

# Feasibility study of the space synthetic aperture radar for the SSETI-ESMO project

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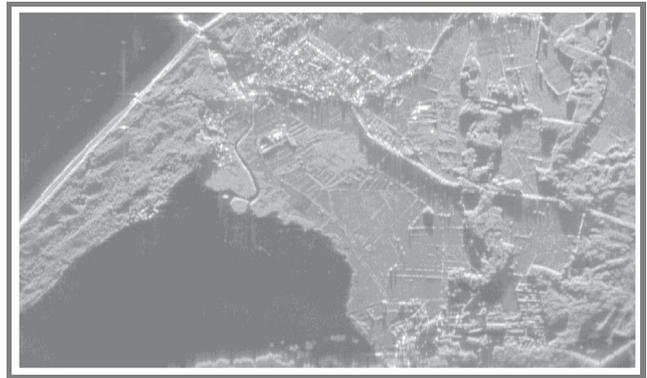
**Abstract**— The following paper presents the analysis of the feasibility study of the SAR radar for lunar space missions. The European Students Moon Orbiter (ESMO) project is conducted by the Students Space Exploration and Technology Initiative (SSETI) association. The phase A of this project is supported by the European Space Agency (ESA).

**Keywords**— SSETI, ESMO, feasibility study, space SAR radar.

## 1. Introduction

For many years space technology has been out of reach for many scientists or students. This situation was changed at the beginning of the 21st century, when in 2001, the European Space Agency (ESA)<sup>1</sup> Education Office founded the Student Space Exploration and Technology Initiative (SSETI)<sup>2</sup> association. The main objective of the SSETI association was to motivate the large number of students from European countries to participate in space projects and learn more about the space and science in general. The SSETI association is supported by ESA. This has enabled students participating in these projects to exchange information with experts from ESA and perform tests of the designed space components at the ESTEC Test Center Laboratory (Noordwijk, The Netherlands). Students are responsible for designing and manufacturing the whole spacecraft. Currently, there are two active SSETI space projects: European Student Earth Orbiter (ESEO) and European Student Moon Orbiter (ESMO). The paper presents the concept of the synthetic aperture radar (SAR) subsystem of the second project. This concept has been worked out by students from space synthetic aperture radar (SSAR) team, who have gained already practical experience with SAR technology, developing and implementing SAR algorithms and processing the recorded data from the airborne campaigns [12, 19]. The example of SAR image obtained from recorded data is presented in Fig. 1.

The involvement of students in working projects has the great educational impact. Nowadays many educational institutions intend to incorporate such projects into their teaching process. The description of another student educational radar project can be found in [15]. In that case students has designed the laboratory models of Doppler



**Fig. 1.** Results of the SAR processing performed by the students: Leba village (Poland).

and SAR radar. Reading their paper, everyone can notice that this project gained their enthusiasm and helped them to enhance the educational experience.

## 2. The SSETI-ESMO

The ESMO satellite is going to be orbiting around the Moon and collecting the Moon surface 3D images. It will be treated as the reconnaissance platform, as well as a step towards the missions to other planets. The launch of the satellite is expected in 2010 year with the use of the Ariane 5 rocket. At the time being, there is no final decision about the ESMO payload. Several possibilities are taken into account. The basic SSETI-ESMO experiment plan consists of: reaching the Moon orbit, making of 2D/3D maps of the Moon surface using optical cameras, synthetic aperture radar in 2D mode and/or interferometric synthetic aperture radar (IfSAR) in 3D mode, making the Moon hight map using laser hight finder of LIDAR (light detection and ranging), the Moon magnetic field study and landing of student-made object at the Moon surface. The satellite in transportation phase should fit into the cylinder 1.5 m height and 1.5 m in diameter. The mass of the satellite should be below 300 kg. The weight of the SAR payload should not exceed the 20 kg. The whole ESMO mission should take 1 month.

