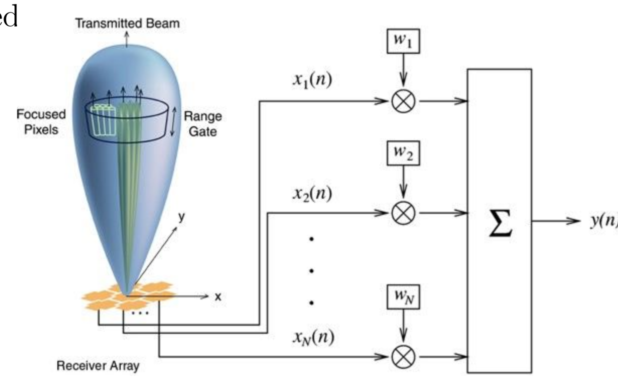
Digital Beamforming and Imaging Radar

1 Learning Objectives:

- *Students will learn about the antenna pattern for planar phased array.*
- *Students will learn about digital beamforming (DBF) technique, which is the main idea behind an imaging radar.*
- *Students will learn about how to implement Fourier-based DBF from a practical system.*

2 Introduction

An imaging radar can produce a snap-shot of the scene, illuminated by a wide transmitting beam, using digital beamforming (DBF) techniques. In other words, a number of receiving beams can be formed simultaneously by weighting the received signals from spatially separated sub-arrays. The concept of an imaging radar is depicted in the figure.



Those weights can be pre-determined or adaptive to the scene the radar perceived to maximize performance such as clutter/interference mitigation. In this project, only the Fourier-based DBF is introduced, where the receiving pattern is determined from the configuration of sub-arrays. The output of a beamformer is given by

$$y(n) = \mathbf{w}^H \mathbf{x}(n) \tag{1}$$

where the superscript H is the Hermitian (conjugate transpose), $\mathbf{x}^T(n) = [x_1(n)\, x_2(n) \cdots x_N(n)]$ is a vector consisting of received signals from N sub-arrays (can be linear or planar array) at time n, and $\mathbf{w}^T = [e^{jk\mathbf{a}_r \cdot \mathbf{d}_1}\ e^{jk\mathbf{a}_r \cdot \mathbf{d}_2}\ \cdots e^{jk\mathbf{a}_r \cdot \mathbf{d}_N}]$ is the vector of weights for each received signals. Moreover, the position vector of the i^{th} sub-array is denoted by $\mathbf{d}_i$, and the beam pointing direction is defined by $\mathbf{a}_r$. As a result, the output power of the beamformer is obtained by

$$P(n) = \mathbf{w}^H < \mathbf{x}(n)\mathbf{x}^H(n) > \mathbf{w}. \tag{2}$$

Note that $P(n)$ is implicitly a function of pointing angle $\mathbf{a}_r$.

The data used in this project was collected by the UMASS Turbulent Eddy Profiler (TEP) with 56 sub-arrays on June 14, 2003. The data can be downloaded from the following website http://www.ou.edu/radar/tep_iqdata.mat. Note that the data from only one range gate centered at 1132 m is given. In the data file (tep_iqdata.mat) there are five variables. The location of the 56 sub-arrays is stored in the variable "D" and the altitude of the range gate where the data was collected is"r". The"timestamp" gives the time and date of the data collection. For example, you can use datestr(timestamp(10,1)) to find out the time and date of the 10th record of the data. The iqdata are those digital samples that will be used for beamforming. It contains data from 56 sub-arrays and 21 records. Each record has 260 data available for the averaging processing. The prf is 35 kHz and 250 coherent integration has been applied. In other words, each sample in iqdata is spaced by 1/140 sec.

3 Hands-On Activities

You are required to turn in the derivation, figures, discussions (typed), a dvi file for the animation (using movie2avi command) and computer codes. (**The data are for the class use only**). For the ECE 4663 students, **Prob. 1** is extra credit. ***The report is due on March 24, 2008***.

- **Prob 1.** Derive the output power of a beamformer for three sub-arrays centered at $\mathbf{d}_i$, $i = 1, 2, 3$ as a function of $\mathbf{d}_i$, spatial correlation of signals, $R_{ij} = < x_i(n)x_j^*(n) > = R_{ji}^*$, and pointing direction $\mathbf{a}_r$. Discuss your results.

- **Prob 2.** Plot the location of each sub-array in a Cartesian coordinate system.

- **Prob 3.** (a) Plot the 3D antenna pattern (in dB) given the TEP configuration. How many grating lobes are there? (b) Slice the 3D antenna pattern to the 2D antenna pattern in both east-west and north-south directions. Estimate the 3dB beamwidth in both east-west and north-south directions. (c) If you want to steer the beam in the north-south direction, what is the maximum angle (degree) you will design the radar to scan? Discuss your result? (d) Discuss beamwidth increase if scan off broadside.

- **Prob 4.** Implement the digital beamforming to produce 1089 simultaneous beams equally spaced for -15° $\leq \theta_x \leq$ 15° , -15° $\leq \theta_y \leq$ 15° . (a) Animate the map of received power for 21 records and discuss your results. (b) Estimate the average velocity (speed and direction) of the target. Repeat the estimation assuming the target signal is second-time-around echo.