KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DEPARTMENT OF ELECTRICAL ENGINEERING

EE 422 **Antenna Theory**

Introductory Experiment: Antenna Measurements Laboratory

Objective

The purpose of this laboratory session is to become familiar with the equipment used to measure the different radiation characteristics of antennas in the different frequency ranges. Also, you will be introduced to the new Lab-Volt antenna training and measuring system. The antenna measurement laboratory is equipped with a variety of instruments, which include:

- Microwave signal sources
- transmission line and waveguide components
- voltage standing wave and power meters
- Network analysers
- Standard gain antennas
- Microwave receiver
- The measurements performed on antennas include the following set of measurements:
- Antenna radiation pattern
- Antenna directivity, gain and efficiency
- Antenna impedance and standing wave measurements
- Polarisation

The antenna laboratory has been updated with the new antenna training system, data acquisition and measurements software. The new system includes four hardware modules:

1. The RF generator, which provides the RF signal to the transmitting antenna. The module contains two oscillator circuits, one operating near 1 GHz (915 MHz) and the other near 10 GHz (10.5 GHz). These can be operated in CW (continuous wave) mode or 1 kHz amplitude modulated mode.
2. The antenna positioner, which contains the drive motor, required to rotate the receiving antenna. It has a sliding support on which a mast holding the antenna is mounted.
3. The data acquisition interface, which links the antenna positioner with the computer. The data acquisition interface contains its own microprocessor.
4. The power supply, which supplies power to the antenna positioner and the data acquisition interface.

The measurements are performed on a variety of antennas belonging to the different known types of antennas such as wire, aperture, microstrip and antenna arrays. These antennas will be discussed and explained in the different experiments performed in the course.

The 1 GHz antenna include: dipole, folded dipole, l/4 monopole, loop, and Yagi array.

The 10 GHz antennas include: Horns, open-ended waveguide, helical, slot array, rectangular patch microstrip, and patch arrays.

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Computer assignment # 1

Objective

The purpose of this assignment is to compute the directivity of an antenna from knowledge of its radiation intensity function $U(\theta,\phi)$. Also, to plot the radiation pattern versus θ for a given value of ϕ.

Programming Environment

This assignment will be carried out on a PENTIUM microcomputer using WINDOWS 95/98 operating system and running MATLAB for windows.

In order to compute the directivity, we need to use a numerical integration similar to the procedure outlined in the textbook (chapter 2). The function supplied in MATLAB to perform such numerical integration is quad and quad8. These are numeric function integration functions. They have the form:

q = quad('fun',a,b) or q = quad8('fun',a,b)

quad and quad8 return the results of numerically integrating the function fun(x) between the limits a and b.

i.e. $$q = \int_a^b fun(x)\,dx$$

quad uses Simpson's rule while quad8 used Newton Cotes 8 panel rule.

Example:
```
a = quad8('sin',0,pi)
a =
    2.0000
```

Guidelines

- Familiarize yourself with the operation of MATLAB. Practice performing some calculations. Use the Demo and the Help commands. Try the following:

```
>> 2*3
   ans=6
>> a=2*3
   a=6
>> theta=0:.05:pi;
```

```
>> u=sin(theta);
>> plot(theta,u)                size and position the graphics window
>>grid                          To show a grid on the screen
```

- Create two m-files to represent the functions f(θ) and g(ϕ), e.g. fun1.m and fun2.m using the notepad editor.

  Suppose $U(\theta,\phi)=\sin(\theta)\sin(\phi)$
  Then fun1.m should contain:

  ```
  function y=fun1(x)
  y=sin(x).*sin(x);
  y=abs(y);
  ```

  & fun2.m should contain:

  ```
  function y=fun2(x)
  y=sin(x);
  y=abs(y);
  ```

- To compute the directivity you can use the following command:

  ```
  >> D0 = (4*pi./(quad8('fun1',0,pi).*quad8('fun2',0,pi))
  ```

- Use the above outlined procedure to solve problem (2.7). Compare the computed values to the results obtained in home work # 2.
- Draw the radiation patterns for the given functions (versus θ for a given value of ϕ) using the plot and polar commands.

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EE 422 **Antenna Theory**

Experiment # 1 Radiation Pattern of a λ/2 Dipole at 1 GHz

Objective

1. To become familiar with the radiation pattern measurement techniques.
2. To measure the radiation pattern of a λ/2 dipole antenna in the E and H planes.

Setup

Set up the antenna training and measuring system according to Figure 1. Connect the power supply, the data acquisition interface, the antenna positioner, and the computer according to Figure 2. Make sure that the propagation path is free from obstacles, which could affect the accuracy of the measured patterns.

Procedure

1. The main elements of the Antenna Training and Measuring System (ATMS), that is the data acquisition interface/power supply, the RF generator, the antenna positioner and the computer must be properly setup before beginning this experiment.
2. Place the antenna mast with horizontal clips on the transmission support and clip the Yagi antenna onto it. Orient the elements so they are horizontal as shown in Figure 3. The transmission antenna is then horizontally polarised.
3. Calculate the required length of a λ/2 dipole at 1 GHz (the exact transmission frequency is 915 MHz). Take into consideration that a resonant λ/2 dipole antenna is approximately = 0.45 λ in order to compensate for the length to diameter ratio, the end effect and the impedance mismatch resulting from the presence of the Balun circuit (balanced-to-unbalanced transformer).
4. Using the answer of your calculation choose the appropriate pair of wires to set the λ/2 dipole. Adjust the dipole length in accordance with your result, as shown in Figure 4.
5. Place the antenna mast with vertical clips on the sliding support of the antenna positioner, then clip on the λ/2 dipole. Ensure that the antenna is in line with the rotation centre of the antenna positioner. Screw the 10-dB attenuator to the RF input on top of the positioner. Connect the antenna to the attenuator using the short SMA cable.
6. Position the antennas a distance of r= 1 m. apart. Adjust them so that they are at the same height and directly facing each other.
7. Adjust the RF generator to 1 GHz oscillator mode set to 1kHz. Keep the RF power of both 1 GHz and 10 GHz set to OFF. Power up the RF generator and the power supply. Turn on the computer and start the LVDAM-ANT software.
8. Set the 1 GHz oscillator RF power switch on the RF generator to the ON position. Use the attenuator control to optimise the acquisition of your radiation pattern.

