Optics and Radar based Observations F7003R, 7.5 ECTS
2012

Assignment 2
Pulse modulation techniques.

Assignment shall be done in a group of 2 people. Each group shall submit one report.

Introduction:

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). 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). ESRAD operates at a frequency of 52 MHz corresponding to a wavelength of 5.77 m. The transmitter consists of 72 1-kW solid-state modules that are grouped into 12 6-kW power blocks. The resulting peak power output power is 72 kW and the maximum duty cycle is 5%. 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 allows 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 12 x 12 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). The 4 central positions in the array are not filled so as to allow for a small hut, containing the transmitters, receivers and control computer, to be located at the centre of the array. 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. It also gives the possibility for phase-steering of the beam to off zenith directions. The array is located so as to allow for possible future expansion in all directions.

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.

Part 1. (Dr. A. Enmark)

Your task is to write an overview over some common pulse coding techniques. You shall study and compare the properties of long pulses, short pulses, phase coding with Barker codes and complementary codes, and frequency coding with LFM. Pulse coding can be studied using auto correlation and ambiguity functions. In your paper you shall use these tools to discuss and compare the properties of the different techniques. Your report shall include interesting plots illustrating the properties of the different pulse designs.

You will find a Matlab program on your Fronter course room. The program is based on code presented in Appendix 3A of the book:
N. Levanon & E. Mozeson, *Radar Signals*, John Wiley & Sons, Inc., Hoboken, New Jersey (2004).

The book is available on pdf-format on http://knovel.com (when you are logged on to the LTU network).

Part 2A.

Data files are available on Fronter under Assignment 2. Folder ”HeightResolution” contains data for Part 2A. Folder “Codes” contains data for Part 2B.

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
….
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”. Compare the results and make conclusions.

Part 2B.

Pulse coding is a signal-processing technique which allows the effective height resolution to be reduced while retaining the echo-strength of a longer pulse.

Folder "Codes". ASCII files TXT_date_test3, TXT_date_test4 and TXT_date_test5 contain radar data with Barker coding, complementary coding and uncoded data, respectively. Each test has been run for 1 min. They were shifted by each other every minute:
Test 3 – 1 min
Test 4 – 1 min
Test 5 – 1 min
Test 3 – 1 min
….
Make plots of signal-to noise ratio (SNR) as a function of universal time (UT) and altitude for each dataset. Use Matlab commands "pcolor", "shading flat", "colormap jet". Compare the results. Estimate values and directions of horizontal winds. Provide a short analysis of data.

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

Report

The structure of the report should be:

- Title page
- Introduction to the problem
- Part 1. Analysis and discussion. References should be given in the text.
- Parts 2A, 2B. Data analysis and discussion. References should be given in the text.
- List of references. Web pages are permitted.
- Implemented Matlab codes (Parts 2A, 2B)
- Confirmation that you have participated in the current work.

The length of the report (excluding the title page, Matlab codes and confirmation) should not exceed 10 pages. Please note that using "copy-paste" techniques will result in report rejection. Plagiarism will be reported to LTUs lawyer according to the Swedish national legislation.