A Primer on Digital Beamforming

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Introduction

Beamforming is the combination of radio signals from a set of small non-directional antennas to simulate a large directional antenna. The simulated antenna can be pointed electronically, although the antenna does not physically move. In communications, beamforming is used to point an antenna at the signal source to reduce interference and improve communication quality. In direction finding applications, beamforming can be used to steer an antenna to determine the direction of the signal source.

This introduction to beamforming covers the basic properties of antennas and antenna arrays, then explains how beamformers are built using digital radio hardware and DSP's. Super-resolution direction finding is also explained.

Antennas and Wavelength

An antenna for a radio transmitter converts electrical signals on a cable, from the transmitter, into electromagnetic waves. The antenna consists of electrical conductors (wires, pipes, reflecting surfaces, etc) that create electric and magnetic fields in the space around them. If the fields are changing, they propagate outward through space as an electromagnetic wave at the speed of light.

Speed of Light **$c = 3 \times 10^8$ meters/sec**

Any antenna that transmits can also receive. Passing electromagnetic waves excite currents in the antenna's conductors. The antenna captures some energy from passing waves and converts it to an electrical signal on the cable.

When designing an antenna, its dimensions are specified in terms of the ***wavelength*** of the radio signal being transmitted or received. Wavelength is the distance from the beginning of one electromagnetic wave cycle to the next.

$$\lambda = c / f_c$$

λ is wavelength in meters
f_c is the carrier frequency of the radio signal in Hz
c is the speed of light (3×10^8 meters/sec)

Wavelengths For Common Radio Signals

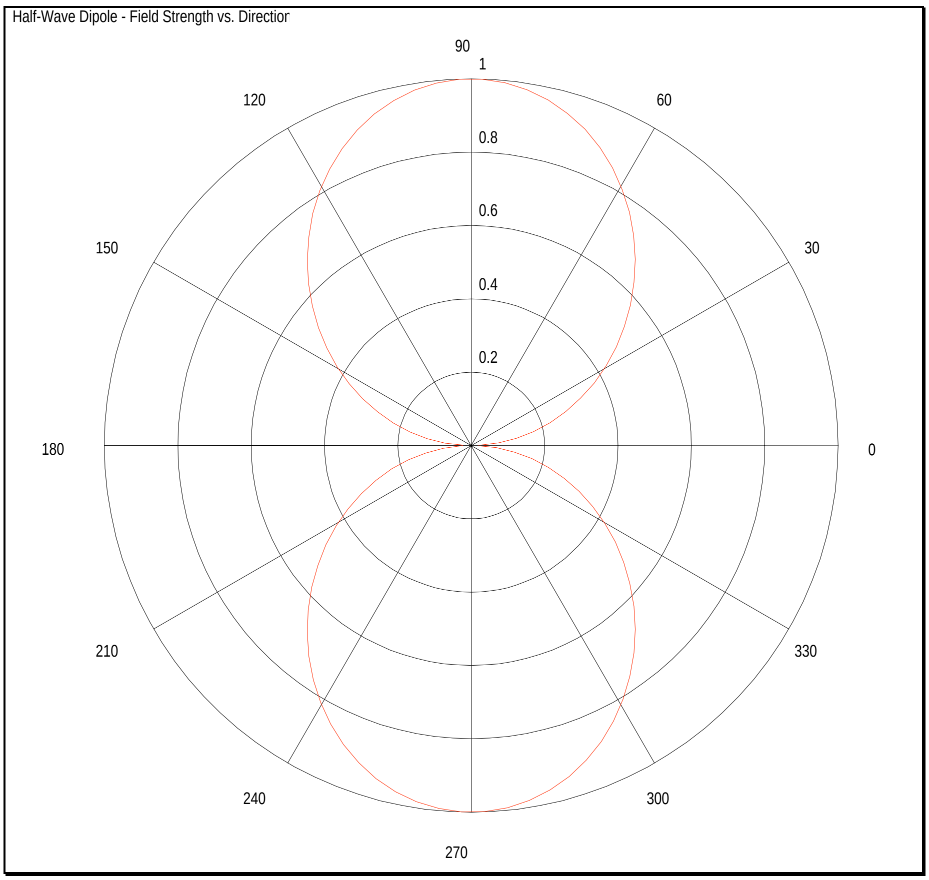
Signal	Frequency	Wavelength
AM Radio	1 MHz	300 meters
FM Radio	100 MHz	3 meters
Cellular Telephone	850 MHz	35 cm
Cellular PCS	1,800 MHz	17 cm
X-Band Radar	10,000 MHz	3 cm

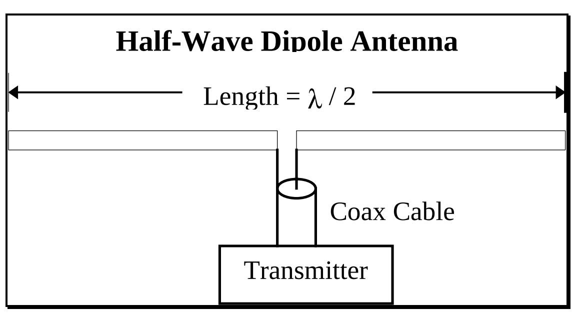
Antenna Radiation Patterns

A transmitting antenna generates stronger electromagnetic waves in some directions than others. A plot of field strength vs. direction is called the antenna's ***"radiation pattern."*** It's always the same for receiving as for transmitting.

