EE 556

ANTENNA AND PROPAGATION SYSTEMS

TERM PROJECT

ULTRA-WIDEBAND ANTENNA DESIGN AND SIMULATION

INSTRUCTOR

PROF. İBRAHİM TÇKİN

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Introduction

In the antenna and propagation systems course; we, Özlem Kalkan and Sertaç Yılmaz, decided to design and implement an ultra-wideband antenna. We preferred because ultra-wideband system is a new, important and hot topic in the present industry. Also due to the requirements of the ultra-wideband systems that are explained in the next chapter, the antenna needs wide radiation bandwidth. Therefore the ultra-wideband antenna can be used for other applications and tasks like triple-band or dual-band antennas.

At the beginning we decided to design and implement an ultra-wideband antenna at resonance frequency 4 GHz and Bandwidth is 3-6 GHz so that we researched the different types of wideband or broadband antennas by the Internet and the books and we tried to find the most suitable design for our task. Next we modified the antennas for our design requirements. In the modification two designs gave us meaningful solutions; one of them is doubled substrate microstrip patch antenna and the other one is the notch antenna. In the report we explained both of them separately.

The Doubled Substrate Microstrip Patch Antenna

It consists of two substrates, one microstrip patch conductor and a conductor ground. First we designed a basic single-layered microstrip patch antenna with resonance frequency at 10 GHz. Then we added additional substrate with same properties to the top of our patch. Covering the patch with a substrate instead of air increases the effective dielectric constant $\epsilon_{eff}$ so that the resonance frequency value and bandwidth will be increase. To prove our hypothesis, we designed a single-layered microstrip patch antenna at $f_r=10$ GHz on the Duroid substrate with $H=1.59$ mm and $\epsilon_r=2.2$ and then we put another Duroid substrate on the patch. We simulated the design in the HpAds since the implementation of the microstrip patch antenna is simpler than the other simulation software. After the s-parameter simulation, we got the expected results as given in the below. The resonance frequency equaled to 18 Ghz and the radiation bandwidth was from 15.2 GHz to 21 GHz. Also from the Smith Chart the same result can be understood.

![Figure 1](image.png)

Figure 1. Patch view of the doubled substrate microstrip patch antenna at $f_r=18$GHz
Figure 2. S(1,1) magnitude and smith chart graphs of the doubled substrate microstrip patch antenna at fr= 18 GHz

Next we tried to modify our design by changing the size of the patch in order to make it suitable for our project requirement. We designed a single-layered patch antenna at fr=2.5 GHz with FR4 substrate and covered it with another FR4 substrate, then we simulated the s-parameters. However the double substrate microstrip patch antenna hypothesis does not work for low frequencies.

Figure 3. Patch view of doubled substrate microstrip patch antenna at fr=
Figure 4. S(1,1) magnitude and smith chart graphs of the doubled substrate microstrip patch antenna

Ultra-Wideband Antenna Properties

The normal definitions and equations for antenna parameters, such as gain and beamwidth, implicitly refer to parameters at a specific frequency and explicitly contain the wavelength. When dealing with antennas of conventional “wide bandwidth”, a range of gain and beamwidth is usually specified, but the operation is usually bandwidth restricted in a narrow range of frequencies within this wide bandwidth.

UWB radar operates simultaneously over a very large bandwidth and the antenna parameters must refer to simultaneous performance over the whole of bandwidth. The bandwidth is:

$$BW = 200\times(\frac{f_h - f_l}{f_h + f_l})\%$$

where $f_h$ and $f_l$ are the highest and lowest frequencies, respectively.

Figure 5. Fractional Bandwidth

The frequency range over which a UWB antenna must respond can be judged from the pulse characteristics. The pulse risetime defines the highest frequency needed; the pulse...
length defines the median frequency, \( f_m \). The approximation with the risetime and pulse length in picoseconds, are:

\[
f_h = 500 \\
f_h = 500/\text{Risetime GHz} ; f_m = 500/\text{Pulse-length GHz}
\]

where

\[
f_m = \sqrt{f_h \times f_l} \text{ GHz}
\]

Example implementation of risetime and pulse-length can be given as; a pulse with a risetime of 100 ps ad a pulse length of 300 ps will require a frequency response in the antenna from 0.3 to 5.0 GHz with a median frequency of 1.22 GHz.

From the above equations we see that the lower frequency limit should be as low as possible, that is well below 1 GHz and preferably down to 100MHz to minimize degradation due to low frequency cutoff of any radar component. Atmospheric considerations limit the upper frequency to less than 10GHz.

