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SOLVING THE RANGE-DOPPLER DILEMMA WITH THE SMPRF PULSE CODE, PRACTICAL RESULTS FROM A REAL RADAR

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1. INTRODUCTION

Based on the measurement principles used on Incoherent Scatter Radars, we have developed a pulse code that completely solves the range-Doppler dilemma and can be used with modern magnetron radars.

Fluctuations of the plasma spectrum in the ionosphere, the part of the Earth's atmosphere from the 70 km altitude up to 1000 km and beyond, may well be the most demanding radar target of today. Not only is the signal from the sparse electron gas very weak, but wind speeds are high, reaching occasionally several km/s. In a typical F-region (200–500 km altitude) measurement, for example, the maximum possible pulse separation needed for velocity measurement can be two orders of magnitude shorter than the minimum pulse separation required to make the ranges unambiguous. In the same ionosphere, the lower E and D layers may simultaneously have coherence times of the order of one second.

For this reason the measurement principles in incoherent scatter radars are more complicated and in many ways more advanced than the methods in other radar applications.

2. A NEW WAY OF CODING

Modern magnetron based weather radars allow one to send pulses of changing duration and with changing pulse separation. By using the latter feature alone, it is possible to design a coding which can solve the long standing problem of weather radar measurement, the range-Doppler dilemma. The solution has been presented in the COST 75 final seminar (Pirttilä et al., 1999) with an example of a code that could be used in practice and simulation-based evaluation of the performance of the code. The name of the code is SMPRF, which stands for Simultaneous Multiple Pulse Repetition Frequency code (Lehtinen, International Patent Application, 1999).

In the following (Huuskonen, 2000) we try to make the patented method more tractable by explaining in detail how the code works. For this purpose alone, let us assume a a very simple code which contains only four different pulse separations: 5, 8, 10 and 7 time units. The sum of the separations is 30, which means that the code repeats in steps of 30 time units.

Assume now that samples are taken at 1 time unit apart and that the longest distance producing significant scatter is 20 time units. Figure 1 shows that at time instant 31 the pulse sent at time 30 is at a distance of 1 unit, and the previous pulses at distances 8, 18 and 31. Thus the signal recorded represents a sum of contributions from distances of 1, 8 and 18. We can neglect any previous pulse because of the assumption that no significant scatter is obtained from distance greater than 20 units. The pulse locations are given in Table 1. Figure 1 shows the pulse locations for sampling times 31, 36, 47 and 52. As no data can be recorded when a pulse is being sent, there will be no data from times 35, 43, 53 and 60.

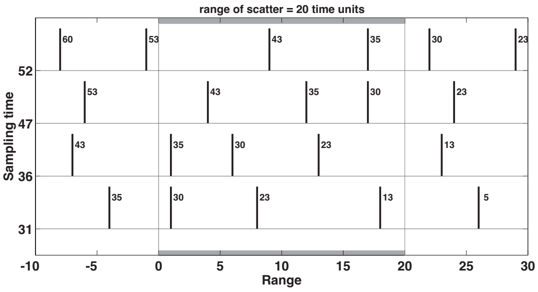

Figure 1: Pulse locations at four time instances (31, 36, 47 and 52 time units).

3. THE RAW RADAR DATA

3..1 The reflectivity data

The power values are obtained by squaring the signal samples and averaging them over the integration period. Thus the pulse location as given in Table 1 also give the contribution ranges in the power estimates. It is seen that the power estimates are ambiguous because they represent sums of powers at many ranges. A closer look at the numbers shows that the combinations of ranges are different at each time instant. Thus we may form a set of linear equations, where we have 26 equations and 20 unknowns, and can solve for the power at each range. The number of equations is less than 30, because there are 4 time instants when a pulse is sent and no data is recorded. In this way we obtain

time	ranges	time	ranges	time	ranges
31	1, 8, 18	41	6, 11, 18	51	8, 16
32	2, 9, 19	42	7, 12, 19	52	9, 17
33	3, 10, 20	43	no data	53	no data
34	4, 11	44	1, 9, 14	54	1, 11, 19
35	no data	45	2, 10, 15	55	2, 12, 20
36	1, 6, 13	46	3, 11, 16	56	3, 13
37	2, 7, 14	47	4, 12, 17	57	4, 14
38	3, 8, 15	48	5, 13, 18	58	5, 15
39	4, 9, 16	49	6, 14, 19	59	6, 16
40	5, 10, 17	50	7, 15, 20	60	no data

Table 1: Locations of the contributing pulses for sampling times 31 ... 60.

an unambiguous power profile from the ambiguous observations.

