UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
The Edward S. Rogers Sr. Department of Electrical and Computer Engineering

**ECE422H1S: RADIO AND MICROWAVE WIRELESS SYSTEMS**

**EXPERIMENT 2: ANTENNA ARRAYS**

# 1 Introduction

The purpose of this laboratory is to learn about antenna arrays realized from half-wave dipole antennas. You will investigate several linear array configurations studied in class, and characterize their patterns using procedure you have learnt about in Lab 1.

You will need the following pieces of equipment to complete this experiment:

- Agilent network analyzer
- SMA calibration kit (short, open, load, through)
- Planar half-wavelength dipole antenna
- Planar Yagi antenna array
- Microstrip patch antenna
- 2-way Wilkinson power divider (3-port board with oval-shaped trace on it)
- 4-way Wilkinson power divider (5-port board with oval-shaped trace on it)
- Quadrature hybrid (3-port board with square-shaped trace on it)
- 2 mounting tripods and associated hardware
- 2 SMA cables
- 5 UFL cables and SMA-to-UFL adaptors
- Various printed delay lines (2-port boards with microstrip lines printed on them)
- UFL removal key
- 1 metre ruler and masking tape
- Computer running MATLAB or Microsoft Excel, for recording data

# 2 Before You Start

Before beginning the experiments, calibrate the network analyzer from $800$ MHz to $1$ GHz according to the instructions attached at the end of this document. After calibrating the network analyzers, determine the frequency at which the Yagi antenna and the dipoles are operating by measuring their input reflection coefficient, and setting the marker to report measurements at this frequency.

# 3 Two-Element Linear Array

## 3.1 Two-Element Array with $d = \lambda/2$ and $\alpha = 0°$

1. Attach two dipoles to the support beam with spacings of $\lambda/2$. Using tape to fasten the dipoles to the beam.
2. Mount the array beam on the pedestal. The setup should resemble Figure 1, but should only contain two elements.
3. Connect the dipoles to the two-way Wilkinson power diver using UFL cables.
4. Connect the input of the hybrid to the Reflection port using an SMA cable.
5. Align the dipole such that the arms are in parallel with the arms of the Yagi when the tripod pedestal is at $0°$.
6. Press [MEAS] and select S21.
7. Press [FORMAT] and select Log Mag.
8. Press [MARKER] and set the marker to the resonant frequency of the Yagi antenna.
9. Record the $s_{21}$ value measured by the network analyzer.
10. Rotate the pedestal by $15°$.
11. Repeat 9 and 10 until you have completed $360°$ of measurements. It is only necessary to characterize the co-pol characteristics of the array.

Plot the pattern and compare it to the theoretical pattern expected from a half-wave dipole array in this configurations.

### 3.2 Two-Element Array with $d = \lambda$ and $\alpha = 90°$

Repeat the procedure in Section 3.1 but change the array spacing to $d = \lambda$. How many lobes do you observe in the pattern? Compare measurements to theory and comment one what you observe.

### 3.3 Two-Element Array with $d = \lambda/4$ and $\alpha = 90°$

Repeat the procedure in Section 3.1 but change the array spacing to $d = \lambda/4$. To introduce the $90°$ degree phase difference between elements, use a quadrature hybrid (with the isolated port terminated in a $50\ \Omega$ load to feed the array).

## 4 Four-Element Linear Array with $d = \lambda/2$

### 4.1 Uniform Array ($\alpha = 0°$)

1. Attach four dipoles to the support beam with spacings of $\lambda/2$.
2. Mount the array on the pedestal. You should have something similar to Figure 1.
3. Connect the dipoles to the 4-way Wilkinson power divider using UFL cables.
4. Connect the input of the hybrid to the Reflection port using an SMA cable.
5. Align the dipole such that the arms are in parallel with the arms of the Yagi when the tripod pedestal is at $0°$.
6. Make sure $s_{21}$ is measured on the network analyzer and make sure a marker is placed on the resonant frequency of the Yagi antenna.
7. Record the value of the magnitude report by the network analyzer.
8. Rotate the pedestal by $15°$.
9. Repeat 7 and 8 until you have completed $360°$ of measurements. It is only necessary to characterize the co-pol characteristics of the array.

Compare the pattern to theoretical expectations.

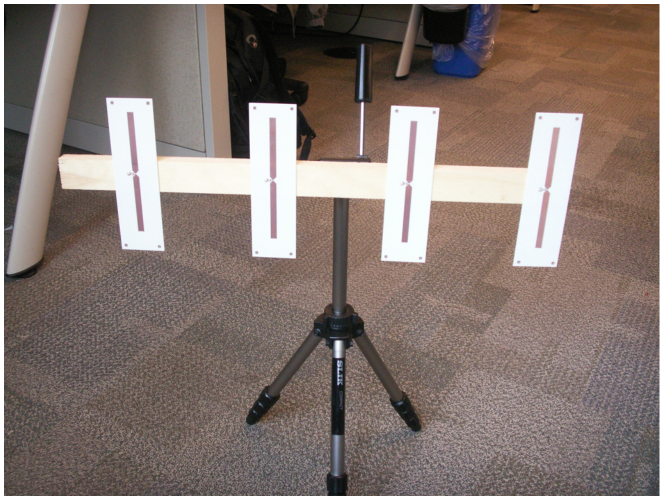

Figure 1: Array mounting.

### 4.2 Progressive Phase Shift with $\alpha = 90^\circ$

Repeat the previous measurements using a progressively phased array by connecting successively longer delay lines between the output of the four-port power divider and the dipole elements. Each delay line provides approximately $90^\circ$ of phase shift at 900 MHz. Calculate the expected beam angle (relative to broadside) and compare it to your measurements.

How would you reverse the beam angle so that it is steered on the opposite side of the broadside axis?

## 5 Additional Questions

1. Classify each pattern obtained as either broadside, endfire, or other.
2. What is the approximate change in measured signal power from the array beam between the two-element array and the four-element array? Does it correspond to theoretical expectations?
3. Explain how the patterns would have changed if the dipoles could have been mounted vertically (with the dipoles pointing along the same axis). Would it be possible to reconfigure each setup to realize this axial configuration? Why or why not?

# 6 Network Analyzer Calibration

This section describes the procedure of how to calibrate the network analyzer. Square brackets [] denote a hard button on the front panel of the network analyzer and round brackets () denote a soft button on the screen of the network analyzer.

1. Press [Preset] $\rightarrow$ (OK). Setting the instrument to a default state.
2. Press [Start], enter 800 MHz. Press [Stop], enter 1 GHz. Setting the frequency range of interest for the measurement.
3. Press [Cal] $\rightarrow$ (2-Port Cal) $\rightarrow$ (Reflection).
4. Connect the appropriate Short/Open/Broadband Load calibration standards to Port 1 and 2 and press corresponding soft buttons on the screen..
5. Press (Return).
6. Press (Transmission). Connect the Short/Open/Broadband Load calibration standards to Port 1 and 2 and press corresponding soft buttons on the screen..
7. Connect a Through standard.
8. Press (Port 1-2 Thru) to measure the standard.
9. Press (Return)
10. Press (Done) to enable the calibration.
11. Check the calibration by making sure the calibration is selected to be ON. Connect the Through calibration standard to make sure the reflection $s_{11}$ is less than $-40$ dB and the transmission $s_{21}$ is near $0$ dB.