The design of UWB antennas is not different in procedure from the design of antennas for other purposes. However special care must be taken when designing UWB antennas because several parameters must be treated a little differently. In particular, transmit and receiver transfer functions are different for UWB antennas. Another aspect is, UWB antennas require the phase center and the voltage standing wave ratio (VSWR) to be constant across the whole bandwidth of operation. The phase center is defined as the apparent point from which the antenna radiates as a specific frequency. A change in phase center may cause distortion on the transmitted pulse and worse performance at the receiver. The VSWR is a measure of the impedance matching between the antenna and the input/output.

To sum up the general requirements of the UWB Antenna Models one can say it requires:
- UWB response
- Non-dispersive
- Good matching
- Small size
- Low cost
- Omni-directional

**Notch Antenna Properties**

As mentioned in the previous section VSWR is an important measure for the antenna design and the notch antennas are particularly well suited for UWB transmissions because of their characteristics: large fractional bandwith, linear polarization, variable antenna gain and directionality. The notch antenna has a bandwidth of greater than 3:1. It may be fed by slotline, printed line or coaxial line, and radiates from the non-stripped face. The shape of the notch antenna is of great importance. Versions with straight edges have been used at HF on aircraft for many years and have been tuned to the required instantaneous frequency over a band of 2 to 30 MHz. The shape of the notch antenna can
be done exponential, if done so the broadband match is much improved and bandwidth of 2 to 20 GHz have been claimed. The figure of a typical notch antenna is shown in the figure 6. The transmitted pulse is radiated from the aperture just as in a horn and the notch antenna can be regarded as a two-dimensional TEM horn with the parallel plate section replaced by a slot.

![Figure 6. Typical Notch Antenna front and back view](image)

To understand the working principle of the notch antenna the recent works are examined. The velocity along the transmission line which forms the antenna is independent of frequency. The notch antenna operates in a traveling wave mode where the energy is radiated continuously along the exponentially curved slot. This radiation mechanism is typical of a surface wave and provides constant gain with frequency, since the point along the slot where the energy has all been radiated is a function of frequency. The beamwidth is therefore constant in the E and H planes.

The notch antenna is a traveling wave antenna. The radiation mechanism is based on a traveling wave propagating in the slot with a phase velocity smaller than that of light, which results in an endfire radiation. Unfortunately, all the parameters have a direct impact on the input impedance.

The notch antenna design have an obligation of notch width which should be less than 0.1 wavelength at any frequency. The input excitation is a problem just as in the TEM horn. There are several methods of manufacturing notches which have different approaches to the excitation. They are:

- **Microstrip input:** printed board can be used where the notch and feed slot are etched out of conducting copper on one side of the substrate and the other is etched off except for the microstrip line. The excitation point is made by connecting the microstrip through the board to the upper side of the slotline.
- **Slotline input:** notch can be printed as explained in the microstrip input part but fed by slotline. This time however a coaxial to slotline transition and connector are required.
- **Coaxial line input:** notch can be cut from a solid sheet of metal with a coaxial line soldered to the metal from the antenna base to the input slot where the central conductor of the coaxial line feeds across the input slot.
The main and probably only two drawbacks of the notch antenna are:
- only linear polarization can be obtained (without complex construction)
- the arraying has to be in the polarization plane, i.e. if the polarization needs to be vertical, the arraying has to be in the vertical plane, etc.

The notch antenna was proposed to be used in wireless communication systems for its extremely wide-band characteristics. This antenna is easy and relatively inexpensive to manufacture, it exhibits a very wide beamwidth in H-plane and high polarization purity. These properties make this type of printed antenna a competitive candidate to be used in wireless communication systems, especially in cases where the antenna is required to be easily interchangeable between different systems.

**The proposed antenna --- Notch AntennaSU**

The antenna design we proposed in this course was taken from the paper called “A UWB Architecture for Wireless Video Networking” by G. R. Aiello, L. Taylor, M. Ho. According to the paper the characteristics of the notch antennaSU is given in the below table:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum frequency</td>
<td>2.7GHz</td>
</tr>
<tr>
<td>Maximum frequency</td>
<td>6GHz</td>
</tr>
<tr>
<td>Polarization</td>
<td>Linear, vertical</td>
</tr>
<tr>
<td>VSWR</td>
<td>&lt; 1.5</td>
</tr>
<tr>
<td>Peak gain</td>
<td>3.75dBi</td>
</tr>
<tr>
<td>Azimuth-Beamwidth</td>
<td>360 degrees</td>
</tr>
<tr>
<td>Elevation-Beamwidth</td>
<td>60 degrees</td>
</tr>
<tr>
<td>Deepest Null</td>
<td>-10dB</td>
</tr>
<tr>
<td>Dimensions</td>
<td>40 x 80mm</td>
</tr>
<tr>
<td>Material</td>
<td>FR4</td>
</tr>
<tr>
<td>Thickness</td>
<td>1.57mm</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>4.75</td>
</tr>
</tbody>
</table>