To fulfill all the requirements, operational team has performed feasibility study on space SAR technology, collecting many different ideas described in open literature. The work has been started by analyzing the geometry of

<sup>1</sup>ESA, <http://www.esa.int>

<sup>2</sup>SSETI, <http://www.sseti.org>

the space borne SAR system. The comprehensive analysis of that problem can be found in [14]. In the second step, the fundamentals of the SAR technology for airborne and space applications have been reviewed. In the article [6] the basic description of radar system design and the limitations of the SAR radar swath width (coverage), range and azimuth resolution in function of radar velocity, antenna dimensions and pulse repetition frequency can be found. After wide analysis of above (and many others) articles and the construction of ESA and NASA SAR satellites, the students SSAR team proposed the ESMO SAR experiment plan. There are planned three stages of SAR image formation. In the first stage the Moon surface will be scanned by SAR/IfSAR radar, and the raw radar data will be stored on the board of the satellite. In the second stage the collected data should be transmitted to the data ground station on the Earth. In the last (third) stage, the final SAR image will be formatted off-line, after application of all required corrections (Fig. 2).

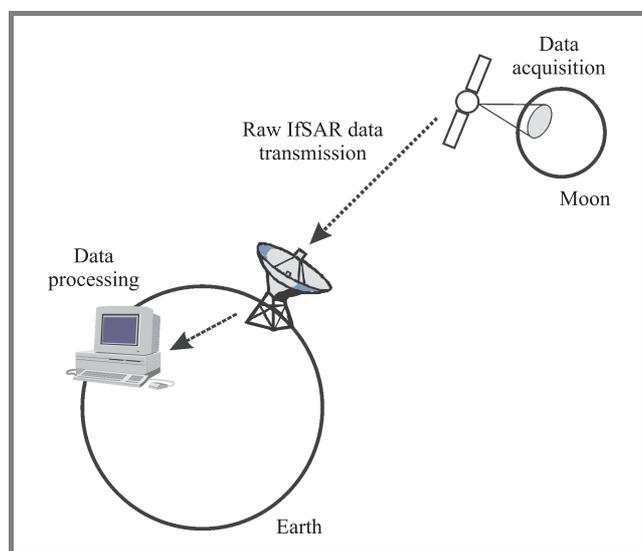


Fig. 2. The SSAR experiment plan.

The authors of this paper reviewed the state of art and the future trends in the spaceborne SAR technology. The design consideration about the key hardware blocks will be briefly discussed in Section 4.

### 3. The SAR, IfSAR technology

Synthetic aperture radar is an aircraft or spacecraft mounted sensor designed to obtain high-resolution radar images of the observed terrain by means of microwave radiation [9]. In this case of imaging, the radar is placed on moving platform. Radar pulses are aimed towards the Earth or another planet. The obtained image is a two dimensional estimate of the electromagnetic reflectivity of the mapped area. The resulting radar image is characterized by resolution in two directions: slant-range and cross-range. Slant-range refers to the range transversal to the path of flight,

while cross-range refers to the range along the path of flight (see Fig. 3).

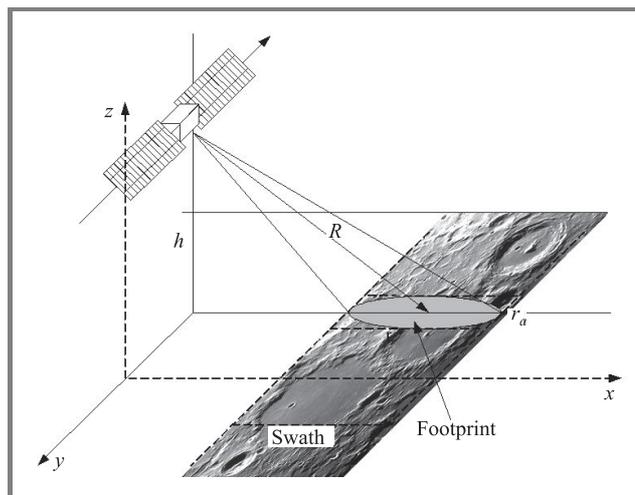


Fig. 3. The SAR geometry.