An electromagnetic wave measured at a point far from the antenna is the sum of the radiation from all parts of the antenna. Each small part of the antenna is radiating waves of a different amplitude and phase, and each of these waves travels a different distance to the point where a receiver is located. In some directions, these waves add constructively to give a gain. In some directions they add destructively to give a loss.

A half-wave dipole is a simple antenna that consists of a half wavelength of wire, cut in the center for connection of the cable. The following figure shows its radiation pattern.

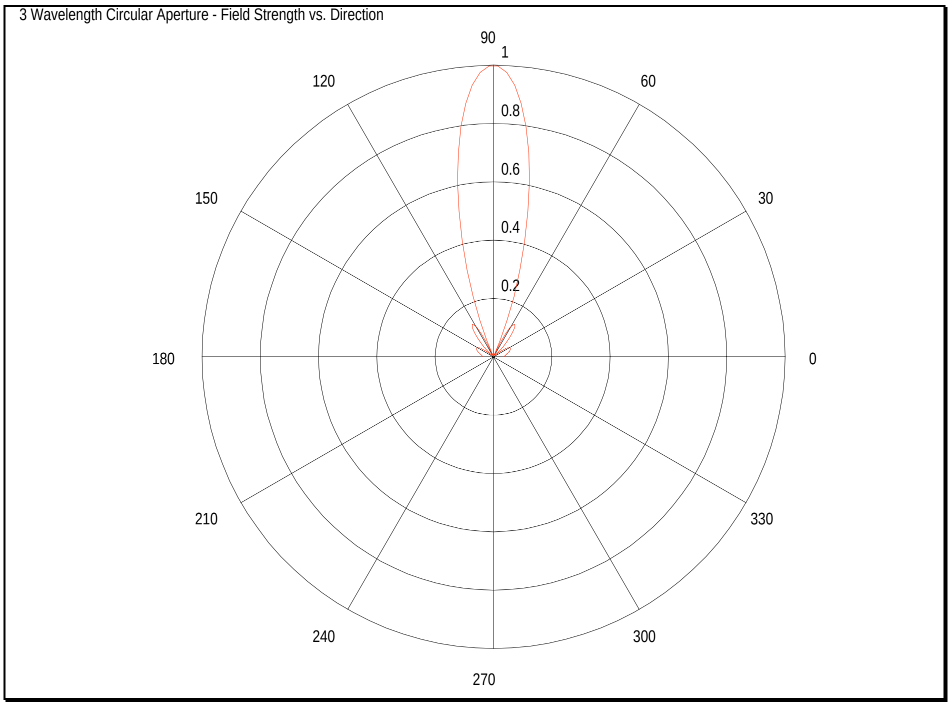


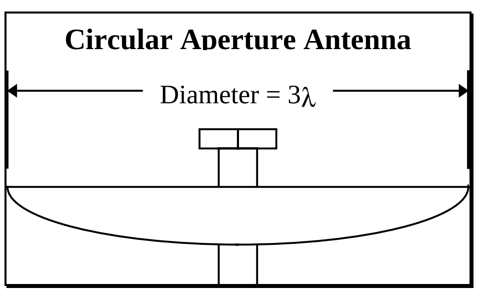


Directional Antennas

A directional antenna is one designed to have a gain in one direction and a loss in others. An antenna is made directional by increasing its size. This spreads the radiating conductors of the antenna over a larger distance, so that the constructive and destructive interference can be better controlled to give a directional radiation pattern.

A satellite dish antenna can, simplistically, be considered a circular surface that radiates electromagnetic waves equally from all parts. It has a narrow central ***"beam"*** of high gain, as shown in the following figure, that is aimed at the satellite. As the dish diameter, in wavelengths, is increased the central beam gets narrower. Notice the smaller beams, called ***"side lobes"***, on either side of the central beam. Directions in which the signal strength is zero are called "***nulls.***"





Linear Arrays

A simple directional antenna consists of a linear array of small radiating antenna elements, each fed with identical signals (the same amplitude and phase) from one transmitter. As the total width of the array increases, the central beam becomes narrower. As the number of elements increases, the side lobes become smaller.

The following figure is the radiation pattern for a line of 4 elements (small antennas) spaced 1/2 wavelength apart.