9. Start the first acquisition. When it is completed turn OFF the RF power. Store the radiation pattern as the E plane of antenna (1). Orient the pattern so that the MSP (max. signal position) is at 0^o.
10. Repeat the first pattern acquisition (both antennas horizontally polarised) when the distance between them is set to r= 1.25 m. Store the pattern in antenna 3 data box.
11. Repeat the procedure for the pattern acquisition after you rotate the transmitting antenna (the Yagi) to the vertical position. Store it as the E plane of antenna (2).
12. Change the dipole antenna to the vertical position by using the mast with the horizontal clips. Perform another acquisition and store the pattern as the H plane of antenna (1). Use the same attenuation level.
13. Measure the half-power beam-width according the following procedure.

Half-power beam-width measurement

1. Click the cursors button on the tool bar. Two cursors appear, one on each side of the 0^o angle. The values displayed on the right part of the screen will also change. These now include two power levels (in dB), the max. value of the main beam and at the bottom right of the window, the positions of the cursors and the difference between these positions (in degrees). When you select one cursor and drag it on the screen Curs1 or curs2 values will change. This is the difference in dB between the maximum of a pattern and the position where the cursor crosses the pattern.
2. Using the two cursors, you can locate the two positions where the pattern drops by 3 dB from the maximum value and then calculate the HPBW from:

$$HPBW_E = \left|\theta_{3-dB\,left} - \theta_{3-dB\,right}\right|$$

Save the antenna patterns and then print your results. Your print out should show the radiation patterns of the data boxes with the main display.

Your report should include the E and H plane patterns of the λ/2 dipole antenna and the measured half power beam-width. The answers to the following review questions will enhance your report:

1. What is the purpose of an antenna?
2. What is the isotropic source and why is it so useful?
3. What is a radiation pattern? what is the difference between transmitting and receiving patterns?
4. Describe the dipole antenna.
5. What is meant by an antenna polarisation? How is the dipole antenna polarised?

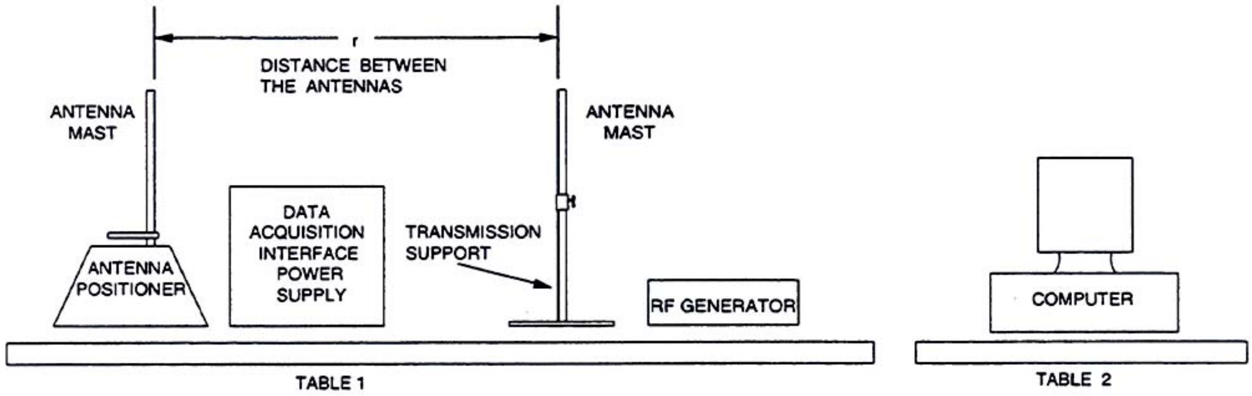

Figure 1. Set up of the ATMS modules

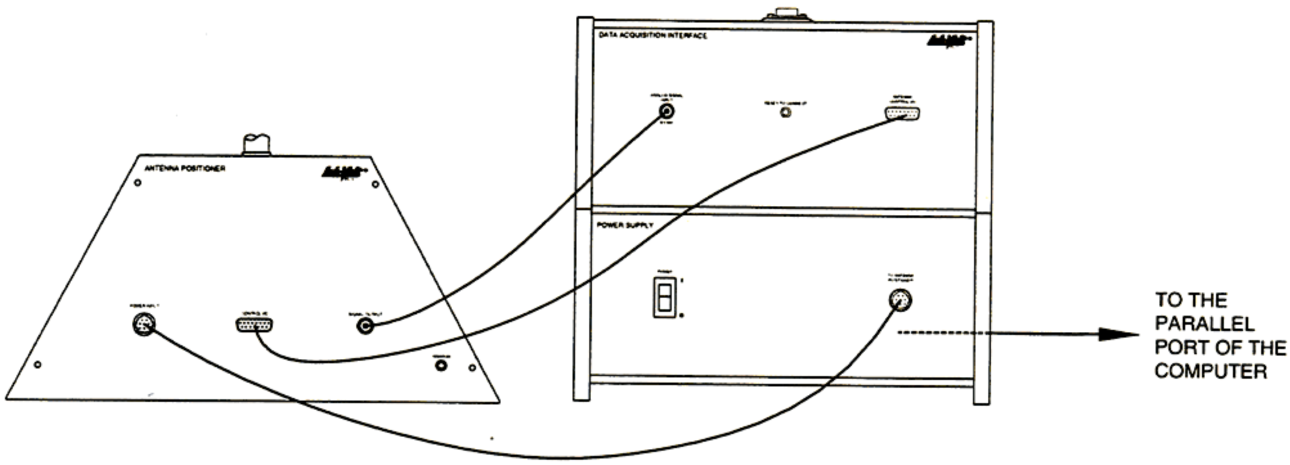

Figure 2. System Connections.