Fine slant-range resolution is obtained by transmission of frequency modulated (FM) pulses, a technique used in many different types of radars, not only in SAR. The slant-range resolution depends on the transmitted signal bandwidth, according to the following equation:

$$\delta_r = \frac{c}{2B},$$

where:  $c$  – light velocity,  $B$  – transmitted signal bandwidth.

Cross-range resolution in SAR is obtained by coherent integration of the received signal, as the radar travels along the mapped area. The process of coherent integration can be thought of as the formation of the large antenna – the synthetic aperture. The theoretically achievable cross-range resolution is equal to the half of the real antenna aperture (antenna along-track length).

Both, slant-range resolution and cross-range resolution do not vary with the distance between the radar and the target. The process of SAR image formation can be divided into two consecutive stages: range processing and azimuth processing. These two steps correspond to resolution improvement in two different directions. The range processing (also called pulse compression) is realized by matched filtering of the received FM signal. The result of the pulse compression is a series of so called range profiles, which are used in further processing. This part of processing is relatively simple, because the parameters of the matched filter are independent of the platform movement and hence are invariant in time. The following step is the azimuth processing which is the essential part of SAR processing. Similarly as in pulse compression, the azimuth compression uses matched filtering. However, this time radar platform's movement strongly influences on the received signal. For this reason the matched filter has to be constantly adjusted to the changing situation. Since there is no navigation system providing that information with required accuracy,

the sophisticated motion compensation algorithms based on received signal are used. For high-resolution imaging, instead of using two single-dimensional filters, it is necessary to use more complicated 2-dimensional filter to mitigate the range-migration effects.

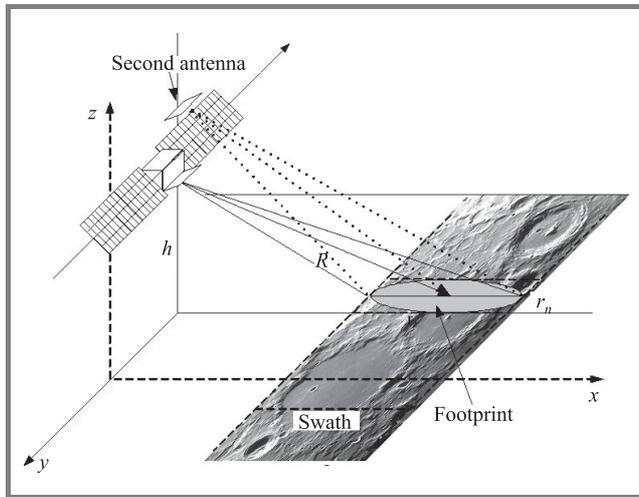


Fig. 4. The IfSAR geometry.

An extension of SAR technology is the IfSAR technology. Using IfSAR configuration (Fig. 4) 3D high resolution images can be obtained. The resulting 3D radar image can be characterized by the resolution in three directions: slant-range, cross-range and height. The IfSAR configuration consists of two receiving antennas so the same objects are observed from different angles. This causes a phase shift between the received signals which enables the height estimation of the observed objects [13].

## 4. Space SAR system considerations

The feasibility of designing and manufacturing of SAR radar for small satellite is limited by the available technology, including antenna technology, microwave transmitters' technology, digital signal processor (DSP) technology and others. Especially in this project, such technology must be available for student team. It is assumed that the temperature for the electronic components should be

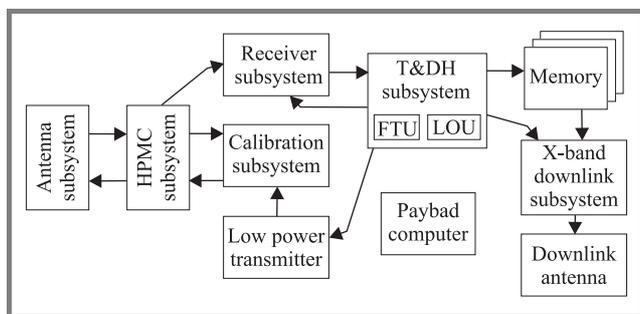


Fig. 5. The SAR radar block diagram. Explanations: FTU – formatter and timing unit, LOU – local oscillator unit.

between  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  (industrial or military grade). The classical concept of space SAR system is presented in [2]. On the basis of the above mentioned concept, the SSAR team proposed the functional block diagram of the SAR radar (Fig. 5).

