FINAL EXAM – ROWAN UNIVERSITY – CSE Radar Systems
Professor Blosfelds
DUE PRIOR TO DECEMBER 20th at 9 pm
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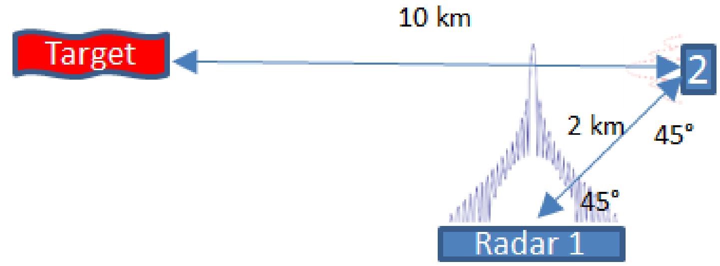
1. (20 points) Coexistence of radar systems. In this problem, we're trying to determine how two radars are interfering with each other. We will need to generate antenna patterns (uniform illumination, $\lambda/2$ spacing) for both radars and determine power densities and SNRs.

   Radar 1
      i. Frequency = 3 GHz
      ii. Peak power = 100 kW
      iii. Circular array – diameter = 2 meters
      iv. Transmit Loss = 2 dB



   Radar 2
      v. Frequency = 3 GHz
      vi. Peak power = 1000 W
      vii. Circular array – diameter = 0.5 meters
      viii. Duty 10%
      ix. Dwell time = 1 ms
      x. Noise Figure = 4.5 dB
      xi. Total System Losses = 10 dB
      xii. Bandwidth = 1 MHz

   a. (10 points) Radar 1 is turned off. Radar 2 is turned on. Calculate the Radar 2 SNR on a 0 dBsm target 10 km from Radar 2 (at broadside). Answer should be in dBs.
   b. (10 points) Radar 1 is turned on and Radar 2 remains on as well.
      i. Calculate the Radar 1 power density (W/m^2) arriving at the antenna face of Radar 2 if both radars are transmitting broadside (as illustrated above).
      ii. If Radar 1 is rotated and pointing directly at Radar 2, does that impact the power density arriving at Radar 2's antenna face? If so, how?

2. (20 points) Probability of detection problem
    1. A radar has a SNR of 12 dB at 25 km on an aircraft flying directly towards the radar at a velocity of 500 m/s. Assume the instrumented range of the radar is 50 km (in other words, all plots should be from 0 to 50 km).
        - The radar has a search frame time of 2 seconds and thus, illuminates the target once every two seconds.
        a. (5 points) Plot SNR versus range.
        b. Use our Swerling 1 Probability of Detection Equation from class and assume N=1 and PFA of 1E-6.
            i. (7 points) Plot P_D versus range.
            ii. (3 points) Plot cumulative P_D versus range.
        c. (5 points) Using the attached propagation factor curve for the radar – aircraft, plot the updated SNR, P_D and cumulative P_D.

To make sure that your representation of the Probability of Detection equation is correct, here are some data points:

1. SNR = 12.00 dB, then P_D = 44.09%

2. SNR = 19.75 dB, then P_D =86.54%

3. (15 points) Alpha-beta tracking problem

A radar is using a simple alpha-beta tracker with alpha = 0.5 and beta = 0.1667. The radar is scanning the target once per second.

i. The target begins at 20 km and is traveling 100 m/s directly towards the radar.
ii. The range accuracy, σ_R, is 250 meters and constant. Assume a normal distribution for each range measurement with a mean of the true range and a standard deviation of 250 meters. In Excel, you can use "Norm.inv(Rand(), Mean, Std dev)"

An alpha-beta tracker is relatively easy to implement but does not handle maneuvering targets. It can be enhanced with additional algorithms to handle maneuvering targets.

$$\widehat{x}_n = x_{pn} + \alpha(x_n - x_{pn})$$

$$\widehat{v}_n = \widehat{v}_{n-1} + \frac{\beta}{T_s}(x_n - x_{pn})$$

$$x_{p(n+1)} = \widehat{x}_n + \widehat{v}_n T_s$$

where:

$\widehat{x}_n$ = Smoothed target position, meters
x_{pn} = Predicted target position, meters
α = Position smoothing parameter, no units
x_n = Measured target position, meters
$\widehat{v}_n$ = Smoothed target velocity, meters/second
β = Velocity smoothing parameter, no units
T_s = Time between measurements, seconds

a. (8 points) Plot range versus time, including the true range, the measured range, and the smoothed range. The range axis should be from 1 km to 20 km.
b. (7 points) Since range accuracy is a function of SNR, re-do "a" assuming a starting SNR of 5 dB at 20 km and a bandwidth of 0.2 MHz. Assume free-space conditions with the SNR varying as a function of R^4. The equation in the class notes should be modified slightly where the range accuracy, σ_R, is determined by "c / (2 B sqrt(2 SNR))" where SNR is a linear term.

Note – to start the tracker at 20 km for both "a" and "b," assume $V_{n-1} = 0$ and assume $x_{pn} = x_n$

4. (30 points) Power density problem, search detection, sizing of system

   Solid state, active radar comprised of T/R modules, with the following characteristics:

   i. Frequency = 3 GHz
   ii. Rectangular (square) array with T/R module spacing = λ / 2
   iii. Duty 10%
   iv. Noise Figure = 5.06 dB
   v. Total System Losses = 10 dB
   vi. Required detection SNR = 15 dB
   vii. Search volume = 0 to 50 degrees in elevation, 360 degrees in azimuth
   viii. Search frame time = 6 seconds

   a. (12 points) Using equation 2.44 and assuming a single, rotating phased-array, plot number of elements versus T/R module peak power for a radar that can provide 150 km detection against a 0 dBsm target.
   b. (8 points) From your plot, choose the antenna size with 90 W peak power per T/R module. Determine the number of beams required to search the volume assuming 3 dB spacing in real space (broadside beamwidth, NOT sine space).
   c. (5 points) Assume the instrumented range is 150 km as well as clear, single pulse dwells. What are the radar resources in ms required to do one complete scan?
   d. (5 points) With a pulsewidth of 50 us and a pulse compression ratio of 100:1 and a PFA of 10^{-6}, how many false alarms would you expect per single scan? (Remember, range eclipsing impacts the number of range cells such that the radar will only process returns from the minimum or eclipsed range to 150 km)

5. (15 points) Range-Doppler Space (Blind Zone Map)
    i. The clutter spread is ±25 m/s
    ii. The duty factor is 10%
    iii. For each map, use the following axes:
        1. Range Axis = 0 to 100 km
        2. Doppler (velocity) = 0 to 2000 m/s

    a. (6 points) Plot (electronically or by hand is fine) range-Doppler coverage (write on the graph the percentage of un-eclipsed range coverage and the separate percentage of clutter-free Doppler coverage). Also, specify the unambiguous Range and Doppler values. Frequency = 3 GHz and PRF = 5 kHz
    b. (5 points) Repeat "a" for the combined range-Doppler coverage of PRF-frequency pairs (5 kHz & 3 GHz and 6.6 kHz & 3.3 GHz). Find the unambiguous range and Doppler for this multiple PRF-frequency pair.
    c. (4 points) From the results of "b," plot the number of detection opportunities as a function of range for targets traveling 200 m/s, 500 m/s, and 600 m/s.