df_4(e)}{de} y_3 \]
\[ w'_{15} = w_{15} + \eta \delta_5 \frac{df_5(e)}{de} y_1 \]
\[ w'_{25} = w_{25} + \eta \delta_5 \frac{df_5(e)}{de} y_2 \]
\[ w'_{35} = w_{35} + \eta \delta_5 \frac{df_5(e)}{de} y_3 \]
\[ w'_{46} = w_{46} + \eta \delta \frac{df_6(e)}{de} y_4 \]

\[ w'_{56} = w_{56} + \eta \delta \frac{df_6(e)}{de} y_5 \]
Microstrip patch antennas are relatively new kind of antennas, started to grow at 70’s and active in application areas. Its revolutionary idea is to build an antenna on PCB.
**Advantages**
1. Low profile, low cost, lightweight
2. Easy to build, small in size
3. Conformable to planar and non-planar surfaces
4. Easy to integrate with other component
5. Easy to make circularly polarized wave
6. Easy to make dual polarized multi-band antennas
7. Relatively high directivity (5-9 dB)
8. Easy construction of antenna arrays

**Disadvantages**
1. Low bandwidth
2. Low polarization purity
3. Spurious radiation caused by feeder’s discontinuity
4. Unwanted surface waves
5. Low power (~100 mW max)
Applications

- Satellite and mobile communication
- Doppler and other radars
- Radio altimeter
- Command and control Systems
- Satellite telemetry
- Weapon fusing
- Remote sensing
- Satellite navigation, GPS
- Biomedical radiators
Patch Structures
Patch Structures

Antenna 5

- Patch: W=20mm, L=15mm
- Feeding Point: 10mm, 5mm
- Ground Plane

Antenna 6

- Patch: W=20mm, L=15mm
- Feeding Point: 18mm, 12.35mm, 3.5mm
- Ground Plane

Antenna 7

- Patch: W=20mm, L=15mm
- Feeding Point: 4mm, 1mm, 6mm, 4.5mm, 7mm
- Ground Plane

Patch Structures with dielectric constant ε=2.4
## Results

### Simulated

<table>
<thead>
<tr>
<th>Antenna structure</th>
<th>Resonant Frequency (GHz)</th>
<th>Return loss (dB)</th>
<th>-10dB % BW (MHz)</th>
<th>Frequency ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna5</td>
<td>5.586</td>
<td>13.11</td>
<td>140</td>
<td>2.39</td>
</tr>
<tr>
<td>Antenna6</td>
<td>(a) 4.570</td>
<td>33.94</td>
<td>098</td>
<td>2.14</td>
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<tr>
<td></td>
<td>(b) 8.606</td>
<td>26.56</td>
<td>320</td>
<td>3.72</td>
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<tr>
<td>Antenna7</td>
<td>(a) 4.595</td>
<td>17.23</td>
<td>108</td>
<td>2.35</td>
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<td></td>
<td>(b) 5.550</td>
<td>20.39</td>
<td>200</td>
<td>3.60</td>
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<tr>
<td></td>
<td>(c) 7.363</td>
<td>21.79</td>
<td>105</td>
<td>1.42</td>
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<td></td>
<td>(d) 9.111</td>
<td>15.74</td>
<td>360</td>
<td>3.95</td>
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</table>
## Results

### Experimental

<table>
<thead>
<tr>
<th>Antenna structure</th>
<th>Resonant Frequency (GHz)</th>
<th>Return loss (dB)</th>
<th>-10dB % BW (MHz)</th>
<th>Frequency ratio</th>
</tr>
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<td>070</td>
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<td></td>
<td>(b) 8.39</td>
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<td>Antenna7</td>
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<td>090</td>
<td>1.98</td>
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<td></td>
<td>(b) 5.46</td>
<td>23.7</td>
<td>160</td>
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<td>(c) 7.11</td>
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<td>(d) 8.82</td>
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<td>1.94</td>
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Problem in Designing Microstrip Antenna

- No fixed rule exists for designing microstrip antenna (within a definite size) for given antenna parameters.
- Normal computation procedure cannot be used.
- Artificial Neural Network can be used for solving such type of problem.
\[ f(x) = \frac{1}{1 + \exp(-x)} \]
Frequency Selective surfaces

- In communication engineering filter is one of the fundamental and useful circuits. These are however used in wired circuits. In microwave communication the wireless counterpart of a filter is a frequency selective surface (FSS).