The payload computer unit controls all aspects of payload operations. The high power microwave circuit (HPMC) provides the amplification of the radar signal from the LPT (for radar pulse transmission) or received by the antenna. Timing and data handling system (T&DH) provides very stable synchronization (master oscillator) of every SAR subsystem and formats the received raw data for storage in the on-board memory and transmission to the Earth. The key system blocks for every SAR radar are: antenna, microwave transmitter-receiver, memory storage devices and signal processing subsystem (performing calibration and image formation tasks).

### 4.1. Antenna subsystem

There are two main antennas technologies which can be taken into consideration: planar and dish antenna. The main advantage of the dish antenna is the ease of the manufacturing and simplicity. The main disadvantage is its weight and dimensions. The alternative concept is the usage of planar antennas. The planar antenna can be designed and manufactured in three technologies: waveguide, microstrip and as an active array of T/R modules. However, the fast development of the active antenna arrays enables new processing schemes in SAR technology [17]. The usage of such device in this project seems to be impossible because of the high costs of this technology. The usage of the waveguide or microstrip technology seems rather interesting, due to antenna low weight, low manufacturing costs and wide bandwidth.

### 4.2. Microwave amplifier (HPMC subsystem)

The authors of [1] deal with the problem of building a small (less than 120 kg) satellite with SAR radar on-board. The main conclusions are that manufacturing and building SAR radar for microsatellite is feasible, however its parameters (resolution) won't be comparable with big systems like ERS 1/2 or EnviSAT. The main advantage of such system would be low costs of obtaining satellite SAR images. The effective swath size would be about 3 km width (antenna aperture width about 2 m). Such satellite could operate at the altitude of 400–500 km, using the 300 W TWT (travelling wave tube) amplifier. The SSAR team performed similar studies taking into account technology available for the students at Warsaw University of Technology and the cost reduction. The main assumptions were as follows: X-band radar, 11 dB detection threshold, 12 dB of total hardware system loss,  $0.7 \times 1.5$  m antenna aperture, 2.5 kHz pulse repetition frequency,  $50 \mu\text{s}$  pulse time duration. The transmitted pulse power in the SAR mode for 30 km orbit, 60 km orbit, 120 km orbit height and

45° incidence angle were as follows: 10.3 W (1.2 W average), 82.4 W (9 W average), 659 W (72 W average). It appeared that the best solution for this student project is to use solid state amplifier. That limits the orbit to about 60 km, because of the maximum available transmitting power.

### 4.3. The SAR data compression

The SAR technology generates high amount of data. For example for the SAR radar analyzed in this article raw rate data transfer can be up to 10 Mbit/s for the 12 bit ADC (analog to digital converter) [10]. The study of the literature [23] and SSAR team research [10] showed that SAR data can be sampled using 8–12 bit ADC and then degraded to 1–4 bit representation using block adaptive quantization (BAQ) algorithm [21]. The example images obtained using 12 bits data and 1 bit data are presented in Figs. 6 and 7, respectively.

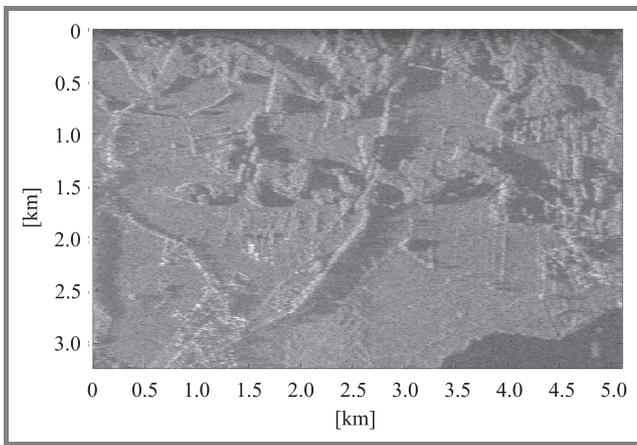


Fig. 6. The SAR image for 12 bit ADC.

