A Miniaturised Coded SAR Transponder for Target Tagging

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Abstract

Although modern airborne and space-borne SAR instruments have increasingly high resolution, and the images contain more and more detail, detecting and identifying small objects in SAR images is unreliable. Hence, there is a need for artificial radar tags to guarantee reliable detection and unambiguous identification. The paper describes a concept for a miniature SAR transponder and the important technology developments needed, specifically the signal delay circuitry and the antenna. The design of a practical transponder is discussed.

1 Introduction

SAR transponders usually use separate receive and transmit antennas to suppress the transmit signal coupled across to the receiver input. A single antenna can be used, if the transmit signal can be delayed until the received pulse has decayed, greatly reducing the size of the transponder. In order to locate the transponder signal accurately, the delay has to be highly stable and well known. The technique described compresses the received SAR signal to derive a pulse synchronised with the chirp modulation. This pulse can be used to trigger a delayed replica of the SAR signal, or, more relevant for tagging, to trigger a new signal with a unique structure, enabling it to be unambiguously identified by the radar. In the following, a coded signal is transmitted back to the radar [1]. The pulse compression greatly increases the transponder's limiting sensitivity and enable a low gain antenna to be used. This is important, because the transponder antenna needs to have a wide beam-width to cover the range of the hemisphere occupied by radars without pointing. The transponder described is intended to be used with SAR systems, specifically with the Envisat ASAR, but it could be used with any radar using pulse compression techniques.

2 Transponder Design

The miniature transponder is based on a regenerative design using FPGA technology for as many of the circuits as possible. RF circuitry is limited to amplifiers, frequency conversion to translate the signal frequency into a convenient band and a circulator to couple the receive and transmit paths to the antenna (see Figure 1).

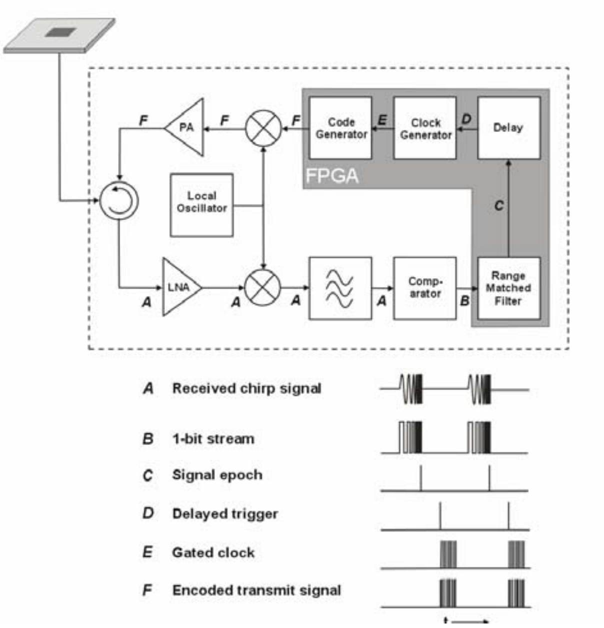


Figure 1 Schematic of the transponder and a sketch of the processed signals at the intermediate stages.

The signal received from the radar by the wide beam antenna passes via the circulator to the low-noise amplifier and is then converted down into a frequency band low enough for the modulation to be within the bandwidth of the FPGA. The signal is converted into a single bit stream by a comparator.

The regenerated signal is encoded to provide unambiguous identification. The SAR data are appropriately processed to locate and identify the transponder signal.

The transponder is designed for operation with the Envisat ASAR sensor, see Table 1.

Table 1 Relevant characteristics of the Envisat ASAR sensor (approximate).

Frequency range	C-Band 5.331 GHz	
Polarisation	Vertical and horizontal	
Antenna size	10 x 1.3 m	
Antenna gain	45 dB max.	
Transmit power	2000 W	
NESZ	-20 dBm^2/m^2	
Mode	Image	Wide swath
Spatial resolution	30 m	150 m
Incidence angle	15° to 45°	
Altitude	800 km	

3 Trigger Pulse Generation

Delay lines with a delay longer than the transmit pulse duration of a radar are bulky and lossy. The miniaturised transponder therefore uses signal regeneration to delay the transmit signal.

It is possible to derive a trigger pulse from the received SAR signal using a simple envelope detector. However, the input signal of such a detector requires a high S/N ratio to ensure reliable detection and low jitter. To achieve high sensitivity, real time range compression is needed, the compressed pulse being used to derive the trigger. SAR signal range compression contains several computationally demanding steps, requiring a large amount of memory storage. Real time SAR processing requires about 1013 multiplications and summations to be performed every second. There are FFT cores available which can perform real time SAR processing, but the cost and power consumption of these devices is often very high.