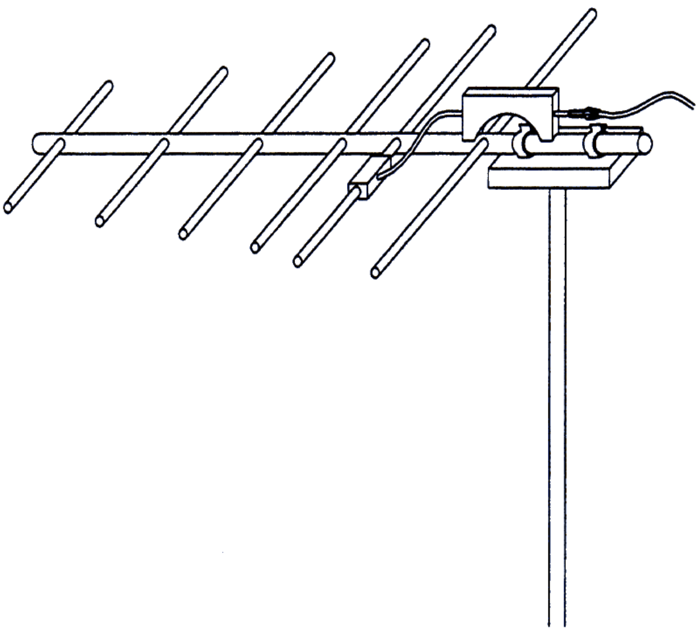

Figure 3. Set up of the horizontally polarised Yagi antenna.

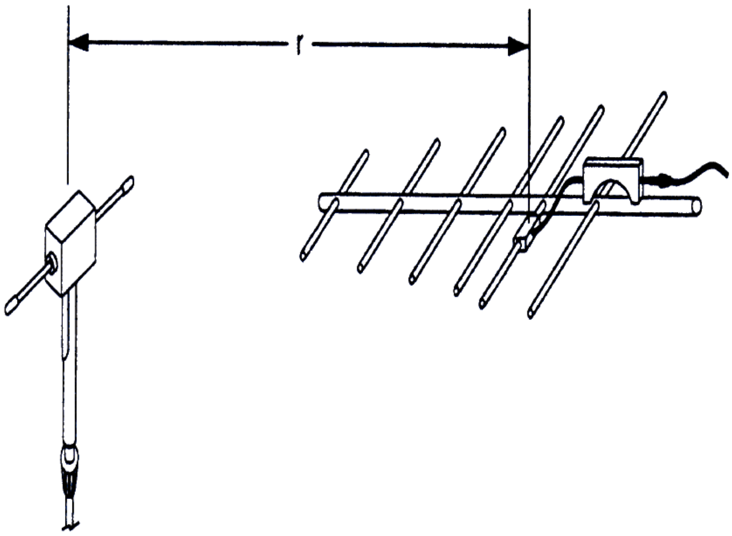

Figure 4. λ/2 dipole assembly.

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Experiment # 2 Radiation Pattern of an Open Waveguide at 10 GHz

Objective

1. To become familiar with the radiation pattern measurement techniques.
2. To measure the radiation pattern from a uniform rectangular aperture.
3. To become familiar with aperture antennas, where radiation is due to the field distribution across the aperture.

Setup

Set up the antenna training and measuring system. Connect the power supply, the data acquisition interface, the antenna positioner, and the computer. Make sure that the propagation path is free from obstacles, which could affect the accuracy of the measured patterns. This setup is the same as the setup used in the previous experiment.

Procedure

1. The main elements of the Antenna Training and Measuring System (ATMS), that is the data acquisition interface/power supply, the RF generator, the antenna positioner and the computer must be properly setup before beginning this experiment.
2. Insert the antenna mast with locking ring into the transmission support. Couple a large horn antenna onto the waveguide-to-coax adapter. Avoid any discontinuities at the waveguide junction.
3. For the first acquisition, orient the horn so it is horizontally polarized, as shown in Figure 1. Install the long SMA cable on the 10 GHz Oscillator output of the RF generator, then connect the antenna.
4. Place the other mast with locking ring on the sliding support of the antenna positioner. Connect the open-ended waveguide to the waveguide-to-coax. Adapter. For the first experiment we will create a discontinuity at the junction of the waveguide. To do this, connect the two pieces so that the largest sections of their apertures are perpendicular to each other. Install the antenna on the mast with the longer side of the aperture oriented vertically. Using the sliding support, ensure that the open-ended waveguide is in line with the rotation centre of the antenna positioner. Connect the receiving antenna to the RF input on top of the antenna positioner using the intermediate SMA cable.
5. Position the antennas a distance of r= 1m. apart as shown in Figure 2 and adjust them so that they are at the same height and directly facing each other.
6. Set the RF generator to 1kHz (10 GHz oscillator mode), oscillator RF power to OFF. Then power up the RF generator and the poser supply. Turn on the compute and start the LVDAM-ANT software.
7. Set the 10 GHz oscillator RF power switch on the RF generator to the ON position and the attenuation level to 0 dB.

CAUTION!
For your safety, never look directly into the horn antenna while the RF power switch is ON.

8. Start the first acquisition. When it is complete, turn off the RF power. Store the radiation pattern as the E plane of antenna 1. Use the information box to clearly identify the pattern. Orient the pattern so that the MSP (max. signal position0 is at 0^o.
9. Repeat the acquisition after correcting the connection between the open-ended waveguide and the adapter to get continuity at the junction of the two components. Store this new pattern in the antenna 2 data box and adjust its MSP to 0^o.
10. Compare the E plane patterns of antennas 1 and 2 and comment on the results. Find out the attenuation of the signal due to the discontinuity at the junction of the waveguide.
11. Position the antennas a distance of r= 1.5 m. apart, still oriented in the E plane. Use the attenuation control to optimise the signal reception. Start acquisition and store it in the antenna 3 data box.
12. Rotate both antennas by 90^o, to orient them according to the H plane. Perform a new acquisition and store it in the antenna 3 data box. Now you have the E-pland and H-plane radiation patterns of the antenna. Make sure that the MSP of both patterns are set to 0^o. Select the H-E and 3-D buttons to observe spatial representations of those patterns. Print the 3-D representation.