For calculation we selected the same value for length and same equipments like FR4 substrates. In simulation phase we used HFSS v9 since HpaDs is not appropriate for design. Ads assume the ground conductor infinitely large; however we have a finite ground and slot. The antenna made of two sided-substrate; one side is feed stripline and the other side is ground slot conductor. The feed stripline has 3 mm width in order to radiated at 3 GHz and its length which exceeds the slot is not very important because it changes only the gains of radiation. The shape of the slot in the ground plane is the most important issue in the design. In the below different slot shapes are shown in the figures from the beginning up to the end.
In the simulation we feed the stripline, then the electric field on the stripline couples into the slot when it reaches \( y=0 \). The coupled E fields radiated out of the slot in the \(-y\) direction. The radiation behaviour of the notch antennas is given in the previous part. The current and electric fields flows on the substrate as shown in the figure 12 in the V/m unit.

![Figure 11. The last view of the notch antenna SU design](image)

![Figure 12. The Magnitude of Electric Fields seen from the front side. You can watch it in the .gif format from the link of](image)

http://students.sabanciuniv.edu/~sertacvilmaz/Notch_Antenna/rad_pattern/rad_pattern.gif
The magnitude of S(1,1) versus frequency graph is given of the antenna is shown in the figure 13. We expected that the radiation frequencies are from 2.7 GHz to 6 GHz; however we got radiation from 2.6 GHz to 3.5 GHz and from 5 GHz to 5.2 Gzh. We thought that there was a matching problem between stripline and slot but we could not avoid it although we tried all matching methods.

![Figure 13. S(1,1) Magnitude Graph from 2 GHz to 7 Ghz](image)

Our last simulation result is radiation pattern of the notch antennaSU. We told that the antenna radiates in the −y direction and also it radiates in the +y direction a little bit due to slot and the position of the stripline. The radiation pattern of the antenna is given in the figure 14.

![Figure 14. Radiation Pattern of the Notch AntennaSU at f=3.2 GHz](image)
Implementation Procedures

After we complete the design phase in the tool HFSS, we started the implementation using the university’s manufacturing materials & equipments. The implementation phases are done in the following order:

- The substrate dimensions are set and the material cut according to those dimensions.
- The substrate surfaces are cleaned to remove the dust and damage on it.
- The implementation is done twice since the both surfaces are used for different functions, and have different properties.
- One of the surfaces is nail polished to protect from following steps that would be done for the opposite surface. The reason is the nail polished surface implementation is different than the opposite surface.
- The non-polished surface is dyed with positiv20.
- After the above step 2 hours of waiting time was necessary to let it dry in the dark.
- Meanwhile the antenna surface design is printed on asetat

![Figure 15. Front and back views of the asetat outputs](image)

- The asetat is possed over the surface under the UV light
- This step takes about two minutes which would be necessary to print the picture on the substrate
- Then the substrate is put in the NAOH basic solution
- After the conductor part is seen over the solution surface we put it in the HCL & H₂O₄ & H₂O solution
- While the substrate is in this solution the shaking speed-up the reaction and the unpossed parts are wiped off after a while.
- At this level one of the surfaces of the antenna design is obtained.
- The nail-polish is removed via acetone.
- This time the implemented surface is covered with the nail-polished to protect it from the following steps.
- The other surface (microstrip line) is dried with positiv20.
• Again 2 hours waited for it to dry
• The correct placement (according to the opposite surface) is done by placing asetat over the substrate
• The possing done again using the UV light
• This possed substrate is again put in the solutions in the same following sequence as above.
• After obtained the results the polish is removed from other surface.

The last view of the notch antennaSU is shown in the figure 16.
Conclusion

First of all this project has given us privilege to practice the theoretical work we have learned during the class in real life application. The phases we have gone through can be summarized as the decision phase where we searched over internet and through books to come up with reasonable antenna designs, we decided on two of them to work on and the results are shown above; in the design phase we worked both on ADS and HFSS tools to develop our antenna demo, the HFFS tool is new for all of us and it took a lot of time to achieve the results which is not done before in the university; in the implementation phase we used university facilities to fabricate our antenna; in the final reporting phase we obtained many different trial results and compare tool simulation results with the implemented antenna design simulation results obtained in the network analyzer.
As a conclusion, this work has given us a large spectrum of idea about UWB antennas, notch antennas and implementation steps of an antenna.

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References


