Spatial Response of Practical Patch Antenna Systems

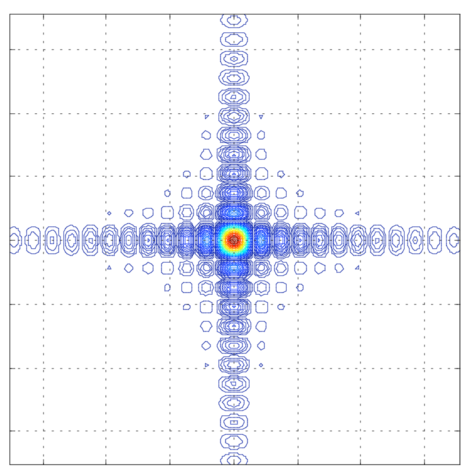
Learning Objectives:

A. Students will learn how to analyze the spatial response of practical patch antenna systems based on theory and measured laboratory data.
B. In the frequency domain, students will learn about the antenna's narrowband properties. The width of the antenna's passband will be studied, as it relates to the waveform requirements of weather surveillance.
C. Students will learn about the gain of a patch antenna system (comprised of multiple patches) and the system's spatial response.
D. Students will learn about the voltage standing wave ratio (VSWR).
E. Laboratory measurements will be provided to the students to allow students to repeat experimental data plotting and analysis procedures.
F. Students will learn about the Hamming window may be used to modify the spatial response.

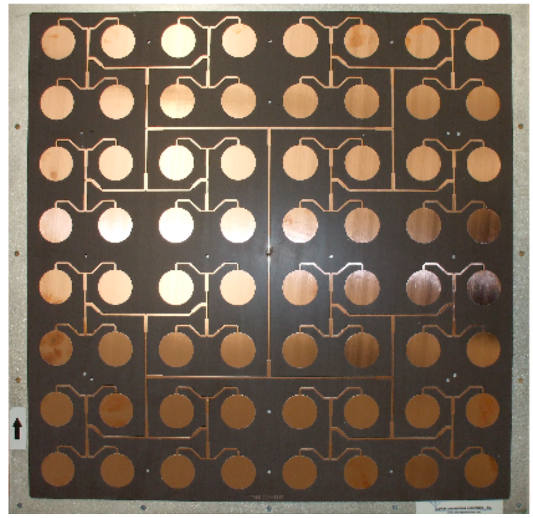
Introduction:

Recently, patch antennas have been gaining attention because they are thin, lightweight, and rugged, thus allowing convenient mounting on a variety of surfaces. By definition, a patch antenna is a member of the microstrip antenna family and is fabricated by etching the antenna element pattern using metal trace bonded to an insulating substrate, see (M. Sharawi, 2006) and (Pozar, 1986). The dimensions of the patches are inversely proportional to the radar's operating frequency. For instance, for an X-band system, one might expect to see each patch antenna to be about the size of a small postage. By working in unison, the ouputs a one-dimensional or two-dimensional array of patches on a single substrate may be summed to create an antenna (or phase center) with a specific gain and spatial response. In general, an array of patches on a single substrate is similar to a phased array, but can't be electronically steered. Given k_y and k_z, the direction cosines, the spatial response of a two dimensional array of patches may be defined and plotted, as noted below. The variable N defines the number of elements in one dimension, while the variable d defines the spacing between elements.

$$E(k_y,k_z)=\left|\frac{\sin(Nk_y\pi(d/\lambda))}{k_y\pi(d/\lambda)}\right|\cdot\left|\frac{\sin(Nk_z\pi(d/\lambda))}{k_z\pi(d/\lambda)}\right|$$

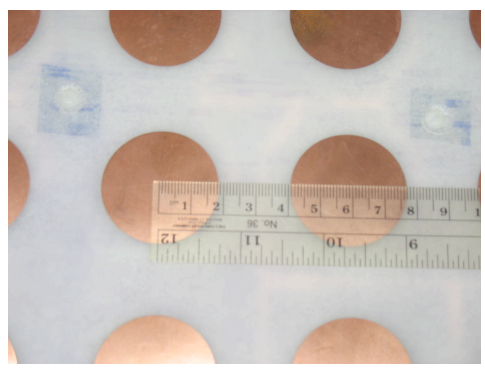


About the data in the Activities Section:



The figure on the right is a photograph of an antenna that is in the team's lab, which was manufactured by Seavey for a project in the ARRC's Lab. According to the company, "we can make a square array anywhere between 4 and 64 elements. Single element is 8.5 dBi. Whenever you double the amount of elements the gain increases by 3 dB; therefore, 4 elements (~5"x5") would have ~14 dBi and 64 elements (~20"x20") would have ~26 dBi."