Half-power beam-width, directivity and effective area

1. Use the cursors to evaluate the half-power beam-width of the E and H planes of your open ended waveguide antenna.
2. Using the two cursors, you can locate the two positions where the pattern drops by 3 dB from the maximum value and then calculate the HPBW from:

$$HPBW_E = \left|\theta_{3-dB\,left} - \theta_{3-dB\,right}\right| \; = \; \_\_\_\_\_\_ ^\circ$$

$$HPBW_H = \left|\theta_{3-dB\,left} - \theta_{3-dB\,right}\right| \; = \; \_\_\_\_\_\_ ^\circ$$

3. Calculate the directivity of this antenna using: $D = \frac{4\pi}{\Omega_A} = \frac{41252}{HPBW_E \cdot HPBW_H}$.
4. If the radiation efficiency of the open ended waveguide is close to 1, and the frequency of operation is 10.5 GHz, Calculate the effective area of your antenna according to:

$$A_e = \frac{\lambda^2}{4\pi} G_a \quad \text{m}^2.$$

5. Compare A_e with the physical aperture A_p and calculate the aperture efficiency according to :

$$\eta_p = \frac{A_e}{A_p} \times 100\%$$

Your report should include the E and H plane patterns of the open-ended waveguide antenna and the measured half power beam-widths. The answers to the following review questions will enhance your report:

1. Describe the open-ended waveguide antenna and its radiation pattern.
2. Did you expect a difference between the maximum signal for antennas 1 and 2? Explain.
3. Give the definition of the antenna directivity and explain the use of the approximate formula used in the calculation?

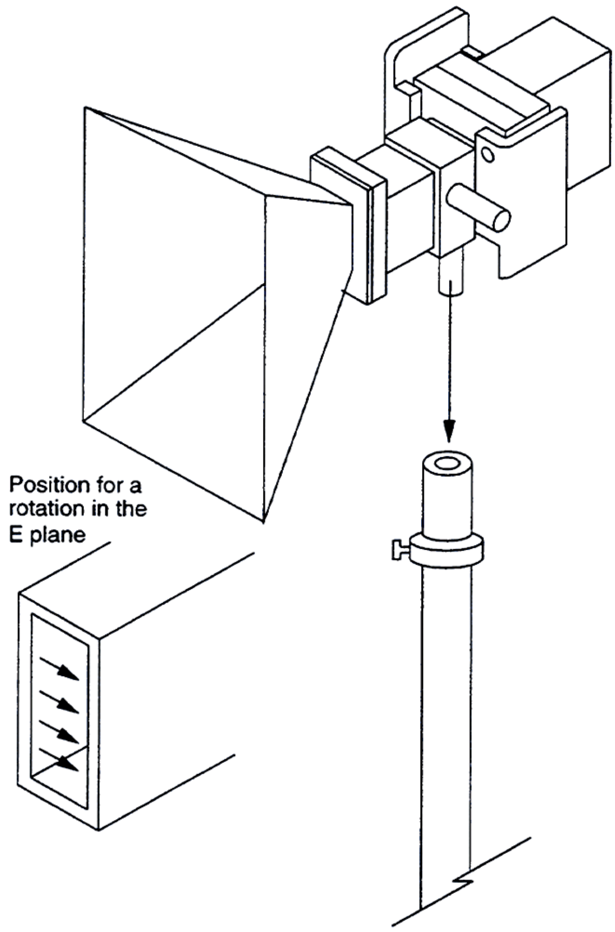

Figure 1: Set-up of the transmission antenna

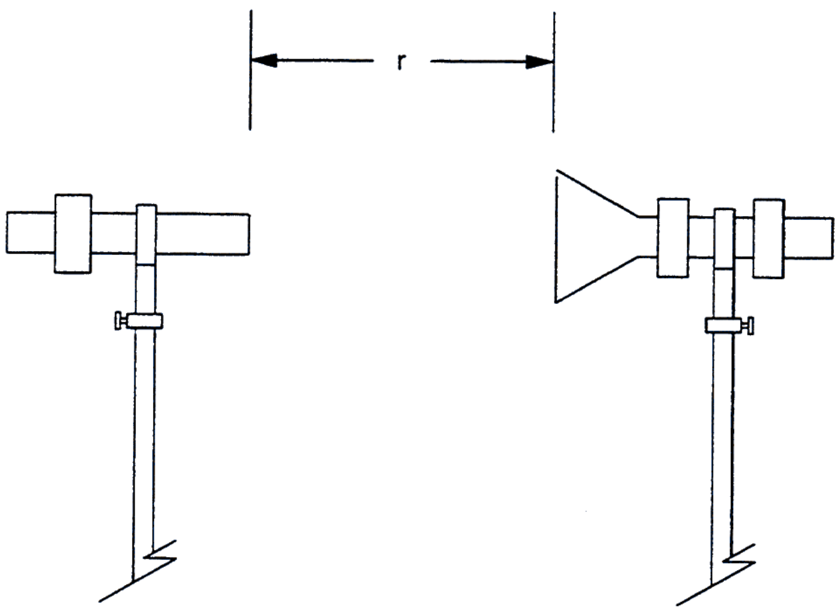

Figure 2: Distance r between the antennas

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EE 422 **Antenna Theory**

Computer assignment # 2

Objective

The purpose of this assignment is to compute and study the radiation characteristics of a finite length dipole antenna.

Programming Environment

This assignment will be carried out on a PENTIUM microcomputer using WINDOWS 95/98 operating system and running MATLAB for windows.

The program

A program is to be developed to compute the radiated power, radiation resistance, and the directivity of a finite length dipole. The radiation pattern of the dipole antenna is to be plotted in any elevation plane versus θ.

The inputs

The length of the dipole relative to the wavelength is to be supplied as an input to the program. You may use MATLAB's input statement which reads like this:

```
x=input('prompt')
l=x(1);
```

where 'prompt'='Dipole length? l/λ…'

The outputs

The program should compute and display the radiated power, radiation resistance, and the directivity. The program should also display the radiation pattern of the dipole.

Your program should perform the following steps:

- Get the dipole length from the keyboard;
- Compute the radiation intensity U for $0 \leq \theta \leq \pi$
- Compute the total radiated power
- Compute the radiation resistance
- Compute the directivity
- Plot the radiation intensity versus θ in a graphics window.

