A MODERN DATA ACQUISITION AND ANALYSIS METHOD FOR THE EISCAT INCOHERENT SCATTER RADARS

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ABSTRACT

In this paper a new data acquisition and analysis method for EISCAT (European Incoherent SCATter) incoherent scatter radars are presented. The system allows storing the incoherent scatter radar signal itself instead of its autocorrelation function estimates. Samples of scattered signals and transmissions are stored in a single data stream on hard disk. This solution has great benefits; e.g. the ground clutter can be eliminated with only a small loss in statistical accuracy, and the true phase of the transmitter in phase coded experiments can be measured. In data analysis a very flexible signal processing can be applied.

INTRODUCTION

EISCAT (European Incoherent SCATter) incoherent scatter radar systems operate in Northern Scandinavia and on Svalbard at 928.4 MHz, 224 MHz and 500 MHz (for detailed descriptions of the EISCAT radar systems see [1] and [2]). The sytems were established with the intention of making measurements on the ionised component of the Earth's upper atmosphere. Development work by the EISCAT community continually raised the measurement accuracy as well as the range and temporal resolutions. These developments involve both advances in hardware and innovations in modulation methods and data analysis (e.g. [3] and [4]).

As a further step in this development the present paper describes a new data acquisition and analysis method for the EISCAT incoherent scatter radars. This system was successfully tested both by the ESR radar on Svalbard and the EISCAT UHF and VHF radars in Tromsø with different versions of the hardware. Only the ESR (acronym for Eiscat Svalbard Radar) version using a new experiment is described here.

In Fig. 1 the standard ESR receiver is drawn on the left and the new data acquisition system which has been connected in parallel with the standard receiver is shown on the right. In this kind of arrangement one can record the data in both systems simultaneously. For descriptions of standard reciever, see [2]. In the new reciever, the 70 MHz IF signal was taken into a spectrum analyser acting as a combination of a downconverter, an AD converter and a quadrature detector. In the spectrum analyser the signal was first mixed down to 6.4 MHz and then sampled by a 12-bit AD converter at a frequency of 20.0 MHz. Subsequently, the nominal frequency was downconverted to zero by means of a digital mixer. After a digital low pass filter and a decimator, complex digital samples at a rate of 4 MHz were obtained. The samples were then fed into a PCI-bus based programmable digital I/O card (GURSIP by Invers Oy, Finland), which performed a 4-sample summing operation to give an effective sampling rate of 1 MHz, large enough to span all the frequency channels used. Finally the resulting samples were stored on hard disk. Sampling is continuous and therefore it also contains samples of the transmitter modulation. Unlike a conventional receiver which separates each transmission frequency into its own channel, this arrangement produces a single data stream which contains all frequency channels in a sequence of I/Q detected complex samples. Quite flexible signal processing is used later which includes channel separation, clutter removal, Barker decoding, lag profile calculation and mathematical inversion (for details see [5]).

