SS-BSAR with Transmitter of Opportunity - Practical Aspects

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Abstract

This paper presents progress in the study of Space-Surface Synthetic Aperture Radar (SS-BSAR). The signal processing required to acquire an image is reported and results obtained after processing experimental data are presented

Keywords: bistatic synthetic aperture radar, space-surface radar, non-cooperative radar,

Introduction

Synthetic aperture radar (SAR) generates high-resolution images of the earth's surface by integrating returns along the flight path of the radar platform. Although the radar's transmitter and receiver are on the same platform in a monostatic SAR, the transmitter and receiver can be separated to form a bistatic SAR (BSAR), one form of which is *Space-Surface Bistatic SAR* [1]. This consists of a space-borne transmitter and a receiver mounted on an aircraft (Figure 1). One of the peculiarities of the SS-BSAR architecture shown in Figure 1 is its asymmetric structure. This is in contrast to a more usual BSAR configuration where the transmitter and receiver are moving along collinear trajectories.

The SS-BSAR topology fits well with the use of non-cooperative transmitters (NCT) such as broadcasting, communications, or navigation satellites. As a result, SS-BSAR with NCTs has generated a lot of interest in the recent years [2-6].

The main aim of the current project is the comprehensive study of SS-BSAR with an airborne receiver, utilising microwave emissions from global navigation satellite systems (GNSS) as the ranging signals. Experimental confirmation of the main results is included in the programme.

Our previous publication [2] discussed the hardware developed to study SS-BSAR experimentally. This paper focuses on the signal processing required to acquire an image and highlights the results obtained after processing experimental data. For experimentation, GLONASS satellites are used as the NCTs. Although we are using a particular satellite system, the structure and main parameters of the radar system are generic and could be used with different space-borne transmitters.

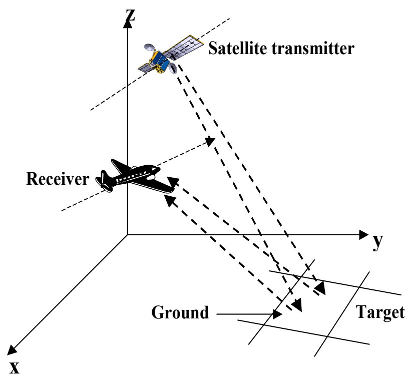

Figure 1 *SS-BSAR with NCT*

GLONASS Signal Structure

Figure 2 shows a block diagram of the structure of GLONASS signals transmitted in the L1 frequency band [7]. The C/A and P-code signals are in phase quadrature. The

C/A code rate is 511 KHz and the code period is 1 msec. The C/A code sequence is added (mod 2) to a 100 Hz navigation message. The P-code has a chip rate of 5.11 MHz and is a truncated M-sequence repeated every 1 sec. The navigation message on the P-code has a clock rate of 50 Hz.

The P-code will be used for the purpose of imaging, as it provides a reasonable range resolution of about 30m(quasi-bistatic case) and is no longer encrypted. It is worth mentioning that utilisation of a GALILEO satellite signal would improve the range resolution to about 15 m

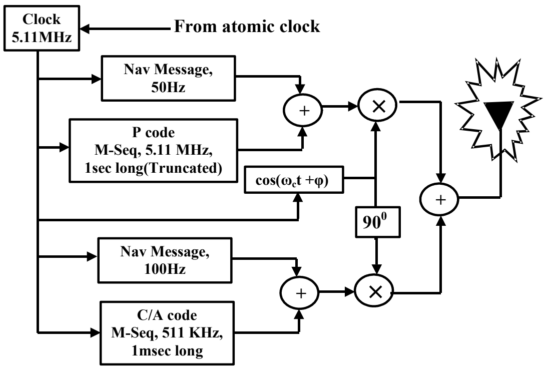

Figure 2 *GLONASS signal structure*

Interference Problem

Using GNSS as an illuminator in SS-BSAR presents a problem in signal detection. In addition to the desired target echo, a number of interference signals are present in the system. GNSS signals are modulated continuous waves and the desired reflected signal has to be detected against a continuous interference background. The first type of such interference is direct path interference, which is the signal received directly by the radar antenna from the illuminating satellite. The second type is co-channel interference coming from another GNSS satellite operating in the same frequency band. These interference sources were discussed in [3].

