A Passive Multistatic CW Radar System using Geostationary Illuminators

Steffen Thölert, Microwaves and Radar Institute, DLR, Oberpfaffenhofen, Germany
David Hounam, Microwaves and Radar Institute, DLR, Oberpfaffenhofen, Germany

Abstract

In this paper a new passive radar system using a geostationary TV satellite as an illuminator and ground-based receivers is presented. The system can be operated as a monostatic or multistatic radar and can be used for target detection or reflectivity measurements. Full polarimetric operation is possible. The measurement technique and the system hardware of an experimental system are described, particular attention being paid to the methods of signal synchronization. The results of experiments with the radar are presented and future developments discussed.

1 Introduction

A bistatic synthetic aperture radar (SAR) system, based on a ground receiver receiving scattered signals transmitted by a geostationary digital TV satellite has been presented previously [1]. The radar is parasitic in the sense that it uses signals which are transmitted for other purposes. To resolve the echoes, they are correlated with the directly received satellite signal from an antenna directed toward the satellite. The receivers for the reflected and direct signals need to be synchronised to maintain coherence.

First experiments were performed with the receivers being fed with the same local oscillator signal. This has the limitation that the receivers cannot be placed far apart, otherwise cable losses and instability become too great. Hence, techniques were investigated to separate the receiver positions and maintain coherence. With freedom to place the receivers apart, monostatic, bistatic and multistatic systems can be realized. An additional advantage of such a passive system is the low cost in comparison with other radar systems, due to the fact that signal sources already exist and for most of the microwave hardware, commercial TV satellite components can be used.

Using the daily motion of the geostationary satellites, a synthetic aperture can be achieved of about 60-80km over 12 hours. The resolution depends on the geographical location and the local topography.

2 Working Principles of the passive System

A digital TV signal transmitted by a geostationary satellite serves as the signal source. This signal is directly received, as a reference, by a commercial satellite receiver with parabolic reflector. As the second receiver, a horn antenna including an LNB (Low Noise Block), is pointed towards the ground to receive the scattered echo. Both signals are down converted, digitised and then cross-correlated to perform range focusing. Scatterers at different range positions will produce peaks in the correlation.

3 Hardware

Coherent System

A two channel coherent receiver is is shown in Figure 1. In the following we call this coherent system the reference system. The system consists of two antennas, a receiver, a digital oscilloscope (used for A/D conversion) and a computer.

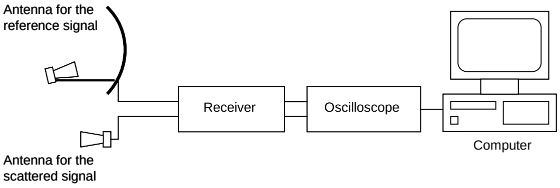

Figure 1 Block diagram of the coherent receiving system

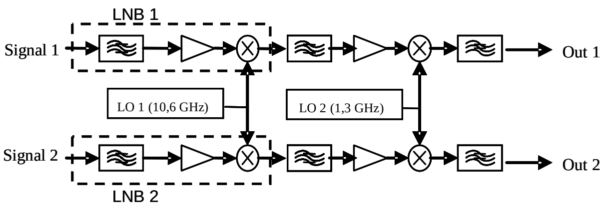

Figure 2 Schematic of the coherent receiver

The receiver is shown in Figure 2. The first stage of each channel uses a commercial TV-Sat low noise block (LNB) as input filter, amplifier and down converter. The LNBs are modified so that an external local oscillator signal at 10.6 GHz can be applied. The second stage performs another coherent down conversion using a common local oscillator at about 1.3 GHz. The output filters are low pass filters with 200 MHz bandwidth.

The signals of both channels are digitized using a four channel digital oscilloscope (8 bit ADC). The sampling rate is 500 MSamples/s. The oscilloscope is controlled via GPIB by a computer, on which the acquired data finally stored.

The coherent system gave good results but for multistatic applications the coherent hardware structure is not practicable. Thus, a system was investigated using the internal oscillators of the LNBs.

Incoherent System

The receiver structure with unmodified LNBs and without the first external oscillator is shown in Figure 3. The rest of the circuit is the same as in the coherent system.