If the received signal is only 1-bit quantized the amplitude information of the signal will be lost, leaving only the phase information. The radar image will not have the same quality as if 4-bit or 8-bit sampled data had been used, but the result may still be good enough for the application considered, like or application of deriving a trigger pulse.

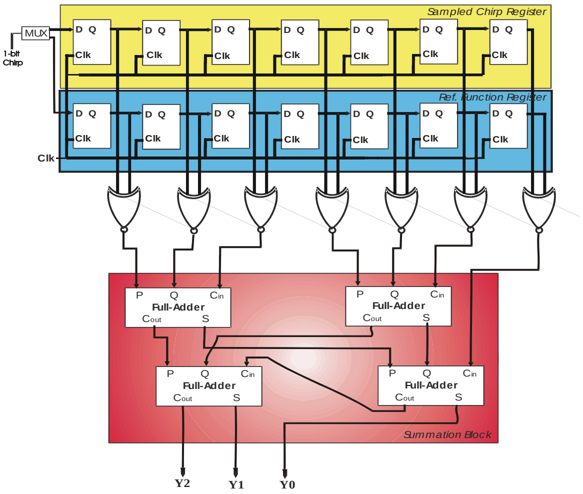


Figure 2 Example of a summation circuit for a 7 bit long convolution. The 3 bit output will be a maximum (7) when all the sampled input signal and reference signal are correlated.

The signum code algorithm is used for reducing the data processing complexity, i.e. less computational time is used, which leads to a faster signal processing. The received raw signal is passed through an ideal limiter and is coded as +1 for the positive part of the signal, and –0 for the negative part.

The range compressor therefore uses a 1-bit real-time convolution algorithm, as described in [2]. Convolution is performed in four different steps: reflection – shifting – multiplication - summation. The first two steps are easily performed in shift registers. By using the 1-bit coding technique, multiplication is reduced to an XNOR function and summation may be performed in an adder block. First the reference function is 1-bit coded. Every data sample of the signal is stored in a register and kept there through the entire process. When the reflected signal is received, a 1-bit A-D converter samples the signal. For every clock pulse one sample of the signal will be shifted into a register, and bit-wise treated by the XNOR function, with the reference function and the result stored in a new register. The received signal is sampled with a sampling frequency equal to twice the bandwidth. There is no need to sample at a faster rate, since for a chirp signal the frequency will either increase (up-chirp) or decrease (down-chirp), making the period of time when the chirp frequency is equal to the bandwidth very short. For the summation operation, a chain of adders is used. Figure 2 shows an example for a 7 bit convolution, the output being a 3 bit binary number. The maximum number is detected to obtain the epoch of the chirp signal, from which the delayed trigger pulse is derived. For the transponder, a ripple chain adder was used. This uses full-adders serially, and sends the summed output to the next full-adder, and the carry output to next level of adders.

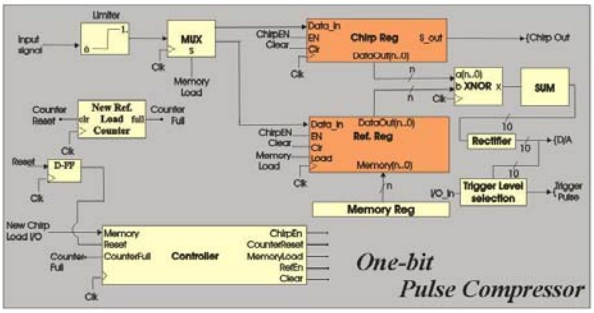


Figure 3 Schematic of the FPGA 1-bit pulse compressor.

The real-time compressor was built using an ALTERA Stratix FPGA, tests being performed on the evaluation board. Figure 3 shows the functions. The input signal is 1-bit digitised and passed to the chirp register. The reference chirp can be read to the reference register from memory, or the input signal can be read in. The latter is useful if the modulation is unknown or changing. After summation, the signals for the result of the correlation are passed to the trigger level selection, which detects the maximum for generating the trigger pulse. The rectifier was included to remove the offset for display purposes.