In GLONASS, there is another internal source of interference, which is the presence of the C/A code when using the P-code as the ranging signal. It should be noted that this interference would also be present in a GPS signal, which has a structure similar to that of a GLONASS signal.

The spectra of the P and C/A codes in the transmitted signal overlap (Figure 3-a). The C/A code has 10 times narrower bandwidth compared with the P-code. At the range output of the multi-channel correlator, the P-code will be masked by the C/A code (see Figure 3-b). Therefore the C/A code needs to be filtered at the receiver before any appropriate signal processing is applied for antenna synthesis. This process is not complicated, if only one satellite is present. It involves filtering out the C/A code in the heterodyne channel (HC), by means of highpass filter, before correlating it with the radar channel (RC). Figure 3-c shows the correlation, when the C/A code is filtered in the HC. It is evident that the effect of C/A is suppressed.

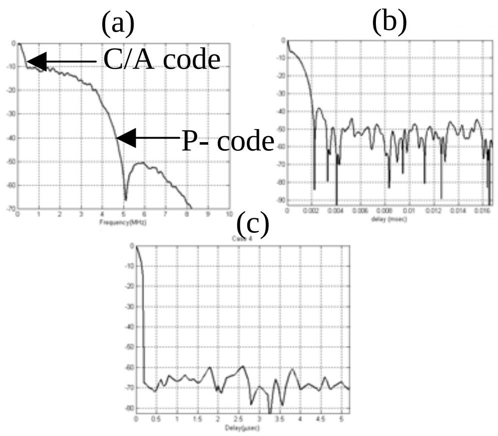

Figure 3 *(a) Spectrum of GLONASS signal. (b) Correlation between HC and RC before filtering of C/A code.(c) Correlation after filtering C/A code in the HC.*

However, in a practical scenario multiple satellites are present; even if the C/A code of the desired satellite signal is filtered out, the signal correlation properties are degraded by the C/A code of the interfering satellites (see Figure 4-a,b,c,d). One possible solution is to correlate the RC signal with a locally generated P-code.

Figure 4-e shows this correlation; clearly, the effect of the C/A signal is suppressed. However, a 50 Hz navigation message is superimposed on the received P-code in the RC and, as a result, one cannot directly correlate the RC with the locally generated P-code. Therefore we propose modification of the locally generated signal. This involves message decoding, which in turn requires signal synchronisation. The correlation process (range compression) is explained as follows

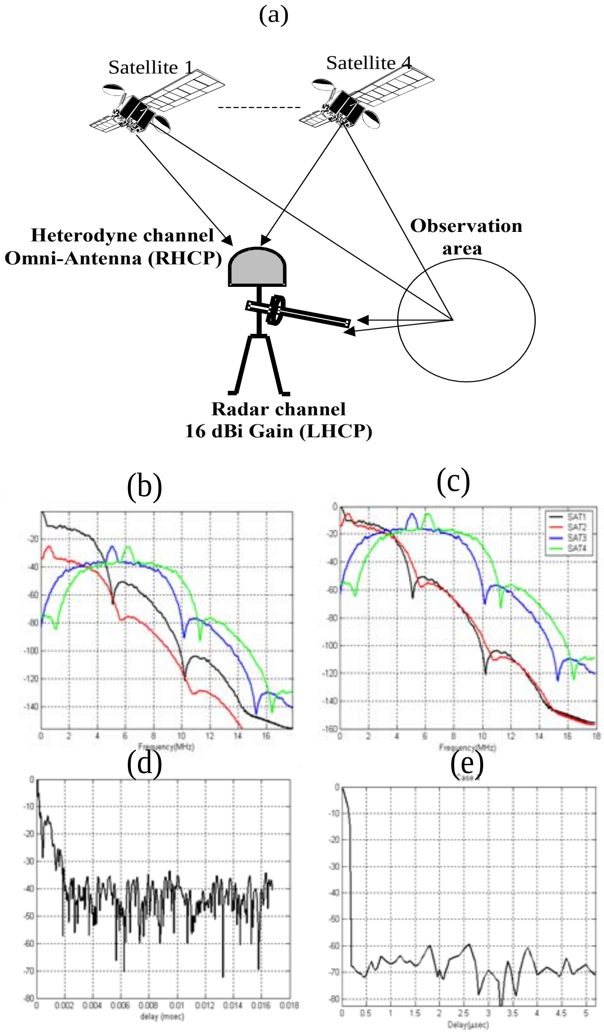

Figure 4 *(a) Received signals (b) Spectrum of HC Signal. (c) Spectrum of RC. (d) Correlation after filtering C/A code in the HC. (e) Correlation between C/A+P-code and only P-code*