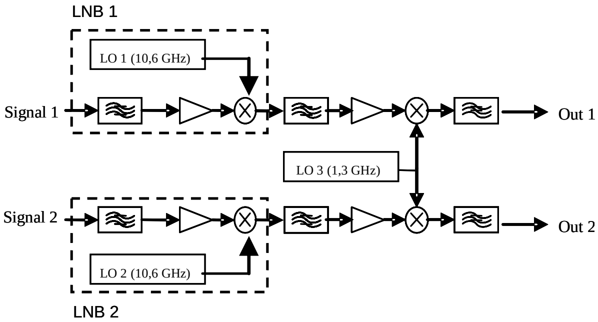

Figure 3 Schematic of the incoherent receiver

The difference between the incoherent and the coherent system is that the local oscillator frequencies in the two channels are different and can drift over time. For synchronization with the incoherent system, we assume that the drift is negligible during the data acquisition time (it's around 250 µs). The difference in local oscillator frequencies is not negligible and the result is a shift in the frequency spectrum between the reference and scattered signals. The method to correct this frequency offset is described below.

Incoherent Undersampled System

To reduce the complexity of the receiving system further, the band-pass undersampling technique is used [3]. The idea behind this method is to use the A/D converter as digital down converter. Therefore, the IF signals have to be limited with a band-pass filter.

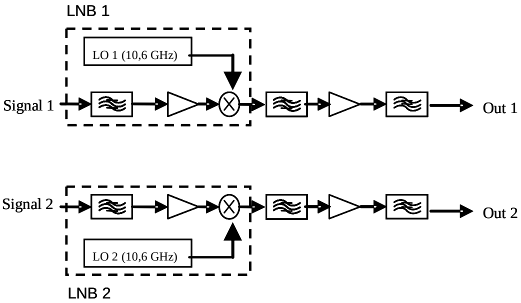

Figure 4 Schematic of the incoherent receiver for undersampling and dispensing with the second down conversion

The circuit of the receiving system is shown in Figure 4. In comparison to the receiving system shown in Figure 3 the second stage of down conversion is omitted. Instead of the second mixer the sampling rate of the digital oscilloscope is in the range of the second stage local oscillator frequency (around 1.3 GHz).

4 Signal Processing

The data acquired by the digital oscilloscope are real samples. In the first processing step they are transformed into complex signals. This is realised by a Hilbert transformation. If we have coherent input signals from the system as shown in Figure 2, we can directly correlate the reference und the scattered signal. A convenient way to perform the correlation is a multiplication of the two signals transposed into the frequency domain followed by an inverse Fourier transformation. The result is the range focused signal. To reduce side lobes, a Hamming filter is used in the frequency domain.

For the incoherent system the processing is somewhat different, as it is necessary to find the frequency offset of the direct and reflected signals and correct for it. The idea is to perform an iterative process shifting the spectrum of the scattered signal and then correlating it with the reference signal. At the position where the both spectra are identical, the correlation has its maximum peak, corresponding to the frequency shift Δf between the two LNB oscillators. The range of the shift will be around +/-3 MHz according to typical LNB specifications.

Now the range compression can be performed with the shifted spectrum of the scattered signal. The steps of the processing for the incoherent system are shown in Figure 5.

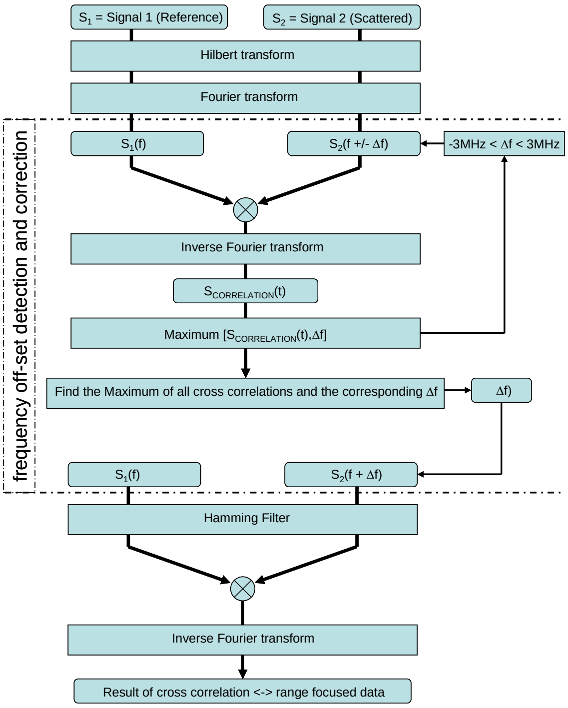

Figure 5 Schematic of signal processing of the data acquired by the incoherent system

For the undersampled incoherent system, the processing is similar. The only difference is in the scaling of the range, due to the different sampling frequency.