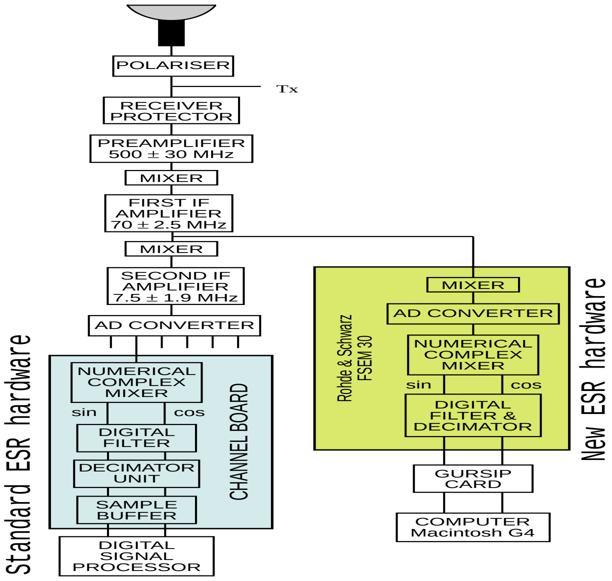

Fig. 1. Schematic diagram for ESR data acquisition system

EXPERIMENT

The first measurements with the new method was conducted on November 16, 1999 using the EISCAT radar on Svalbard. Detailed descriptions of this experiment are presented in [6]. Here the main features are briefly reviewed. The experiment applies an unconventional modulation principle. It consists of two different modulations at two frequencies as shown in Fig. 2. A 22-bit code with a sign sequence $+ - - - + + + - - - - + + + + + - + - + -+$ is first transmitted at 500.25 MHz. Each bit is further modulated by a 5-bit Barker code $+ + + - +$ with a bit length of 6 μs. After a 6-μs gap, a second modulation with a 5-bit code $+ + + + -$ is transmitted at 499.75 MHz. Also this code is modulated by a 5-bit Barker code with a 6-μs bit length. The lengths of the 22-bit and 5-bit codes are 660 μs and 150 μs, respectively, and that of the total transmission pattern is 816 μs.

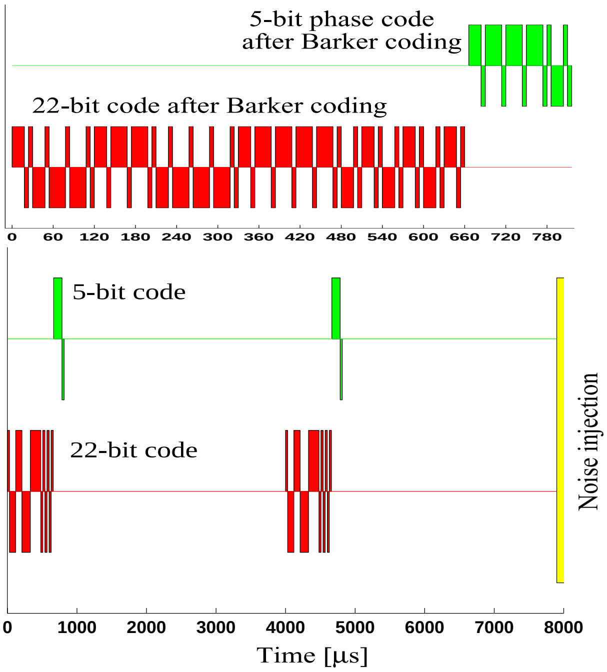

Fig. 2. Modulation envelopes of the experiment before Barker coding (bottom panel) and after 5-bit Barker coding (top panel)

The transmissions are repeated at intervals of 4000 μs, and a 80-μs noise injection is inserted at the end of every second interval. Thus the total length of the experimental cycle is 8000 μs. Samples of the two transmissions and scattered signals are recoded in a single data stream. Thus in data analysis the two channels must first be separated. This can be made by means of digital mixing and low-pass filtering as shown in [5]. Next the ground clutter has to be removed. When the sample profiles are available, this can be made with practically no loss of statistical accuracy. The method is based on the fact that ground clutter is stationary. It is accomplished by subtracting from each sample profile an average sample profile calculated over a time interval long enough to make the mean scatter signal to zero. The next step is Barker decoding which is made using an unconventional filter. Unlike the conventional Barker decoding, this filter produces no sidelobes. In principle the impulse response of such a decoding filter has an infinite length, as already pointed out by [7]. The impulse response is not needed in practice, however. It turns out that this can be done in a convenient way using Fourier transforms (for details see [6]).

ESTIMATION OF PLASMA AUTOCORRELATION FUNCTION

The experiment gives full lag profiles at multiple values of the bit length of the 22-bit and 5-bit codes at $n \times 30\mu$s, where $n = 0, 1, ..., 21$. In addition to this full lags, fractional lags [8] at $n \times 30 \pm 2$ and $n \times 30 \pm 4$ are calculated. We have also calculated the corresponding range ambiguity function from the transmission samples. For example, the real part of 30μs lag range ambiguity function calculated from 5-minute post-integrated samples of 5-bit code is displayed on the left panel of Fig. 3 (after 2-μs decimation). Here range ambiguity function with its leading edge near 96km shows the four separate height ranges that contribute to one value of the 30μs lag profile. A 30μs lag profile calculated from 5-minute post-integrated scattered signals is shown on the right panel. Sporadic-E layer (around 100km) and space debris (around 400km) are seen in multiple copies. The other lags and the corresponding range ambiguity functions are calculated in a similar way. Finally, the range ambiguity problem is solved by means of mathematical inversion. The short lags are obtained both from the 22-bit and the 5-bit code. Thus we have many measured lag values, and statistical inversion is directly applied. In the case of longer lags the number of measurements and the number of required lag values from the inversion are the same, and therefore regularization is used to produce unambiguous lag profiles for all lags (for lags 1-4 this would not be necessary). Finally, each full lag and the neighbouring fractional lags are combined to single lag profile, also by means of mathematical inversion. Calculation of each lag profile is treated as a separate inversion problem and data from both frequency channels is combined for shorter lags (e.g. see Fig. 4). The mathematical solutions of this problem are shown in [5].