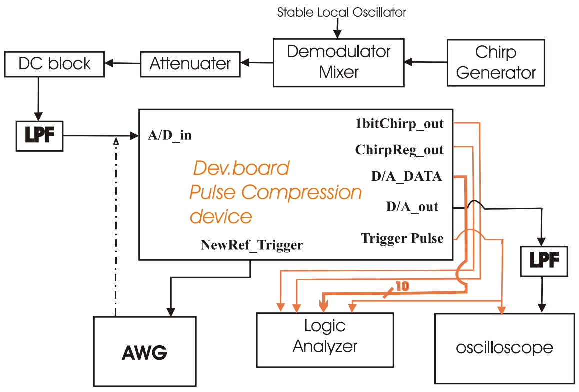
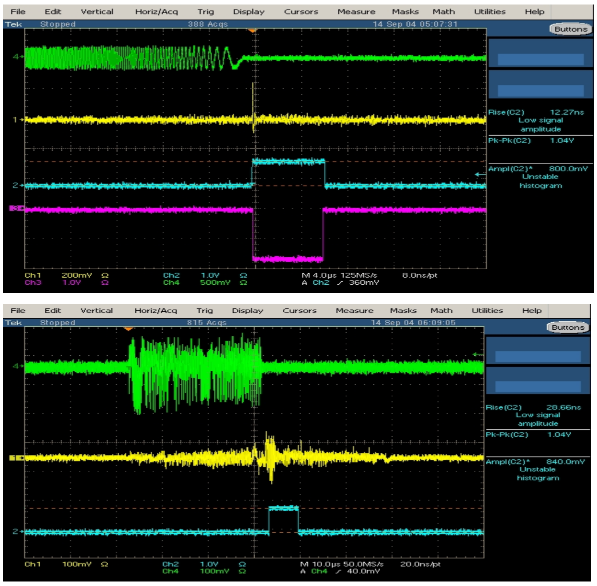


Figure 4 Test setup for the real-time 1-bit range compressor with the functions for generating a radar pulse at the top.

The evaluation board circuit was tested with the setup shown in Figure 4. The signal from a chirp generator is mixed down and low-pass filtered before being applied to the A/D input of the board. A waveform generator was used to read in the reference signal. The output signals were analysed with a logic analyzer and an oscilloscope. The chirp used corresponded to the Envisat/ASAR signal.



Tek Stopped 388 Acqs 14 Sep 04 05:07:31
Rise(C2) 12.27ns Low signal amplitude
Pk-Pk(C2) 1.04V
Ampl(C2)* 800.0mV Unstable histogram
Ch1 200mV Ω Ch2 1.0V Ω M 4.0µs 125MS/s 8.0ns/pt
Ch3 1.0V Ω Ch4 500mV Ω A Ch2 ∕ 360mV

Tek Stopped 815 Acqs 14 Sep 04 06:09:05
Rise(C2) 28.66ns Low signal amplitude
Pk-Pk(C2) 1.04V
Ampl(C2)* 840.0mV Unstable histogram
Ch1 100mV Ω Ch2 1.0V Ω M 10.0µs 50.0MS/s 20.0ns/pt
Ch4 100mV Ω A Ch4 ∕ 40.0mV

Figure 5 Oscilloscope screenshots for the test with the chirp signal alone (top) and with added noise (below). Input signal (green), result of the correlation (yellow) and trigger pulse (blue).

Two results are shown in Figure 5. The top screenshot shows the correlation peak at the end of the chirp and the 7 µs pulse, which was generated from it. Below, the result can be seen for the noisy signal, whereby the S/N is less than 1.

The trigger pulse is accurately related in time to the input chirp signal and can be used for regenerating a signal for transmitting back to the radar. For the single-antenna transponder the trigger pulse has to be delayed for more than the length of the radar pulse.

4 Stripline Patch Antenna

Because the transponder is not intended to be pointed at the SAR, the antenna has to have a wide beam. Also, because, like for most SARs, the Envisat ASAR is linearly polarised, circular polarisation was chosen for the antenna. A loss of nominally 3 dB is obtained but this is independent of the orientation of the transponder.

Table 2 Specification goal of the stripline antenna.

Frequency range	5.2 – 5.4 GHz
RF power	1 W peak, 100 mW average
Polarization	circular
Main-lobe 3 dB width	+/- 60°
Connectors	SMA
DC power	< 2 W
Size	Envelope 100 x 100 x 50 mm max.
Weight	< 100 g
Shock	< 20 G
Environment	Outdoor, -30 to +49 °C, humidity <100 %

Hence, the antenna uses a single circularly polarised patch to provide wide coverage independent of the plane of polarisation. The specification in Table 1 was the goal. Four designs (see Figure 6) were simulated and extensively analysed. The characteristics of most interest are input reflection coefficient, bandwidth, impedance matching (Smith chart), axial ratio, far field pattern, beam width, efficiency and gain.

A selection was first made on the basis of the reflection measurement using a network analyzer.

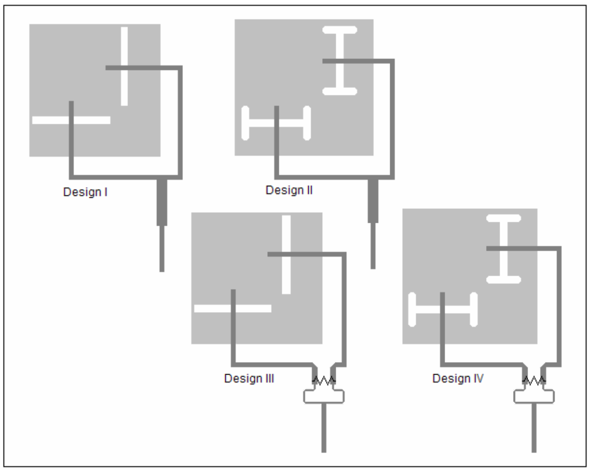


Figure 6 Four patch antenna designs which were simulated, constructed and tested. Design III was best.

