INF5410: Signal Processing in Space and Time

Mandatory Exercise 1

Document revised on March 1, 2012.

- Write a report with all plots, results and discussions. Convert your report to PDF format.

- Name your report file `mandatory_1_LASTNAME.pdf`, where you replace `LASTNAME` with your last name. Include your MATLAB code printed as an appendix in the PDF report, and also as m-files.

- Name your MATLAB files following the pattern `mandatory_1_LASTNAME_MYFILETAG.m`, where you replace `LASTNAME` with your last name and `MYFILETAG` with whatever you prefer.

- Deliver your files to `svenpn@ifi.uio.no`, as a zip archive named `mandatory_1_LASTNAME.zip`, where you replace `LASTNAME` with your last name.

Please produce a tidy and structured, however not exhaustive, report: all plots must have correct axis scaling and naming, the important calculations must be included, the questions must be answered in the given order, etc.

Delivery deadline: Friday March 23 2012, at midday (12.00 noon)

Part 1: From Johnson & Dudgeon

1) Exercise 3.7.
   In order to make the answer more straightforward: Assume circular elements instead of hexagonal elements. See Fig. 1.

2) Exercise 3.11. *You don't need to answer part a)*

3) Exercise 4.5. *Hint: See Fig. 1*

Part 2: Matlab coding project

Array Pattern

Write a MATLAB program for computing the array pattern (aperture smoothing function) of an M-element array with the elements symmetrically located on the x-axis. Assume initially that each element is omni-directional. Plot the result in dB and give the result both as a function of wavenumber (*e.g.* as a function of sin(angle)) and angle. Plot only the visible region.

Grating lobes

1) Assume a linear array with $M = 10$ elements with unity weight. Let the elements be uniformly spaced and try four different element spacings: $d = \lambda/4, \lambda/2, \lambda$, and 2λ. Plot the results and discuss the differences as the inter-element distance varies.

Element weighting and element spacing

2) Consider the array with spacing $d = \lambda/2$ and $M = 10$, and use the Remez program in MATLAB's Signal Processing Toolbox to find the symmetric set of element weights that produces a uniform sidelobe level of -20 dB.
   [MATLAB 7 command: `firpm`, MATLAB 6 command: `remez`. See Mitra, Digital Signal Processing, chapter 7.7.1, Oppenheim & Schafer, Discrete-Time Signal Processing, 1999, chapter 7.6 or Proakis & Manolakis, 3rd edition, chapter 8.2.4 for additional information on the Remez method]

3) Let the array have $M = 10$ elements with unity weights and let the element spacings be given by $\{0.21464, 0.38517, 0.46147, 0.52586\}$ where the first number is the spacing from $x = 0$ to the first element, the second number is the distance from element 1 to element 2 and so on in units of λ. The last element is placed so that the aperture is equal to the equi-spaced array with $\lambda/2$ spacing, that is: the total array aperture is $D = 10\lambda/2$. The array is symmetric about $x = 0$.
   [The element locations have been taken from H. Schjær-Jacobsen and K. Madsen, "Synthesis of nonuniformly spaced arrays using a general nonlinear minimax optimization method," IEEE Trans. Antennas and Propagation, vol. AP–24, pp. 501–506, July 1976.]
   Hint: The solution should resemble that of the previous paragraph.

   Compare the solutions from 1), 2) and 3) with respect to beamwidth, aperture, sidelobes, grating lobes, etc.

Thinning

4) Assume an array as in 1) with $d = \lambda/2$. Make a thinned, symmetric array with 6 elements with the same aperture as the 10-element array by discarding 4 elements. By trying various combinations of thinning, find the thinning pattern which gives the smallest maximum sidelobe. Note that the distance between the outermost elements has to be $D = 10\lambda/2$ for all configurations.

   Compare with the full array.

Element directivity

5) Consider again the arrays in 1) with $d = \lambda$ and $d = 2\lambda$. Assume that each element is of size d and include the element factor in the computation of the array pattern. Compare
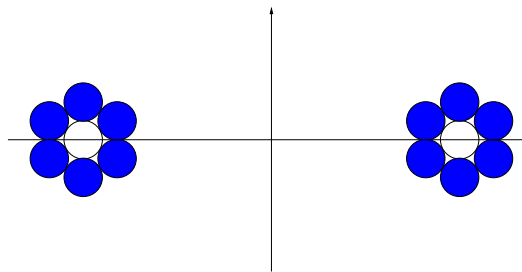

Figure 1: Hints regarding the geometry to be applied in Exercise 3.7 and Exercise 4.5. Each sub-aperture (blue circle) is of radius r, and the distance between the two big sub-apertures is $2 \cdot D$. In Exercise 4.5 b): Assume $r = 6$ cm and $D = 3$ m.

with the results in 1) and discuss the differences.

6) Apply steering to the array with the element responses in the previous paragraph and see what happens as the steering angle is increased.

7) Linear arrays with element spacing larger than $\lambda/2$ are regularly used in medical ultrasound imaging systems. Assume 10 unity weighted, regularly spaced elements and an element of size d equal to the element spacing. Design a linear array with as large aperture as possible that makes it possible to steer $\pm 15°$ with acceptable sidelobe and grating lobe levels.