Experiment # 3 Radiation Characteristics of λ/2, λ, and 3λ/2 Dipoles at 1 GHz

Objective

To become familiar with the radiation characteristics of λ/2, λ, and 3λ/2 Dipoles.

Setup

Set up the antenna training and measuring system. Connect the power supply, the data acquisition interface, the antenna positioner, and the computer. Make sure that the propagation path is free from obstacles, which could affect the accuracy of the measured patterns. This setup is the same as the setup used in the previous experiment.

Procedure

1. The main elements of the Antenna Training and Measuring System (ATMS), that is the data acquisition interface/power supply, the RF generator, the antenna positioner and the computer must be properly setup before beginning the experiment.
2. Place the antenna mast with horizontal clips on the transmission support and clip the Yagi antenna onto it. Orient the elements so they are horizontal. The transmission antenna is then horizontally polarised.
3. Calculate the required length of a λ/2 dipole at 1 GHz (the exact transmission frequency is 915 MHz). Take into consideration that a resonant λ/2 dipole antenna is approximately = 0.45 λ in order to compensate for the length to diameter ratio, the end effect and the impedance mismatch resulting from the presence of the Balun circuit (balanced-to-unbalanced transformer).
4. Using the answer of your calculation choose the appropriate pair of wires to set the λ/2 dipole. Adjust the dipole length in accordance with your result.
5. Place the antenna mast with vertical clips on the sliding support of the antenna positioner, then clip on the λ/2 dipole. Ensure that the antenna is in line with the rotation centre of the antenna positioner. Screw the 10-dB attenuator to the RF input on top of the positioner. Connect the antenna to the attenuator using the short SMA cable.
6. Position the antennas a distance of r= 1 m. apart. Adjust them so that they are at the same height and directly facing each other.
7. Adjust the RF generator to 1 GHz oscillator mode set to 1kHz. Keep the RF power of both 1 GHz and 10 GHz set to OFF. Power up the RF generator and the power supply. Turn on the computer and start the LVDAM-ANT software.
8. Set the 1 GHz oscillator RF power switch on the RF generator to the ON position. Use the attenuator control to optimise the acquisition of your radiation pattern.

9. Start the first acquisition. When it is completed turn OFF the RF power. Store the radiation pattern in the antenna (1) E plane data box. Orient the pattern so that the MSP (max. signal position) is at 0^{o}.
10. Remove the antenna mast with vertical clips from the sliding support and replace it with the second antenna mast with the horizontal clips. Replace the short SMA cable with the intermediate one. Install your dipole on the new mast making sure that it rotates in the H plane. Rotate the Yagi antenna so that it is vertically polarized. Perform a new acquisition and store it in the H plane of antenna (1).
11. Replace the pair of wires making the dipole antenna with the appropriate lengths to make a l dipole and repeat the acquisitions and sore the results in antenna (2) data box.. Perform another acquisition and store the pattern as the H plane of antenna (2).
12. Compare the patterns of the λ and λ/2 dipoles.
13. Replace the dipole wires with the appropriate lengths to make a 3λ/2 dipole. Calculate the required distance between transmitting and receiving antennas so as to insure that measurements are in the far field. $r > \frac{2L^2}{\lambda}$ where $L = \frac{3\lambda}{2}$. Position your antennas at a distance $(r + 10)$ cm apart and perform new E plane and H plane acquisitions.

Half-power beam-width and directivity

1. Evaluate the half-power beam-width of the λ/2 and λ dipoles' E plane patterns
   $HPBW_{E\text{-}\lambda/2}$ = $\quad ^{o}$
   $HPBW_{E\text{-}\lambda}$ = $\quad ^{o}$
   Compare your evaluations of the beam-widths with the theoretical ones.

2. Evaluate the approximate directivity from:

$$D_o = \frac{41242}{HPBW_E . HPBW_H}, \text{ where } HPBW_H = 180^o$$

Your report should include the E and H plane patterns of the different dipoles and the measured half power beam-widths. The answers to the following review questions will enhance your report:

1. Among the 3 dipoles you have measured, which one do you think offers the best performance and why?
2. If the directivity of the λ dipole is better than the λ/2 dipole, why wasn't this antenna chosen as the answer to question 1?
3. Does the distance of 1m satisfies the far field distance for pattern measurements for the λ/2 and λ dipoles?

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Experiment # 4 Gain Measurements of Pyramidal Horn Antennas

Objective

To become familiar with the characteristics of pyramidal horn antennas and with the techniques used to calculate and measure their gain.

Antenna gain measurements

There are different methods for the measurement of the antenna gain.

1. The direct method. This can be used when you have two identical antennas. The two identical antennas are used as transmitting and receiving antennas. If the transmitted and received powers are measured, then the gain may be obtained from:
$$\frac{P}{P_t} = G^2\left[\frac{\lambda}{4\pi R}\right]^2$$
2. The comparison (or substitution) method. This method depends on comparing the power received by a reference antenna P_{ref} to the power received by the antenna P_{test}. The gain of the unknown antenna is given by:
$G_{test} = \frac{P_{test}}{P_{ref}} G_{ref}$, which can be expressed in dB as:
$G_{test}(dB) = P_{test}(dB) - P_{ref}(dB) + G_{ref}(dB)$ Before using the substitution method, the reference antenna must be calibrated. The direct method could be used to do that.

Pyramidal Horn Antennas

This is the most popular horn antenna. The geometry, the E-plane, and H-plane cross sections are shown below in Figure (1). The horn is usually fed from a rectangular waveguide. The field lines of the dominant mode usually extend into a spherical form, which gives rise to phase error Δ as shown in Figure (2). The phase errors are described by the normalized path errors s and t. These can be expressed as:

$$s = \frac{\Delta_E}{\lambda} = \frac{B^2}{8\lambda l_E} \qquad \text{and} \qquad t = \frac{\Delta_H}{\lambda} = \frac{A^2}{8\lambda l_H}$$

The approximate gain of the pyramidal horn can be calculated using:

$G = \frac{32}{\pi}\left[\frac{A}{\lambda}\right]\left[\frac{B}{\lambda}\right] L_E L_H$, where L_E *and* L_H represent the losses due to the phase error.