Design III gave the best result with design II as a backup. These prototypes were then measured on the

DLR's far-field antenna test range. The patterns are shown in Figure 7. The gain is greater than 0 db over a range of ±45° and greater than -10 db over ±90° for both vertical and horizontal polarisation. Hence, the antenna can cover a hemisphere.

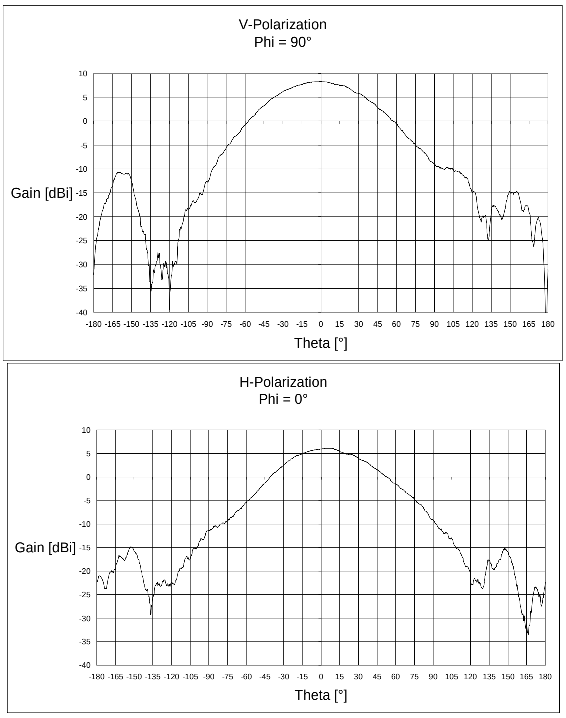


Figure 7 Patterns of the selected patch antenna (Design III) for horizontal and vertical polarisations.

Figure 8 shows a photograph of the patch antenna.

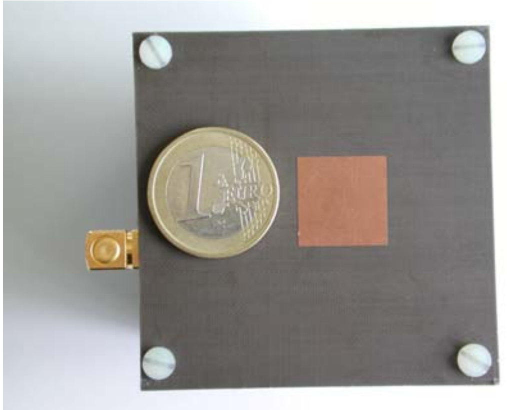


Figure 8 Photograph of the selected patch antenna (Design III).

5 Conclusions

Based on the parameters in Table 1, the ASAR noise power density on the ground is approx. -54 dBW/m^2. This means that to achieve an equivalent RCS in the SAR image of the transponder of 30 dBm^2 within the beam of the transponder (-10 dB beam width) of the antenna, the transponder EIRP has to be -24 dBW. For -10 dB antenna gain, this results in a transmit power of approx. -14 dBW, or 40 mW. This RCS is sufficient to detect the transponder in the SAR data, particularly if the signal is coded to decouple it from natural targets. Note, the SAR noise floor is about 0 dBm^2 for ASAR's image mode and 13 dBm^2 for the wide swath mode.

With the aid of the accurate trigger pulse a signal with the same phase as the received SAR signal can be generated. The signal can be modulated with the same chirp as the received signal or coded to allow unambiguous detection and identification. Coding can be from pulse to pulse, as described in [1], within the pulse, or both simultaneously. The SAR data are processed by correlating a reference code with the transponder code.

Using the described techniques, a tagging transponder can be constructed small enough to be mounted on small objects, e.g. vehicles, and even to be conveniently carried by a person. As the transponder only has to transmit for seconds, the power supply can be derived from an accumulator buffered from solar cells, making it totally independent.

The ability of the SAR to image the passive targets of the surrounding areas means that such tags would have unique advantages over other RFID systems.

References

[1] Hounam, D., Wägel, K., A Technique for the Identification and Localization of SAR Targets using Encoding Transponders, IEEE Transactions on Geoscience and Remote Sensing, vol. 39, pp. 3 - 7, 2001.

[2] Franceschetti, G..; Alberti, G..; Pascazio, V.,; Schirinzi, G.: Time-domain convolution of one-bit coded radar". IEEE Proceedings Radar and Signal Processing, October 1991.