Figure 5 shows the proposed range compression algorithm. The reference signal is fed to a standard multi-channel correlator, which uses multiple delay settings to search for the correct range. To generate the reference signal, the locally generated P-code is first synchronised (in delay, Doppler and clock) with the satellite signal received at the HC. The synchronised P-code is then used to decode the message signal from the HC. The message signal is added (mod 2) to the synchronised P-code to generate the reference signal for the correlator. The output of the correlator will have the effect of C/A code interference suppressed, as demonstrated in Figure 4-e.

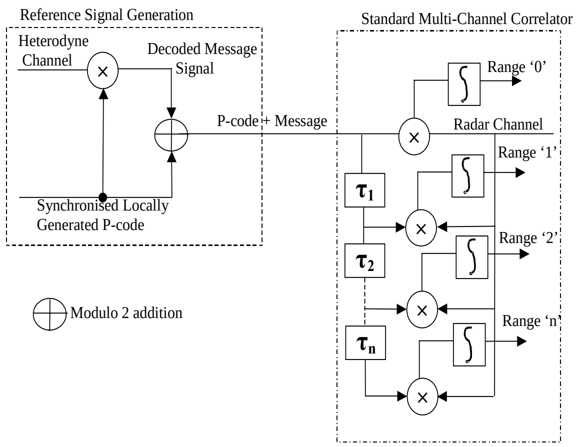

Figure 5 *Propose Range Compression Processing.*

Synchronisation

Figure 6 shows a synchronisation overview. The synchronisation consists of:

- Doppler and phase extraction using the C/A code. The C/A code is utilised due to its short duration, which imposes less computational load. The 'Block Adjustment of Synchronising Signal (BASS)' algorithm was used for Doppler extraction [8].
- The extracted Doppler frequency and phase removes the Doppler shift and phase from the P-code. The P-code is then used to recover the transmitter clock. The P-code has a better clock tracking accuracy due to wider signal bandwidth compared to the C/A code. The clock recovery algorithm is based

on a typical delay locked loop technique [8].

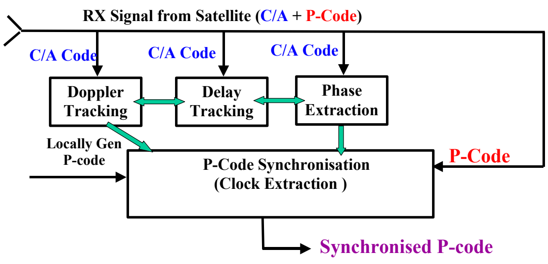

Figure 6 *Synchronisation Overview*

Experimental Verification of Range Compression and Synchronisation

Figure 7 shows the experimental set-up for collecting data from the satellite to verify the range compression and synchronisation algorithms. The signal from the satellite was directly received on two channels (RC and HC). The RC antenna was a stationary omni directional antenna (6 dBi gain) and was separated by some 3 m from the HC antenna. This topology corresponds to a target at 'zero range'. For the HC, a directional spiral antenna, with a gain of 16 dBi was pointed towards the satellite. Table 1 shows the satellites detected using the omni directional antenna on 6-03-06 at 3.05 pm.

A satellite transmitting on channel 10(1607.625 MHz) was used, highlighted in Table 1.

Table 1 *Satellites visible to the omni direction antenna (6-03-06 at 3.05 pm)*

Frequency channel number	Elevation (degrees)	Azimuth (degrees)
10	55	180
06	78	326
02	31	256

Figure 8(a&b) shows the decoded message signals from the C/A code and the P-code after synchronisation, confirming the proper functioning of our algorithm. Figure 8-c represents the correlation obtained from the proposed algorithm shown in Figure 5. It is seen that the algorithm gives a good correlation and confirms our computer modelling result. As expected, the width (first null) of the main lobe is 0.2 μsec. Finally, it is also noted that all the intra-system interference is suppressed (direct, co-channel).