It is instructive to compare the solution with the solution possible when using standard weather radar coding. A similar case appears when velocity is measured with standard Doppler weather radars; the pulses must be sent so close to each other that the power values are not usable. However, the solution presented above is not possible, because each range appears always in an identical combination of ranges.

3..2 The I and Q signals

A Doppler velocity estimate requires that we measure in-phase and quadrature samples of the signal. We can conveniently combine the I and Q samples together to form a complex sample $x_t = I_t + iQ_t$. In standard weather radars the phase angle is determined relative to the transmitted pulse, but it may also be determined relative to a fixed free running sampling clock.

An estimate of the autocorrelation function at a lag value is obtained by multiplying two complex samples together, and averaging over a chosen integration time. Now take samples x_{31} and x_{36} as examples. As seen from Table 1 and Figure 1, the first get contributions from ranges 1, 8, and 18 and the second from ranges 1, 6 and 13. The important thing to note is that scattering from two different scattering volumes does not correlate in the statistical sense. Thus the product $x_{31}x_{36}^*$ gets a statistical correlation from range 1, the scattering from other ranges only appearing as noise. When the same measurement is repeated and products averaged, the expected value of the product is the estimate of the autocorrelation function at range 1 and time delay 5 time units. The pulse locations for range 17 are shown in Figure 1. We see that the non-contributing pulses are now located at closer ranges than the pair producing correlation. This does not hamper the determination in any other way than by the fact that the signal from the non-contributing pulses may be strong compared to the contributing pair.

We will get a statistical contribution for any lag value, which corresponds to any pulse separation in the code. These include in our case 5, 7, 8, 10, 12, 13, 17, 18, 20, 22, 23, 25 and so on.

4. PRACTICAL RESULTS

The Finnish Meteorological Institute has set up a new weather radar on top of the Luosto fell (67°8' N, 26°54' E, 514 m a.s.l.). This radar is a fairly standard magnetron based weather radar from Gematronik GmbH, where the only different feature from the standard is the signal path, which is divided in two branches.

In operational use, the transmitter is controlled by Sigmet RxNet7 signal processor and the signal path that leads to the Sigmet receiver is used. In development use, the transmitter is controlled by Invers Ltd's GURSIP signal processing solution and the corresponding branch of the signal path is used. Our GURSIP solution handles the transmission of the SMPRF codes, sampling of the signal (@30 MHz IF), detection of the signal and first stages of the signal processing chain. From the GURSIP the data was transferred to a powerful RISC workstation running BSD UNIX. Decoding of the SMPRF codes, extended pulse pair processing and analysis of the data is then performed by the workstation off-line. The first SMPRF-measurements were carried out in November 2000. The radar antenna was scanning at 8°/s and 0°elevation angle. The raw data from the radar was recorded on the disk. All the signal processing and data analysis was the done off-line. The test procedure consisted of two measurements: ”ground truth” and SMPRF. The ”ground truth” was measured with a simple pulse sent at constant low PRF. The raw signal from this measurement (fig 2) shows ground clutter together with a small snowfall area.

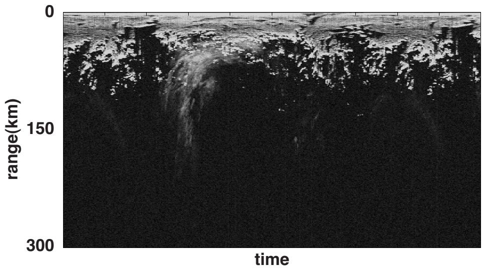

Figure 2: Log10 of the absolute value of the signal measured with the ”ground truth” measurement.