Expressing this equation in dB:

$$G(dB) = 10.08 + 10\log_{10}\left[\frac{AB}{\lambda^2}\right] - L_E(dB) - L_H(dB)$$

The values of L_E and L_H (dB) can be found by first calculating s and t and then obtaining the losses from Figure (3).

Setup

Set up the antenna training and measuring system. Connect the power supply, the data acquisition interface, the antenna positioner, and the computer. Make sure that the propagation path is free from obstacles, which could affect the accuracy of the measured patterns. This setup is the same as the setup used in the previous experiment.

Procedure Summary

In this experiment you will observe the power loss, called the free space propagation loss, due to the separation between the antennas. You will study the characteristics of the pyramidal horn antenna, specially its HPBW, its front to back ratio, its gain, and effective area. To calculate the gain of an antenna you will first calibrate a large horn antenna, and then use this reference with the substitution method to evaluate the gain of the small horn antenna.

Procedure

1. The main elements of the Antenna Training and Measuring System (ATMS), that is the data acquisition interface/power supply, the RF generator, the antenna positioner and the computer must be properly setup before beginning the experiment.
2. Use the two large horn antennas as transmitting and receiving antennas after orienting them to measure the H-plane pattern. Use the 10 GHz signal source and adjust the separation between the antennas to R= 1 m. Perform a pattern acquisition and store it in antenna 1 data box.
3. Repeat step 2 after orienting the antennas to measure the E-plane pattern. Perform a second acquisition and store in antenna 1 E plane pattern.
4. Measure the half-power beam widths for both patterns.

$HPBW_E$ = _________ º , $HPBW_H$ = ____________ º

5. Evaluate the front-to-back ratio of the antennas E plane pattern.

F/B_E (dB) = _________dB

6. Calculate the gain of the large pyramidal horn, knowing that it has the following dimensions: l_H = 11 cm, l_E = 9.4 cm. Measure the inside dimensions A and B
7. Calculate the wavelength λ at f = 10.52 GHz.
8. Calculate s and t, and obtain the phase error losses L_E and L_H in dB.
9. Calculate the gain of the large pyramidal horn.
10. Use the direct method to measure the gain of the pyramidal horn. First remove the antennas and connect the transmitting and receiving waveguides directly and measure the received power, which in this case is the transmitted power.
11. Reconnect the antennas and adjust the separtion R = 1 m. and measure the received power
12. Use the transmission equation to evaluate the antenna gain.

13. Using the last result, you can calculate the gain of a small horn antenna using the substitution method. The large horn antenna becomes the reference antenna.
14. Estimate the effective area of the large horn antenna using the formula:

$$G = \frac{4\pi A_e}{\lambda^2}$$

15. Calculate the aperture efficiency of the horn antenna which is defined as :

$$\eta_{ap} = \frac{A}{A_p} = \frac{A_e}{AB}$$

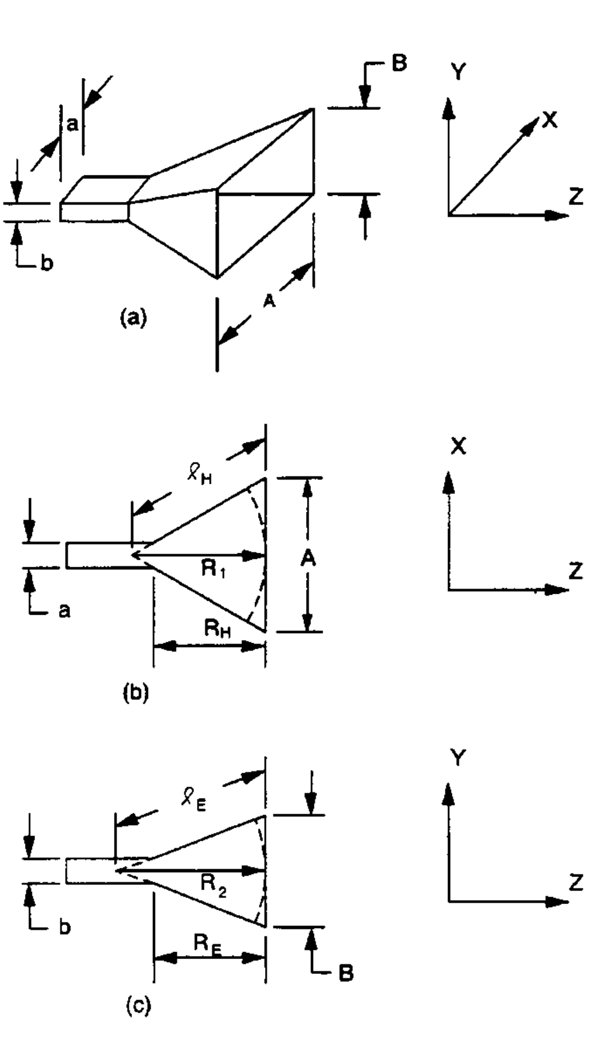

Figure (1)Geometry and dimension of the pyramidal horn.

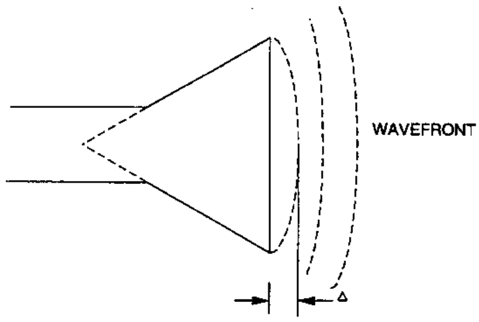

Figure (2)Phase error D of the pyramidal horn.