5 Experimental Results

The first experiment was to demonstrate that the incoherent system is working as well as the coherent system (Figure 6). Both receivers are pointed directly towards the Astra 1H satellite.

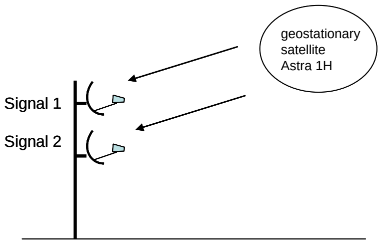

Figure 6 Experimental setup to investigate range focusing

A single transponder channel with a bandwidth of 25 MHz is used. The acquisition time is 250 µs. Data acquisition is performed simultaneously for both systems. After the range compression the results are compared (see Figure 7 and Figure 8).

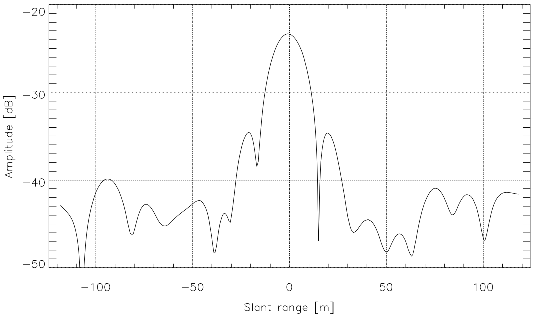

Figure 7 Range focused data of the coherent system with both antennas pointed towards the satellite, 25 MHz signal bandwidth

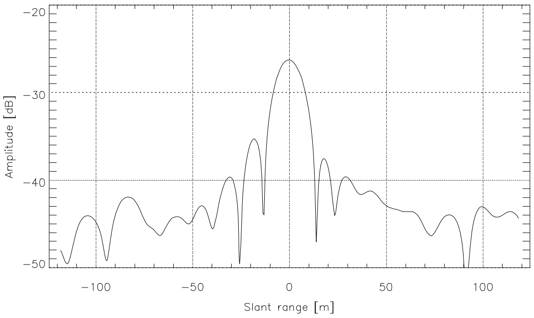

Figure 8 Range focused data of the incoherent system, both antennas pointed towards the satellite, 25 MHz signal bandwidth

The results are very similar. The difference in amplitude is caused by the different gains of the modified and the unmodified LNBs.

A further experiment performed on the DLR site, was to demonstrate the function of the incoherent systems on a real test scene (Figure 9). Measurements were performed with both the coherent and incoherent systems.

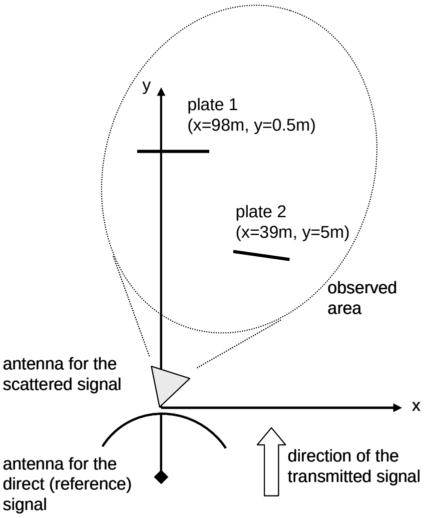

Figure 9 Observed scene for quasi monostatic scattering

Two metallic plates are used as strong targets. They have a size of one square meter and are placed as shown in Figure 9.