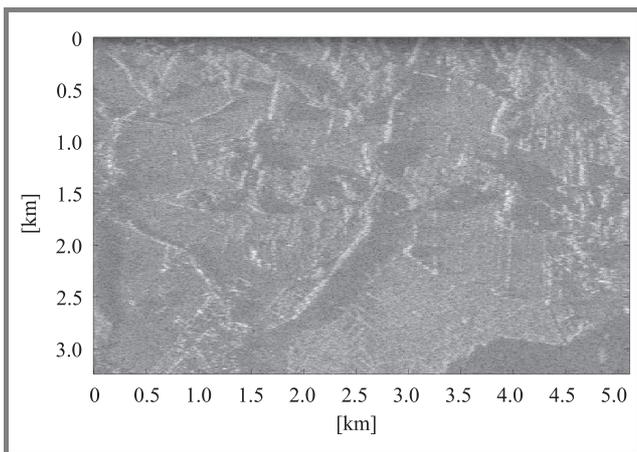


Fig. 7. The SAR image for 1 bit ADC.

Comparing these images (Figs. 6 and 7), it can be clearly seen that the image degradation is acceptable. More detailed analysis can be found in [10]. To simplify

the hardware installed on the satellite, it is assumed that final image processing will be performed on the Earth, using PC's and software SAR processor developed by the SSAR team.

### 4.4. Data storage subsystem

The raw radar data must be stored on the board of SAR satellite prior to sending it to the Earth ground station. There are two reasons for this temporary storage – the satellite can scan the part of Moon invisible from the Earth and this same microwave system will be used both for SAR scanning and for data communication. The fundamental information about designing data storage system for space application can be found in [16]. There are several candidates for mass storage in the outer space. It is possible to record data using hard disks, magnetic tapes, optical discs and solid state memories (DRAM, EEPROM). After intensive analysis, the SSAR team has chosen 2 GB solid state memory for storing raw SAR radar data, photos and data from other measurements. To reduce the costs, the commercial off-the-shelf (COTS) memory components should be used. To enhance its reliability the redundancy and error detection and correction (EDAC) codes should be considered [4, 24]. SAR technology generates large amounts of data and requires high speed data bus (HSDB) to transfer them between transmitter/receiver system and processing and storage system. Very good comparison of data buses properties for space applications is given in [18]. It seems that the most adequate standard to use in the small/microsatellite are the Spacewire [22], and IEEE 1394. The idea of such network is described in [5]. These two buses are very compatible at the physical level and therefore can easily be combined. Analysis presented in that paper shows that the effectiveness of the IEEE 1394/Spacewire architecture can achieve the same fault tolerance capability as the IEEE 1394/I2C architecture with less redundancy. The components for building such network can be implemented in the field programmable gate array (FPGA) structure [11, 20].

The architecture of the processing and storage data system are shown in Fig. 8. It can be seen that the payload subsystems should be connected to the HSDB for fast data

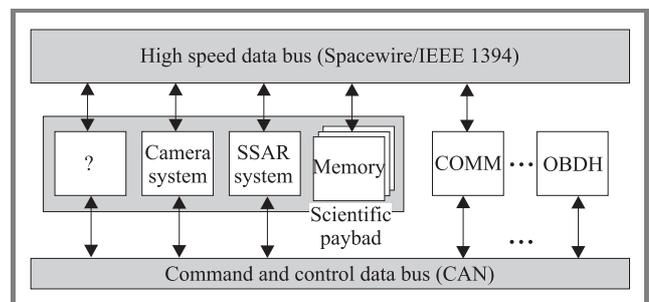


Fig. 8. Processing and storage architecture. Explanation: OBDH – on-board data handling.

exchange and storing in the on-board memory. For the cost and weight reduction, the hardware of the SAR and communication (COMM) systems can be partially combined together [7, 8].