- An FSS is a two dimensional periodic array of patches on a dielectric slab or or that of apertures within a metallic screen.
• The FSS may have band-pass or band-stop spectral behaviour depending upon the array element type (i.e. patch or aperture). Transmitted electric field (T) vs. frequency plots for aperture type and patch type elements are shown in the Figures. It is observed that the maximum transmission occurs at resonating frequency in case of aperture type element. Below and above the resonating frequency transmission gradually decreases and finally becomes zero. Reverse situation arises for patch type frequency selective surfaces. Here transmission is minimum at resonating frequency i.e. reflection is maximum.
An array of printed dipoles were fabricated on one side of a dielectric slab and the copper coating on the other side of the slab was completely removed. Its dielectric constant was 2.4. The FSS was designed in such a way that it may resonate at the frequency of 10 GHz without considering the dielectric loading effect. At this frequency the corresponding free space wavelength is 30 mm.
The experimental results show that the total transmission through the FSS occurs in the frequency ranges of 6 GHz to 7 GHz and 9.5 GHz to 10 GHz and almost total reflection from the FSS occurs at the frequency of 8.1 GHz. Theoretically, the FSS was designed to resonate at the frequency of 7.7 GHz considering the loading effect.
An array of aperture dipoles were fabricated within the copper screen on one side of a dielectric slab and the copper coating on the other side of the slab was completely removed. Dimensions of the dielectric slab were 140 mm, 140 mm, 3.16 mm. Its dielectric constant is 2.4. The FSS was designed in such a way that it may resonate at the frequency of 10 GHz without considering the dielectric loading effect. At this frequency the corresponding free space wavelength is 30 mm.
The experimental results for the slotted dipoles show that almost total transmission through the FSS occurs at the frequency of 7.85 GHz. Theoretically the FSS was designed to resonate at the frequency of 7.7 GHz. That is, almost total transmission should occur at the frequency of 7.7 GHz which is quite close to the experimental data.
Each square patch in the FSS structure of size 7.5 mm. X 7.5 mm. From this square patch, 2 no.s of slots have been cut out.
In a row 14 no. of these square patches are placed in such a fashion so that every alternative patch is at 90° rotation to its adjacent patch. To make the two dimensional array 14 such rows are repeated in such a way that every alternative patch in a column is at 90° rotation to its adjacent patch. The distance between the centers of any two adjacent patches is 8.5 mm.
Theoretical analysis shows that the FSS structure acts like a Band-reject Filter, with resonant frequency of 7.8 GHz. An important observation may be noted here. If we want to design a FSS structure with square patches to resonate at 7.8 GHz, the perimeter of the square patch should be 38.46 mm. i.e. each side of the patch will be 9.62 mm (approx). So area of the patch will be 92.5 mm². But in our proposed structure the area of each square patch is $(7.5)^2$ mm². So the Size reduction of the square patch is $[(9.62)^2 - (7.5)^2]/(9.62)^2] \times 100\% = 39\% (approx)$. Considering 10 dB Bandwidth the reflection bandwidth is more than 2 GHz.
• Designed in such a way that it may resonate at the frequency of 10 GHz. At this frequency the corresponding free space wavelength is 30mm and hence the circumference of the circular patch was also made equal to 30mm. To maintain similar relationship with the wavelength of 30mm, the outer circumferences of the concentric rings were made equal to 60mm, 90mm, 120mm, 150mm and 180mm respectively. The width of each microstrip ring was 2.37mm.
Problem in Designing Frequency Selective Surfaces

- No fixed rule exists for designing FSS (within a definite size) for given filter parameters.
- Normal computation procedure cannot be used.
- Artificial Neural Network can be used for solving such type of problem.
Output Layer with Three Units. The Bias of Each Unit is one

Third Hidden Layer (counted from input side) with Seven Units. The Bias of Each Unit is one

Second Hidden Layer (counted from input side) with Nineteen Units. The Bias of Each Unit is one

First Hidden Layer (counted from input side) with Nine Units. The Bias of Each Unit is one

Input Layer

a/5.5  b/5.5  c/3.0  d/3.0
Input Layer

First Hidden Layer (counted from input side) with Nine Units. The Bias of Each Unit is one

Second Hidden Layer (counted from input side) with Nineteen Units. The Bias of Each Unit is one

Third Hidden Layer (counted from input side) with Seven Units. The Bias of Each Unit is one

Output Layer with Three Units. The Bias of Each Unit is one

a/5.5  b/5.5  c/3.0  d/3.0

D/50  F/15  B/4
Conclusion

- We have achieved
- Size reduction up to 97%
- Gain +11dBi
- Bandwidth up to 400%
- Multifrequency up to six frequency band
- Till date no definite rule is developed regarding reduction of resonant frequency, multi-frequency operation, enhancement of bandwidth and gain.
• Researches have worked a lot on microstrip antenna and microstrip filter regarding reduction of resonant frequency and multi-frequency operation by cutting different types of slots on the patches.

• Value of dielectric constant, its thickness also have an influence on these parameters.

• But till date no definite rule is developed regarding this.
• Our Research team is working hard and they are almost developing this rule with the help of Artificial Neural Network

• For this a lot of data have been generated. These include the values of resonant frequencies for different permutation and combination of dimensions of slots on patches, thickness of the substrate and the value of dielectric constant

• These results are fed to train the ANN
• Once the network is trained, we can use this network for designing microstrip antenna or filter.

• Suppose resonant frequency and its required dimension is given. It is found that it is not possible to design patch antenna to resonant at this frequency with this dimension. Then we have to choose slots to cut or to choose specific thickness and dielectric constant of the substrate.

• This choice is easily possible from the given network.