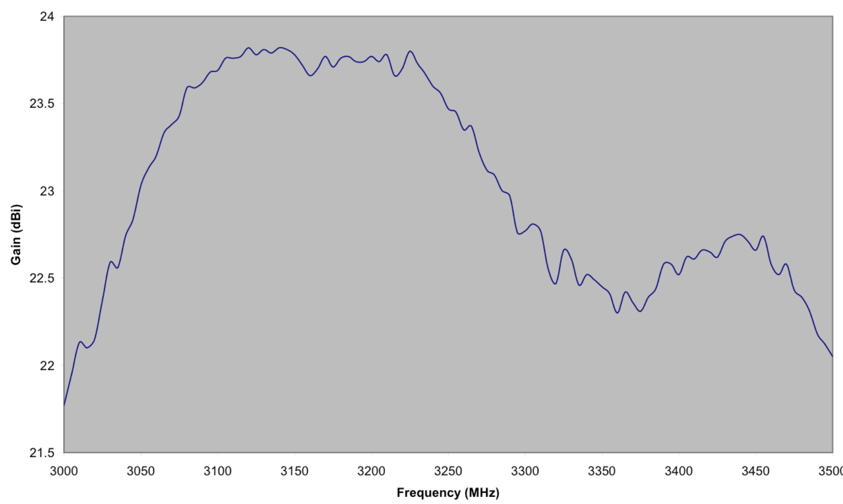
The antenna's characteristics are:



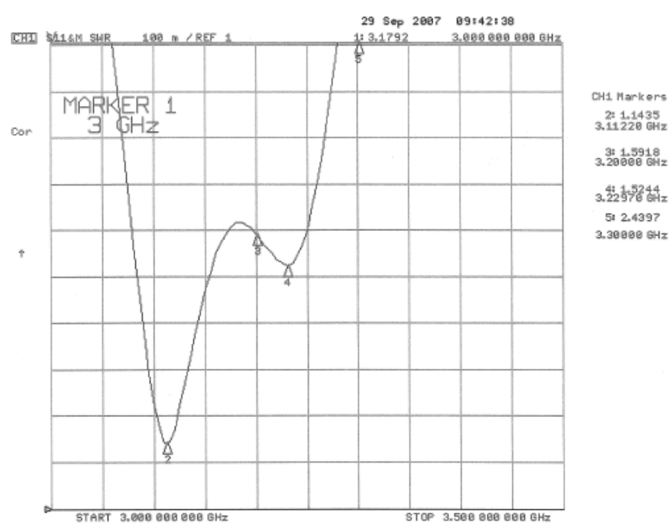
- An 8x8 array of micro-strip patch antennas.
- Patches suspended over a ground plane
- S-band system (precisely 3200 MHz)
- Narrowband. Must be matched to a weather surveillance waveform with a 1.57 us pulsewidth.
- Single SMA connector on the back (50 ohm)
- Rigid metal mounting bracket behind the thin patch network
- Spacing between the elements is depicted below, where *d* is slightly greater than one-half a wavelength.
- Simple and low-cost

In the frequency domain, patch antenna systems are typically suited for narrow band applications. In other words, they are designed to have a particular resonant frequency. Although wide-band antennas are desirable for some applications, antenna design and RF front-end circuit additional costs and complexities arise because of this. The next plot depicts the measured gain of the antenna.

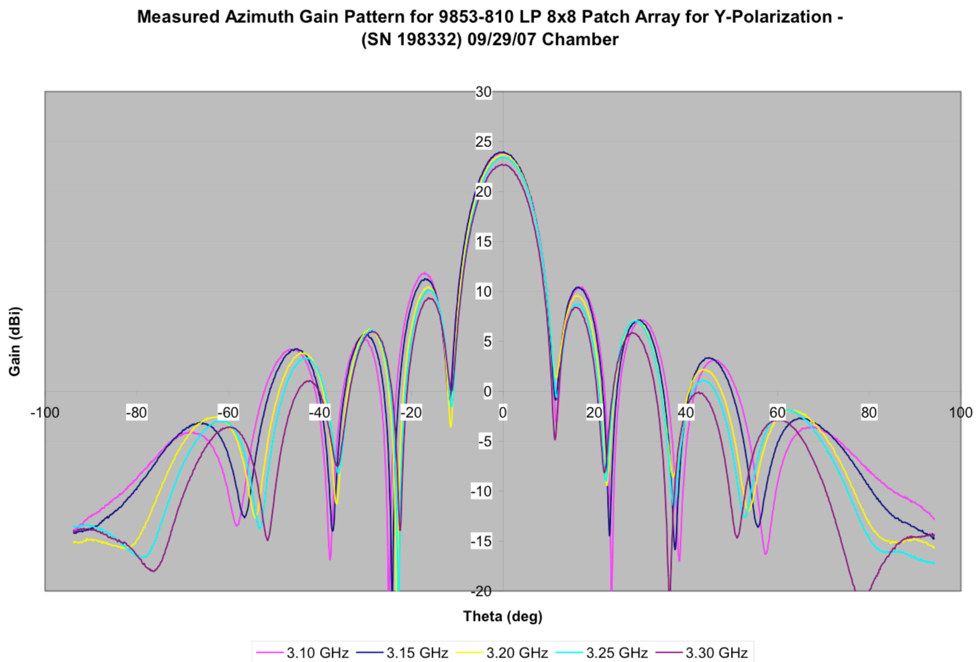
Measured Gain vs Frequency for 9853-810 LP 8x8 Patch Array for Y-Polarization - (SN 198332) 09/29/07 Chamber