#### 4.5. The ESMO SAR satellite vision

After careful and detail analysis, the SSAR team proposed the first vision of the ESMO satellite (Fig. 9). This concept is similar to the one used for the TerraSAR-X [3] satellite. The shape of this satellite is compact and easy to manufacture. The number of moving parts is minimized. The other advantage is connected with the fact that for the certain height and width (during the transport, the satellite should fit in the specific cylinder) a prism has a bigger capacity than a cuboid.

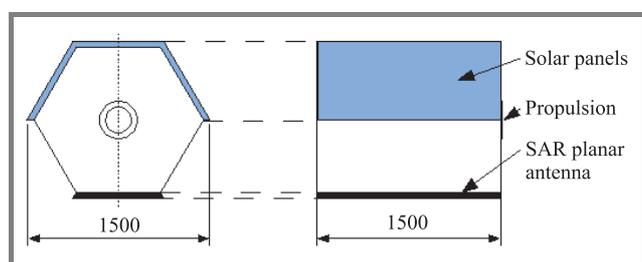


Fig. 9. The SSETI-ESMO satellite vision.

The main advantage of using non moving solar panels, is the simplification of the satellite design and reduction of the probability of system failure. However, during all satellite maneuvers, the precise position of the Sun must be taken into account. Especially during SAR scanning the ESMO satellite must be between the Sun and the Moon's surface. The feasibility of the IfSAR mode requires further studies. The main problem is that the second antenna must be equipped with deployable boom. The position and the baseline (length of the boom) between the two antennas have to be known precisely [17].

## 5. Conclusions

Analysis presented in this paper shows that building SAR radar for small lunar satellite is feasible. The SSAR team has the potential to design space SAR radar and develop the algorithms for SAR data processing. Students at the Warsaw University of Technology have the technical ability to design and manufacture the low frequency part of the system, specify the requirements for the microwave front-end and antenna, implement algorithms for space SAR system control and off-line processing of raw SAR data. The members of the SSAR team think that the state of art of electronic and software engineering technology enables the usage of some COTS components and industrial standards. This of course degrades the reliability of

the system, but such solutions are used with success in many "low budget" space projects.