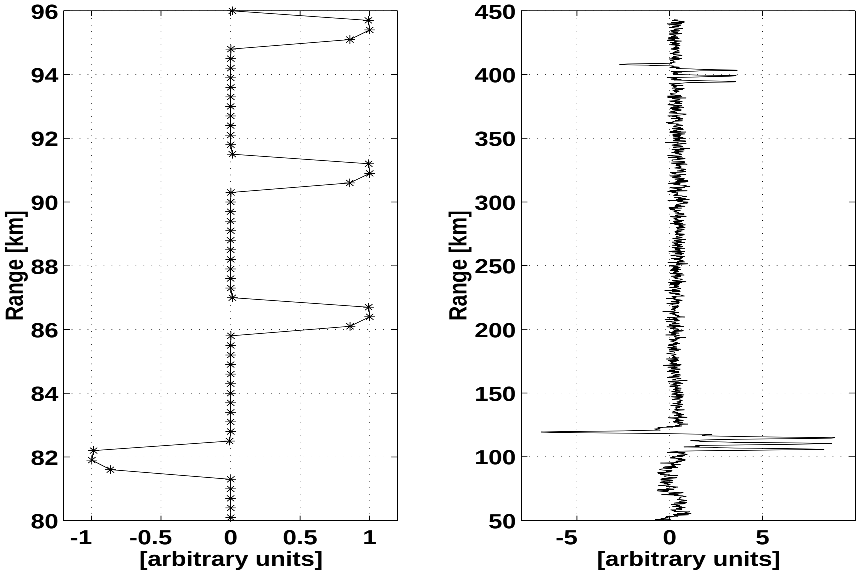

Fig. 3. Real part of 30μs lag measured range ambiguity function (left panel) and real part of 30μs lag profile (right panel) for 5-bit code

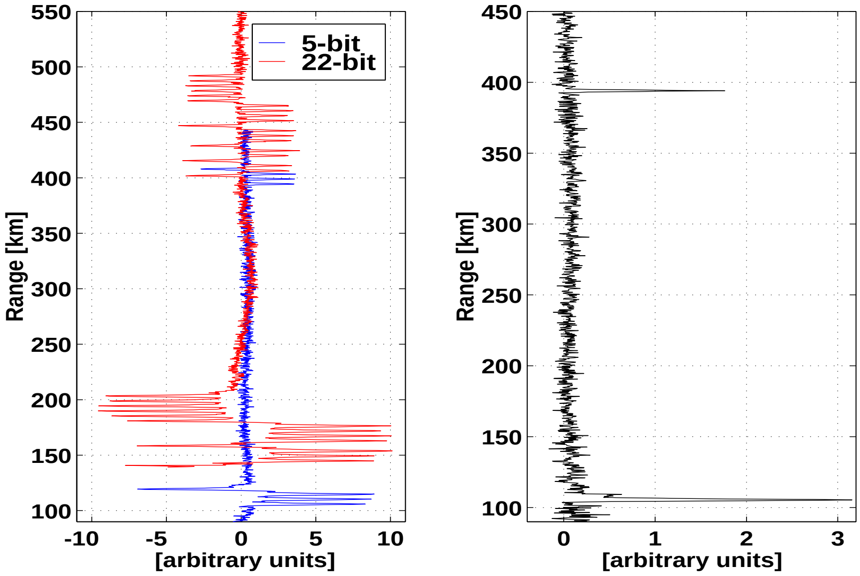

Fig. 4. Real part of 30μs lag profiles from the two modulations (left panel) and real part of unambiguous lag profile obtained from inversion (right panel)

The real parts of 30μs lag profile shown on the left panel of Fig. 4 was obtained by combining the real parts of 26μs, 28μs, 30μs, 32μs and 34μs lag profiles from the two modulations with 5-minute temporal and 150-m range resolution by means of mathematical inversion. As a conclusion, the data acquisition and analysis system described here do work in practice.

ACKNOWLEDGEMENTS

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