The voltage standing wave ratio (VSWR) is another important property of antenna design. It gives an indication of how much of the received energy is absorbed by an incoming wavefront, as opposed to being reflected. A VSWR of unity is the ideal case, which indicates complete absorption. However, most commercial designs yield values of 2.0 or less, for antennas that are available for practical measurements. The VSWR is influenced by a variety of design parameters, especially the antenna's operating frequency. For our antenna, a value of 1.5918 was measured at 3200 MHz. As the measurements indicate above, as the excitation frequency moves away from the antenna's passband, the VSWR increases.



The next plot depicts the response of the antenna for four different frequencies. It is noted that the units of the vertical axis is dBi (directional gain relative to an isotropic radiator).



Hands-On Activities:

The data for this project may be found at: www.ou.edu/radar

A. Prepare a plot of the response of a general antenna. Assume that the patches are on ½ wavelength spacing. Let N=4,6,8,10. Each plot should use dBi for the units on the vertical axis and degrees along the horizontal axis.
   a. Make a 1-D plot (linear array)
   b. Make a 2-D plot (N x N, two dimensional array, symmetric)

B. Prepare a general discussion the gain of a patch antenna system as it relates to the radar range equation. In general, if a designer is given N antenna elements and needs 3 dB more gain, how many more elements are needed? Assuming half-wavelength spacing, pick the right answer: (i) N+2, (ii) N×N, (iii) 2×N, (iv) N×(√2), or (v) 10×N ?

C. Read about patch antennas in the literature and provide explanations.
   a. For example, see M. Sharawi, "Use of low-cost patch antennas in modern wireless technology," *IEEE Potentials*, 2006. From your readings: provide some advantages of patch antennas and provide some reasons why patch antennas are also called micro-strip antennas (write one paragraph).
   b. For example, see D. Pozar, "Microstrip antennas," *IEEE Proceedings*, 1992. From your readings, explain how a microstrip antenna may be modeled by a resistor, inductor, and/or capacitor (write one paragraph).
   c. For example, see C. Balanis, *Antenna Theory*, 2005. From your readings, explain how non-uniform spacing can be used on a linear array of patch antennas to shape the beam (write one paragraph).

D. Download the measured antenna data.
   a. www.ou.edu/radar/9853-810_LPpatcharray_8x8_198333_EL_YP_092907.txt
   b. www.ou.edu/radar/9853-810_LPpatcharray_8x8_198333_AZ_YP_092907.txt
   c. www.ou.edu/radar/9853-810_LPpatcharray_8x8_198332_EL_YP_092907.txt
   d. www.ou.edu/radar/9853-810_LPpatcharray_8x8_198332_AZ_YP_092907.txt

E. Plot the response of the response of the antennas. Plot the data as a function of azimuth. Carefully label the axis's correctly.
   a. Determine the height of the first sidelobe.
   b. Determine the beamwidth
   c. From the finished antennas, the patches are spaced at approximately 6.0 cm. Given the operating frequency of 3.2 GHz is this spacing reasonable? Are there any noticeable effects of the antenna's performance? How does the performance differ from a system based on precisely ½ wavelength spacing.
   d. Do parts a. and b. match theoretical predictions? Explain.
   e. Are any grating lobes present? Explain.
   f. Explain the meaning of dBi and dBm, as they relate to antenna measurements.
   g. Indicate if the data corresponds to a vertical or horizontal cuts.
   h. Explain how polarization relates to the laboratory measurements. Explain the advantages and limitations of single-polarization and dual-polarization antennas.

F. BONUS: Comment on the passband of the antenna. How well is it matched to a weather surveillance waveform with a 1.57 us pulsewidth? What is the smallest pulsewidth that may be supported by this antenna?
   a. By decreasing the pulsewidth, briefly explain how will this influence the range accuracy and radial velocity measurement accuracy?
   b. Assuming a PRT of 1.0 ms and a pulsewidth of 1.57 us, how many spectral lines (with no more than 3 dB of attenuation) will present for the given antenna system?

G. BONUS: Modify the data with a Hamming window and explain how the first sidelobe may be reduced at the expense of broadening the beamwidth. Suggest a method to implement this window during the antenna design process.
   a. Explain how tapering works in the design and manufacturing process.

H. BONUS: Using the laboratory data for the antenna system and by assuming that the system is pitched back by 15 degrees, plot the new spatial response. Be sure to define the appropriate coordinate system and state all assumptions.

I. BONUS: Assuming a center-to-center distance of 60 cm, plot the spatial response of two arrays operating together (assume horizontal orientation).
   a. Discuss the resulting beamwidth and grating lobes.
   b. Determine the gain of the system.
   c. If the distance is increased to 75 cm, repeat the steps above.