## References

- [1] J. P. Aguttes, "High resolution (metric) SAR microsatellite, based on the CNES MYRIADE bus", in *Proc. IEEE Geosci. Rem. Sens. Symp. IGARSS'01*, Sydney, Australia, 2001, vol. 1, pp. 224–226.
- [2] A. Brand and Z. Mi, "Designing a spaceborne SAR for multi mode imaging", in *Proc. Electr. Comput. Eng., Canad. Conf. Digit. Obj. Ident.*, Calgary, Canada, 1996, vol. 1, pp. 17–20.
- [3] S. Buckreuss, W. Balzer, P. Muhlbauer, R. Werninghaus, and W. Pitz, "The TerraSAR-X satellite project", in *Proc. Geosci. Remot. Sens. Symp. IGARSS'03*, Toulouse, France, 2003, vol. 5, pp. 3096–3098.
- [4] G. C. Cardarilli, P. Marinucci, and A. Salsano, "Fault-tolerant solid state mass memory for satellite applications", in *Proc. IEEE Instrum. Meas. Technol. Conf.*, Ottawa, Canada, 1997.
- [5] S. N. Chau, J. Smith, and A. T. Tai, "A design-diversity based fault-tolerant COTS avionics bus network", in *Proc. Depend. Comput. Pacific Rim Int. Symp.*, Seoul, Korea, 2001, pp. 35–42.
- [6] A. Curie, "Synthetic aperture radar", *IEEE Electron. Commun. Eng. J.*, Aug. 1991.
- [7] B. Dawidowicz, M. Piotrkowski, and T. Filipek, "Hardware system analysis for students space synthetic aperture radar (ESA SSETI-ESMO project)", in *Proc. XIV IEEE-SPIE Sig. Proces. Symp.*, Wilga, Poland, 2005.
- [8] B. Dawidowicz, T. Filipek, M. Kuzniak, W. Kulka, M. Malanowski, M. Piotrkowski, and K. Kulpa, "Interferometric SAR for European Student Moon Orbiter", in *Proc. EuSAR 2006*, Dresden, Germany, 2006.
- [9] B. Dawidowicz, M. Malanowski, G. Pietrzyk, M. Piotrkowski, V. Rakevich, and P. Samczyński, "Space synthetic aperture radar system analysis", in *Proc. STEC 2005*, Aalborg, Denmark, 2005.
- [10] B. Dawidowicz, K. Kulpa, M. Malanowski, and M. Piotrkowski, "The reduction of the SAR data transfer for the SSETI-ESMO project", in *Proc. KKRRiT Conf. 2005*, Kraków, Poland, 2005.
- [11] L. Fanucci, A. Renieri, and P. Terreni, "VLSI design of a routing switch for the spacewire serial link standard", in *Proc. Electron. Circ. Syst. 2002*, Dubrovnik, Croatia, 2002, vol. 3, pp. 1103–1106.
- [12] A. Gados, A. Gorzelanczyk, A. Jarzebska, M. Mordzonek, M. Smolareczyk, K. S. Kulpa, and B. Dawidowicz, "First Polish SAR trials", in *Proc. EUSAR 2004*, Ulm, Germany, 2004.
- [13] A. Gromek, P. Jobkiewicz, and P. Samczyński, "Analysis of interferometric synthetic aperture radar on Moon orbiter", in *Proc. STEC 2005*, Aalborg, Denmark, 2005.
- [14] B. Himed, K. Y. Li, and S. U. Pillai, "Remote sensing using space based radar", in *Proc. NATO Adv. Sens. Secur. Appl.*, Il Ciocco, Italy, 2005.
- [15] M. A. Jensen, D. V. Arnold, and D. E. Crockett, "System-level microwave design: radar-based laboratory projects", *IEEE Trans. Edu.*, vol. 43, no. 4, 2000.
- [16] R. R. Katti, "Space data storage systems and technologies", *IEEE Trans. Magn.*, vol. 30, no. 6, 1994.
- [17] W. Keydel, "Perspectives and visions for future SAR systems", *IEE Proc. Radar Sonar Navig.*, vol. 150, no. 3, 2003.
- [18] D.-Y. Kim, K.-H. Kwon, J.-W. Choi, J.-I. Lee, and H.-J. Kim, "Design of a new on-board computer for the new KOMPSAT bus", in *Proc. Aerosp. IEEE Conf. 2005*, Big Sky, USA, 2005, pp. 1–12.
- [19] M. Malanowski "Multilook processing in unfocused synthetic aperture radar", in *Proc. XIV IEEE-SPIE Sig. Proces. Symp.*, Wilga, Poland, 2005.
- [20] M. Nomachi, S. Ishii, Y. Kuroda, H. Nakamura, T. Sugimoto, and T. Takahashi, "A data readout system with high-speed serial data link for balloonborne X-ray detectors", in *Proc. Nucl. Sci. Symp.*, Rome, Italy, 2004, vol. 3, pp. 1478–1482.

- [21] S. M. Parkes, "Data compression and spacewire", in *Proc. Geosci. Rem. Sens. Symp. IGARSS'99*, Hamburg, Germany, 1999, vol. 4, pp. 2267–2269.
- [22] S. M. Parkes, "Spacewire: the standard", in *DASIA 1999 Conf.*, Lisbon, Portugal, 1999.
- [23] V. Pascazio and G. Schirinzi, "Synthetic aperture radar imaging by one bit coded signals", *IEEE Electron. Commun. Eng. J.*, Febr. 1998.
- [24] P. P. Shirvani, N. R. Saxena, and E. J. McCluskey, "Software-implemented EDAC protection against SEUs", *IEEE Trans. Reliab.*, vol. 49, no. 3, 2000.



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