LULEÅ UNIVERSITY OF TECHNOLOGY
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**F7003R Optics and Radar Based Observations, 7.5 ECTS**

**Problems Part 2 (4 points)**
**General radar theory**

**1 (1 point)**
Explain what will determine the choice of the operational frequency for the scientific radar.
There are basically three different branches of the scientific radar: Doppler radar, incoherent and coherent scatter radars.

a) Describe in which frequency ranges these radars are usually operated.

b) Which atmospheric and/or ionospheric parameters do these radars measure, i.e. which information does the radar reflectivity provide?

**2 (1 point)**
Derive the simple form of the radar equation. Show the difference in radar equations for the hard targets and volume scatters. Explain the reason for that.

**3 (0.5 points)**
Derive the equation for estimation of the smallest detectable cross section for radar systems. Calculate the value of this cross section if the object is located at 100 km distance from the radar site, radar operational wavelength is 6 m, transmitted power is 10 kW, antenna gain is 20 dB, total system noise power is $10^3$ K, bandwidth is 1 MHz (Answer: 0.76 $m^2$)

**4 (1.5 points)**
MST (mesosphere-stratosphere-troposphere) radars are applied to study winds, waves, turbulence and instability in the atmosphere. They usually operate near 50 MHz and also called VHF radars (VHF-very high frequency band between 30 MHz and 300 MHz). The MST radars detect echoes from irregularities of the radio refractive index *n*. The refractive index variations in the atmosphere result from random irregularities generated by turbulence, steep gradients introduced by horizontal layering and structuring of the atmosphere. The refractive index variations are directly related to variations of the atmospheric parameters: humidity, temperature, pressure and electron density, and can be expressed by the following equation:

$$n = 1 + \left( 77.6 \cdot \frac{p}{T} + 3.75 \cdot 10^5 \cdot \frac{e}{T^2} \right) \cdot 10^{-6} - 40.3 \cdot \frac{n_e}{f_o^2}$$

where $e$ is the partial pressure of water vapour in mb, $p$ is the atmospheric pressure in mb, $T$ is the absolute temperature in K, $n_e$ is the electron number density in $m^{-3}$, $f_o$ is the radar operating frequency in Hz. The wet term, proportional to humidity, is usually most important up to the middle troposphere, whereas, in the upper troposphere and stratosphere, the dry term, proportional to pressure and inversely proportional to the temperature. At altitudes between 60 km and 100 km the refractive index is determined by ionisation and recombination processes. When atmospheric turbulence or perturbations in the electron gas density mixes the vertical profile of the refractive index and the associated gradients, fluctuations of *n* result, which in turn cause scattering and reflection of radar waves.

ESRAD (ESrange RADar) is VHF MST radar located in northern Sweden (67°56'N, 21°04'E) http://www.irf.se/program/paf/mst/ . It has been in near continuous operation since June 1996. The purpose of the radar is to provide information on the dynamic state of the atmosphere - winds, waves, turbulence and layering from the troposphere up to the lower thermosphere (1 km -100 km altitude). The transmitter frequency is 52 MHz corresponding to a wavelength of 5.77 m, 72 kW peak transmitter power is available with at least a 5% duty cycle. Pulse repetition frequency rates from 100 Hz to 16 kHz are possible. Pulse lengths correspond to height resolutions between 150 m and 3 km. The radar is capable of pulse coding the transmitted signals using both Barker and complementary codes. The radar has 6 separate receivers for detection of backscattered signals from the atmosphere. The complex (in-phase and quadrature) data samples are recorded using a 12-channel data acquisition unit. The bandwidth of the separate receiving elements is 2 MHz. Multiple receivers allow post-detection beam-steering and full spectral analysis of the returned signal. The digital processing system is able to process up to 256 heights per sample and integrates up to 4096 pulse repetitions per sample. The antenna consists of a 16 x18 phased array of 5-element Yagis, each being approximately 6 m high. The Yagis are spaced about 4 m apart (corresponding to 0.7 times the radar wavelength). Each group of 4 nearest neighbour Yagis is separately connected to the control house. This allows a large number of different antenna configurations using a patch board in the control house. The radar runs continuously, cycling between modes optimised for troposphere, stratosphere, or mesosphere. Special cycles, concentrating on one atmospheric region may be run from time to time, for example, in support of rocket or balloon campaigns at Esrange.

The height resolution obtainable with atmospheric radar is limited by the need to transmit a pulse of finite length. Since atmospheric properties change significantly within a few 10s a pulse should be as short as possible. However, the strength of the signal obtained from the atmosphere is proportional to the pulse length. Since the signal should be as strong as possible to be easily detectable above the natural noise, the radar pulse should be as long as possible. In practice we must always choose some compromise between these two conflicting demands.

Folder "HeightResolution". ASCII files TXT_date_test1 and TXT_date_test2 contain radar data with 150 m and 1200 m height resolutions. Each test has been run for 1 min. They were shifted by each other every minute:
Test 1 – 1 min
Test 2 – 1 min
Test 1 – 1 min
….

**Data format in the TXT-files:**

- UT
- Altitude
- Signal amplitude (linear)

- Signal-to-noise ratio (SNR), dB
- Zonal wind, m/s
- Meridional wind, m/s
- Vertical wind, m/s

a) Make plots of signal-to noise ratio (SNR) as a function of universal time (UT) and altitude for each pulse length. Use Matlab commands “pcolor”, “shading flat”, “colormap jet”. Matlab codes should be enclosed.

b) Calculate pulse lengths, inter-pulse periods, pulse repetition frequency and maximum unambiguous range for these height resolutions.

c) Derive the equation that shows relationship between the transmitted pulse length and the strength of the received signal. Support your theoretical results by the ESRAD experimental data.

d) Which part of the atmosphere is observed? Identify the atmospheric parameters that might determine SNR variations on your plots.

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