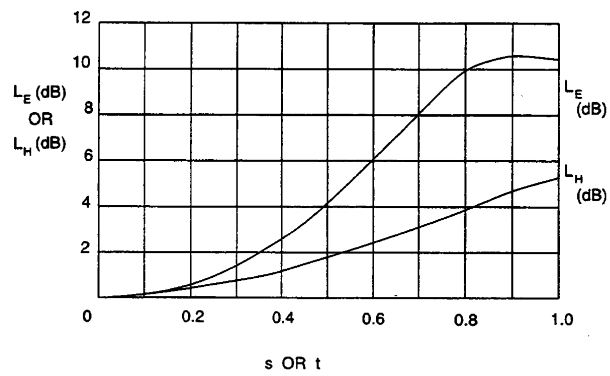

Figure (3)Loss factor for E and H plane flares.

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Computer assignment # 3

Objective

The purpose of this assignment is to compute and study the radiation characteristics of a linear array of isotropic radiators (point sources). The effect of changing the number of elements and the separation between them will also be studied.

Programming Environment

This assignment will be carried out on a PENTIUM microcomputer using WINDOWS 95/98 operating system and running MATLAB for windows.

The program

A program is to be developed to compute and plot the array factor once the number of elements, separation, and amplitude and phase distribution are specified. (Hint: use the general formula for the array factor. i.e. $AF = \sum_{n=1}^{N} a_n e^{j(n-1)\psi}$

The inputs

Use an input statement similar to the one you used in assignment # 2 to supply the number of elements and the separation. The amplitude and phase distribution may be supplied in the form of a matrix with (Nx2) elements before running the program.

>> ap = [a_1 p_1; a_2 p_2; ………]

The outputs

The program should compute and display the direction of maximum radiation, side lobe level, directivity, and half-power beam-width.

Your program should perform the following steps:

- Get the number of elements (N) and separation (d) from the keyboard;
- Compute the array factor for $0 \leq \theta \leq \pi$
- Compute the direction of maximum radiation;
- Plot the array factor vs θ in a graphics window and on a dB scale with minimum of –60 dB.

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Experiment # 5 Radiation Characteristics of a 2-element antenna array at 1 GHz

Objective

To become familiar with the radiation characteristics of 2-element antenna array of $\lambda/2$ dipoles under varying inter-element separation.

Setup

Set up the antenna training and measuring system. Connect the power supply, the data acquisition interface, the antenna positioner, and the computer. Make sure that the propagation path is free from obstacles, which could affect the accuracy of the measured patterns. This setup is the same as the setup used in the previous experiment.

Procedure

1. The main elements of the Antenna Training and Measuring System (ATMS), that is the data acquisition interface/power supply, the RF generator, the antenna positioner and the computer must be properly setup before beginning the experiment.
2. Place the antenna mast with horizontal clips on the transmission support and clip the Yagi antenna onto it. Orient the elements so they are horizontal. The transmission antenna is then horizontally polarised.
3. Calculate the required length of a $\lambda/2$ dipole at 1 GHz (the exact transmission frequency is 915 MHz). Take into consideration that a resonant $\lambda/2$ dipole antenna is approximately = 0.45 λ in order to compensate for the length to diameter ratio, the end effect and the impedance mismatch resulting from the presence of the Balun circuit (balanced-to-unbalanced transformer).
4. Using the answer of your calculation choose the appropriate pair of wires to set the $\lambda/2$ dipole. Adjust the dipole length in accordance with your result.
5. Place the antenna mast with vertical clips on the sliding support of the antenna positioner, then clip on the $\lambda/2$ dipole. Ensure that the antenna is in line with the rotation centre of the antenna positioner. Screw the 10-dB attenuator to the RF input on top of the positioner. Connect the antenna to the attenuator using the short SMA cable.
6. Position the antennas a distance of r= 1 m. apart. Adjust them so that they are at the same height and directly facing each other.
7. Adjust the RF generator to 1 GHz oscillator mode set to 1kHz. Keep the RF power of both 1 GHz and 10 GHz set to OFF. Power up the RF generator and the power supply. Turn on the computer and start the LVDAM-ANT software.
8. Set the 1 GHz oscillator RF power switch on the RF generator to the ON position. Use the attenuator control to optimise the acquisition of your radiation pattern.

9. Start the first acquisition. When it is completed turn OFF the RF power. Store the radiation pattern in the antenna (1) E plane data box. Orient the pattern so that the MSP (max. signal position) is at 0^{o}.
10. Remove the antenna mast with vertical clips from the sliding support and replace it with the second antenna mast with the horizontal clips. Replace the short SMA cable with the intermediate one. Install your dipole on the new mast making sure that it rotates in the H plane. Rotate the Yagi antenna so that it is vertically polarized. Perform a new acquisition and store it in the H plane of antenna (1).
11. Replace the pair of wires making the dipole antenna with the appropriate lengths to make a l dipole and repeat the acquisitions and sore the results in antenna (2) data box.. Perform another acquisition and store the pattern as the H plane of antenna (2).
12. Compare the patterns of the λ and λ/2 dipoles.
13. Replace the dipole wires with the appropriate lengths to make a 3λ/2 dipole. Calculate the required distance between transmitting and receiving antennas so as to insure that measurements are in the far field. $r > \frac{2L^2}{\lambda}$ where $L = \frac{3\lambda}{2}$. Position your antennas at a distance $(r+10)$ cm apart and perform new E plane and H plane acquisitions.

Half-power beam-width and directivity

3. Evaluate the half-power beam-width of the λ/2 and λ dipoles' E plane patterns
   $HPBW_{E\text{-}\lambda/2} =$ ^{o}
   $HPBW_{E\text{-}\lambda} =$ ^{o}
   Compare your evaluations of the beam-widths with the theoretical ones.

4. Evaluate the approximate directivity from:

$$D_o = \frac{41242}{HPBW_E . HPBW_H}, \text{ where } HPBW_H = 180^o$$

Your report should include the E and H plane patterns of the different dipoles and the measured half power beam-widths. The answers to the following review questions will enhance your report:

4. Among the 3 dipoles you have measured, which one do you think offers the best performance and why?
5. If the directivity of the λ dipole is better than the λ/2 dipole, why wasn't this antenna chosen as the answer to question 1?
6. Does the distance of 1m satisfies the far field distance for pattern measurements for the λ/2 and λ dipoles?