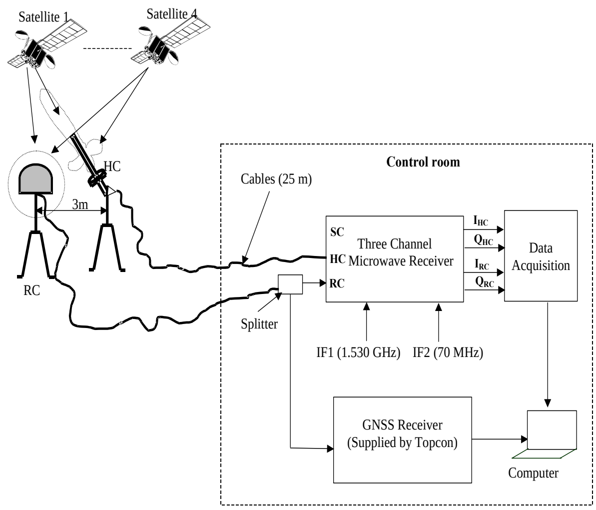

Figure 7 *Experimental Set-up*

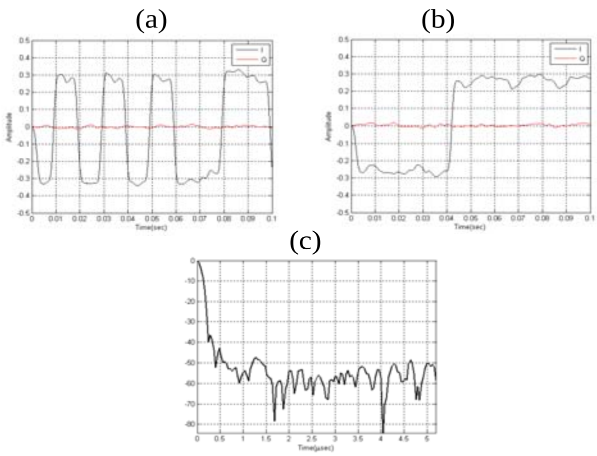

Figure 8 (a) *C/A code message (b) P-code message (c) Range profile.*

SS-BSAR Imaging

The proposed signal-processing algorithm for SS-BSAR is a modification of the standard Range-Doppler Algorithm (RDA). The receiver's motion is used for aperture synthesis, the transmitter being either stationary or slow moving; the transmitter-target range R_T can be considered to be constant throughout the whole integration time (see Figure 9). For a block diagram of the proposed algorithm see Figure 10. It is seen that the only difference between the standard RDA and the proposed algorithm is in the design of the azimuth filter. After range correlation, a target at distance R_R from the receiver is located by the radar at the range R_T+R_R. However, since R_T is constant, the azimuth signal is formed only from the variation in R_R with receiver aperture position.

Therefore, in order to design an appropriate azimuth filter, for each range bin we need to find R_R from R_T+R_R. If the transmitter's position is known, R_R can be estimated using simple trigonometric equations.