The second measurement was an SMPRF-measurement carried out immediately after the ”ground truth” measurement. Estimate of the reflected power was decoded from the SMPRF-measurement, and the result is shown in figure 3. When one compares the figures 2 and 3, it is easily seen that decoded power from the SMPRF measurement shows exactly the same features as the signal from the ”ground truth” measurement. This shows, that from the SMPRF code it is possible to decode the power estimates also in practice. Note, that at this point we have done nothing to filter out the ground clutter.

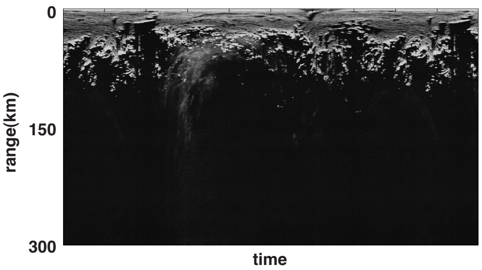

Figure 3: Log10 of the SMPRF power estimate.

The extended pulse pair processing over the SMPRF-code provides us with a handsome number of estimates of the autocorrelation function of the signal. A measured ACF and the corresponding spectrum is shown in figure 4

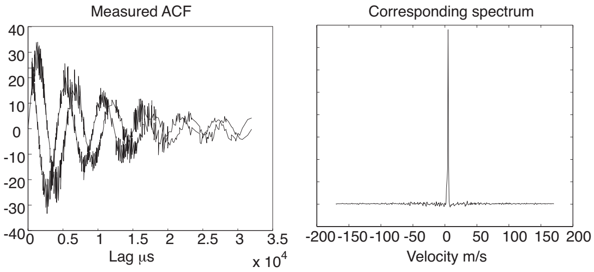

Figure 4: Measured autocorrelation function (left) and the corresponding spectrum (right).

All of these ACF-estimates are used to estimate the spectral moments of the power spectrum of the signal (Z, v, W). This analysis assumes that the spectra might contain ground echo component that has certain characteristics. In addition we assume in the analysis that the spectra might also contain weather echo components.

From the spectra we estimate the parameters of the ground echo component, which are ignored. The traditional basic parameters estimated from weather radar data (Z, v, W) are then the moments estimated from the weather echo component. Reflectivity and radial velocity are shown in figures 5 – 6.

5. SUMMARY

The SMPRF-code is able to solve the long-standing problem of weather radar measurements, the range-Doppler dilemma. The varying pulse separation makes it possible to measure ACF-estimates at a number of suitable lag values. Simultaneously the code produces these ACF-estimates for any number of range gates. The only limiting factor for real time operation is the processing power available from the radar signal processor.

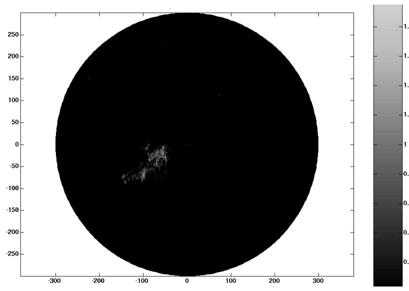

Figure 5: Reflectivity estimates of the weather echoes after ground clutter removal.

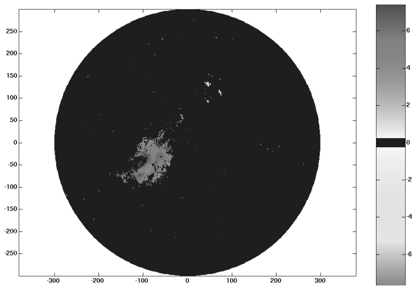

Figure 6: Velocity estimates of the weather echoes.

The practical results from the FMI Luosto radar show, that the code works also in practice with a standard magnetron weather radar. So far the signals were processed off-line.

6. ACKNOWLEDGEMENTS

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