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DEPARTMENT OF ELECTRICAL ENGINEERING

EE 422 **Antenna Theory**

Experiment # 6 Antenna Arrays: The slot antenna

Objective

The objective of this experiment is to become familiar with the basics of antenna arrays. This will be achieved through the measurement of the radiation characteristics of the waveguide slot antenna array.

The slot antenna array

The slot antenna in the antenna training and measuring system is of the "standing wave array" type, which means that the array is terminated by a short circuit at the end of the waveguide. To obtain optimal radiation, the short circuit must be placed at a distance $d = \frac{\lambda_g}{4} + n\frac{\lambda_g}{2}$ (where λ_g = 3.6455 cm. Note that the wavelength in the waveguide is:

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

where f is the signal frequency, f_c is the cutoff frequency of the waveguide and is equal to 6.557 GHz and is the free space wave-length.

Procedure Summary

In this experiment you will learn the importance of the short circuit position in the performance of the standing wave array. You will evaluate the gain of the antenna you test. You will make some modifications to the array in order to better understand how array antennas function.

Setup

Set up the antenna training and measuring system. Connect the power supply, the data acquisition interface, the antenna positioner, and the computer. Make sure that the propagation path is free from obstacles, which could affect the accuracy of the measured patterns. This setup is the same as the setup used in the previous experiment.

Procedure

1. The main elements of the Antenna Training and Measuring System (ATMS), that is the data acquisition interface/power supply, the RF generator, the antenna positioner and the computer must be properly setup before beginning the experiment.
2. Use a large horn antenna as a transmitting antenna and orient it such that it is vertically polarized.

3. Use the small horn antenna as a receiving antenna. Mount it such that it rotates in the H plane. Adjust the separation between the antennas to 1.5 m.
4. Optimize the reception of the signal and start the first acquisition and store the radiation pattern in the antenna 3 data box. Orient the pattern so that the maximum signal position is at 0^o.
5. Replace the receiving antenna by the slot antenna, after connecting the short circuit and the coaxial-to-waveguide adapter to the two ends of the waveguide. Make sure that the short circuit is connected to the end, which is closer to the first slot as shown in Figure 1. The slot antenna will be oriented as shown in Figure 2-a. Start an acquisition and store the pattern in antenna 1 data box.
6. Rotate both antennas by 90^o, so they are oriented for an acquisition of the E plane pattern. The slot antenna will be horizontally polarized as shown in Figure 2-b. Store the new pattern in antenna 1 data box.
7. Repeat steps 5, 6 after exchanging the two ends of the slot antenna. Store the pattern in antenna 2 data box. Compare the patterns of antenna 1 and 2.
8. Measure the $HPBW_E$ and $HPBW_H$.
9. Using the results of antenna 1 and antenna 3 (small horn). Measure the gain of the slot antenna: $G_{slot} = P_{slot} + G_{ref} - P_{ref}$.
10. Use pieces of adhesive copper tape and seal three slots as shown in Figure 3-a. Perform an acquisition and store in antenna 2 data box..
11. Repeat the aquisition after sealing a fourth slot as in Figure 3-b and sore it in the H plane of antenna 3.
12. Repeat the acquisition after modifying the slot antenna to the configuration of Figure 3-c. Store in the E plane of antenna 3. Compare these patterns to the H plane pattern of antenna 1.

From the measured patterns verify the following:

- Directivity decreases when the number of elements is reduced.
- Gain increases by 3 Db approx. when the number of elements is doubled.
- The appearance of repetitive beams when the elements of lthe array are separated by a distance greater than one wavelength.

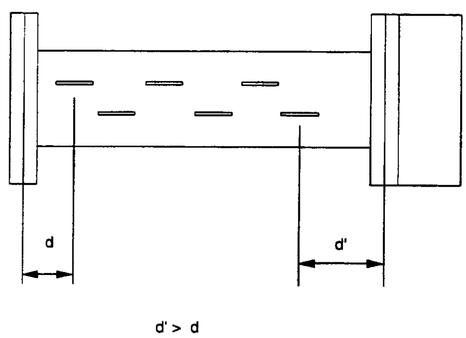

Figure 1 Set up of a slot antenna.

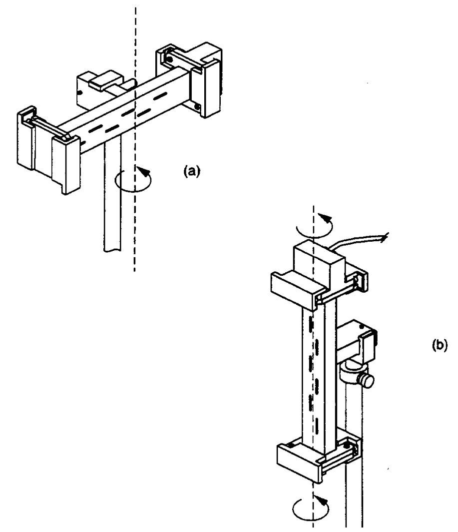

Figure 2 The slot antenna (a) Vertically polarized,
(b) Horizontally polarized.

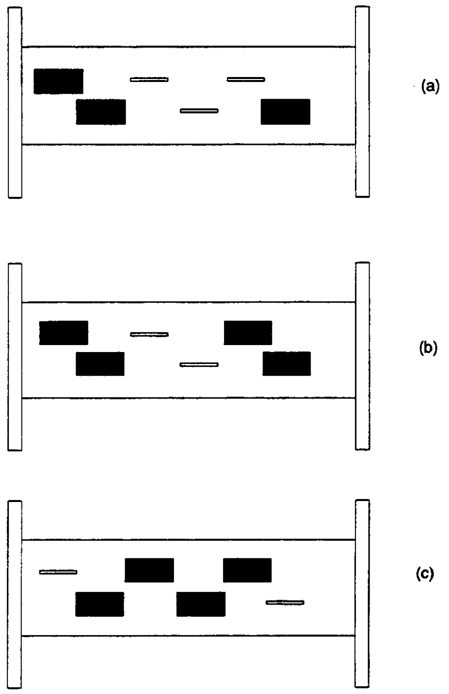

Figure 3 Sealing of slots on the waveguide.