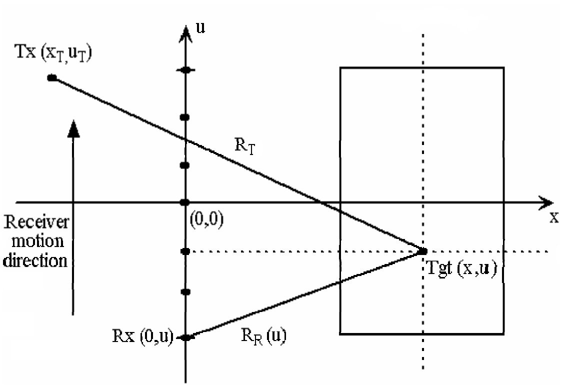

Figure 9 *System Geometry*

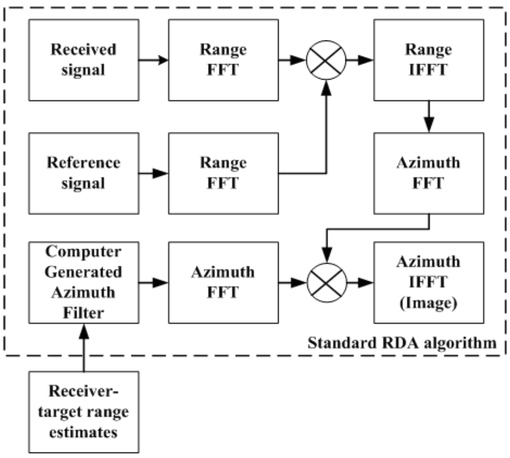

Figure 10 *SS-BSAR proposed algorithm*

It should also be noted that moderate aperture lengths have been assumed; hence the range migration correction step of the normal RDA algorithm is ignored at this stage.

Experimental Verification of Imaging Algorithm

A bistatic experiment was conducted using the flight imitator installed on the roof top of a five-storey building . The transmitter was stationary and the experiment geometry was the same as in Figure 9. The transmitted signal was a CW, 15-bit register M-sequence with chip duration of 0.2 usec. The other experiment parameters are shown in Table 2.

Wavelength	0.1875 m
Signal bandwidth	5 MHz
Receiver velocity	0.6 m/s
Integration time	45 sec
Bistatic angle	5.7^o
Transmitter position	(-2,6.5)m

Table 2 *Experiment parameters*

A corner reflector of $1900m^2$ RCS was placed at coordinates (70, 8.7)m from the origin. The image obtained is shown in Figure 11. The radar image has been rescaled and superimposed on an aerial photograph of the same region for comparison. In the figure, each pixel value has been normalized to the value of the pixel where the corner reflector was found. The colourscale is in dB, 0 dB representing the corner reflector intensity. It is seen that the corner reflector has been found (upper left corner in the image). Also, a building (at range 250m) and part of the structure of a greenhouse (in the range interval 350-400m) have been clearly identified. The grassy areas appear as shades of blue (low intensity) as expected.

Conclusion

This paper has reported the progress made so far in the SS-BSAR study, and has highlighted the signal processing required to obtain an image successfully.

It was shown that the presence of the C/A code in the transmitted signal masks the ranging P-code signal. A range compression algorithm that suppresses the effect of the C/A code was proposed. This algorithm required synchronisation of the locally generated P-code with the signal received from the satellite. Experimental verification of the range compression algorithm and synchronisation was also presented.

Finally, an SS-BSAR imaging algorithm was proposed and experimentally verified using a signal imitator. This algorithm is based on the standard RDA algorithm, the only difference being in the design of the azimuth filter. The filter is derived from analysis of the instantaneous bistatic triangle formed by the transmitter, receiver and the target.

The next step is to obtain a bistatic image using a satellite as the transmitter. This will involve integration of the range compression and the imaging algorithm.

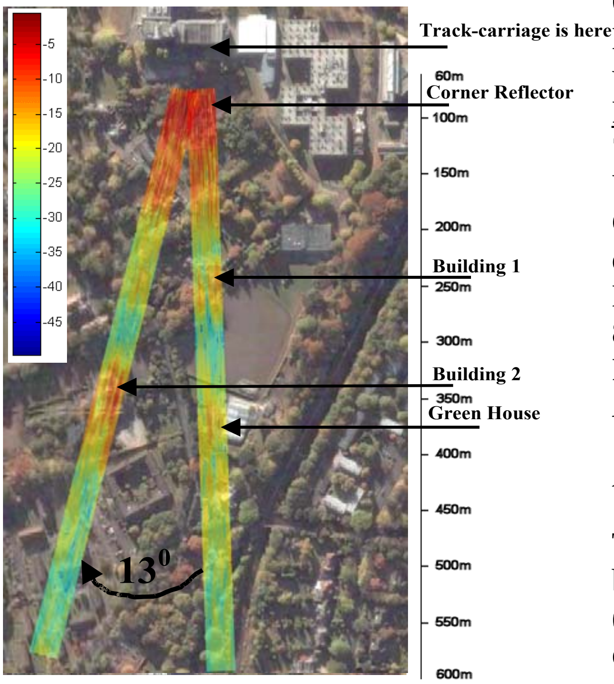

Figure 11 *SS-BSAR image with stationary transmitter*

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