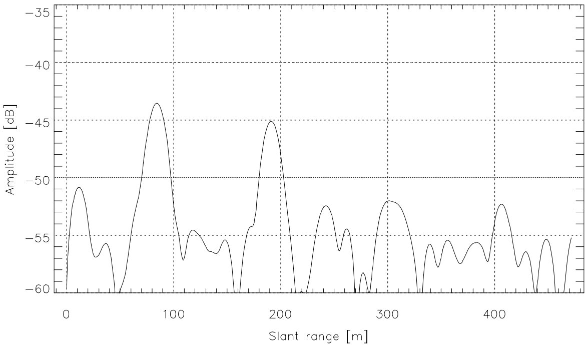

Figure 10 Range focused data of the coherent system from scene in Figure 9. The peaks at 80 m and 190 m are due to the metal plates.

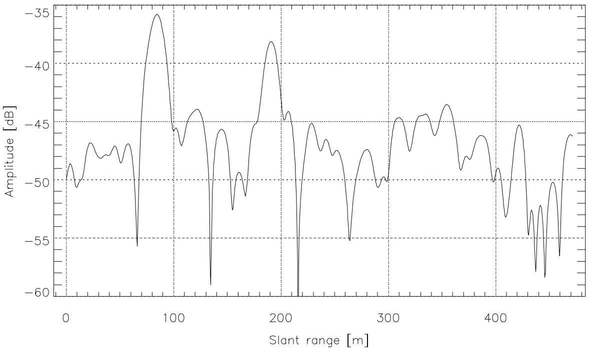

Figure 11 Range focused data of the incoherent system from scene Figure 9 with strong peaks from the metal plates.

Like in the first experiment a single transponder channel with 25 MHz bandwidth is used. The acquisition time is again 250 µs. The measured range focused data are shown in Figure 10 for the coherent system and in Figure 11 for the incoherent system.

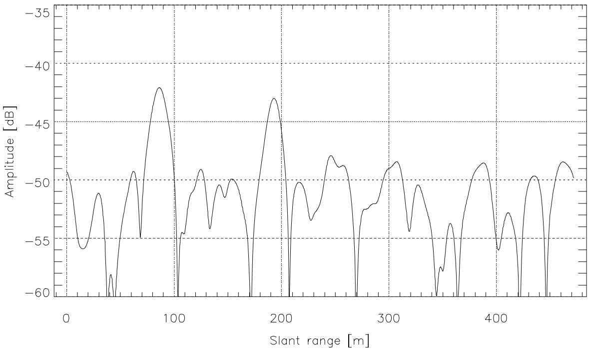

Figure 12 Range focused data of the incoherent band-pass undersampled system from the scene in Figure 9. Again the peaks from the metal plates can be clearly seen.

Both targets are clearly visible in the range focused data for measurements of both systems. The smaller amplitude of the second target is caused by the larger distance in range.

Figure 12 shows the range focused signal for the system worked with sub-sampling.

6 Conclusion

A passive radar system was described allowing detection of objects and measurement of reflectivity with cheap components. It was experimentally shown that the incoherent system and a system with undersampling give comparable results to a coherent system. The undersampled system is even simpler as it dispenses with the second stage of mixing. The frequency offset due to using unmodified LNBs with free-running oscillators is compensated during signal processing.

In this paper we focused on the processing in range. The azimuth focusing can be achieved either by using the movement of the geostationary TV satellites or by moving the receiving antenna. As the satellite transmits signals in vertical and horizontal polarisation, a fully polarimetric measurement system could be constructed.

7 Acknowledgements

The authors wish to thank EADS, Ulm, Germany for supporting the work and SES GLOBAL/ASTRA, Luxembourg for providing orbital data for the Astra 1H/F and Thomas Molkenthin for assisting us with the measurements.

References

[1] L. Cassani, C. Colesanti, D. Leva, G. Nesti, C. Prati, F. Rocca, D. Tarchi, “A Ground-Based Parasitic SAR Experiment”, IEEE Transaction on Geoscience and Remote Sensing, Vol.38, No.5, Sept.2000, pp. 2132-2141

[2] L. Cassani, C. Colesanti, “Esperimenti di SAR passive con illuminatore quasi geostazionario e recevitore a terra”, Tesi Laurea Ing. Telecommun., Politecnico di Milano, Italy 1998

[3] Application Note No.3628, „Mathematical Basics of Band-Limited Sampling and Aliasing“ MAXIM Semiconductor Inc., Sept. 2005