Characteristics of the high-performance highly digitized multi-purpose radar system GigaRad

System concept, System Correction and Calibration, Applications

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***Abstract*— In the past years DLR has developed and operates a very versatile and modular high-resolution radar system for manifold applications. The so called GigaRad instrument [1] is an experimental system operating in X and Ku band, and can provide spatial resolution of a few centimeters. The waveform generation and reception in the baseband is performed by IQ modulation and demodulation, based on full digitization of the baseband signals in transmit and receive path. The system concept providing two transmit and two receive channels allows quasi monostatic, bi static, or MIMO (multiple input multiple output) operation. The normal transmit waveform is a chirp, but also any other waveforms like noise ore orthogonal coded signals are possible [6]. Based on coherent system architecture and the realized degree of automation the applications of the instrument vary from RCS measurements, UAV detection to the Imaging of Satellites in Space (IoSiS) [2], [3]. In this paper the basic system concept, the calibration procedure, and some applications of the instrument are outlined.**

Keywords*— *high resolution, radar, SAR, calibration, imaging of objects in space, RCS measurements

I. Introduction (*Heading 1*)

Since the invention of radar new systems are built with increasing tendency to higher performance in all areas of remote sensing. The common trend for new systems is towards increased performance in polarimetric and radiometric accuracy, sensitivity, complexity of operational modes, and especially in spatial resolution. The experimental system GigaRad was developed with focus on resolution and versatility using edge of technology components for exploring new research fields and applications.

Basically GigaRad performs as pulse radar at a center frequency of 11 GHz providing an instantaneous bandwidth of maximum 6 GHz, allowing the creation of high-resolution range profiles at theoretical range resolution of 2.5 cm. Using an ultra-stable oscillator and an EPLD (Erasable Programmable Logic Device) as timing unit, the system is able to perform Synthetic Aperture Radar (SAR) [9], or alternatively, Inverse SAR (ISAR) [8]. In order to address many operational modes the system is designed as a multi-channel configuration. In the basic setup two transmit (TX) and two receive (RX) channels for simultaneous operation are realized. Using a switch matrix, the system can be extended to a higher number of TX and RX channels. For bi-static applications the TX and RX antennas can be separated several tens of meters by connecting the basic radar hardware, the TX power amplification, and the low-noise RX section via an optical fiber.

The high degree of digitization and the overall high performance enables a wide variety of applications. A detailed description of the instrument, the error correction strategy, and two applications via illustrative measurement results are presented next.

II. System Description

The high degree of versatility of the GigaRad radar results in a very complex electronic design. For basic understanding a simplified block diagram is shown in Fig. 1. The main functional parts of the instrument are the arbitrary waveform generator (AWG), the IQ (In-phase and Quadrature) transmit and receive part, the high-speed data acquisition (HDA), and the error correction network (ECN).

Purely digital signal generation is performed by using a high-performance AWG, providing a maximum data rate of up to 10 GS/s. This allows required flexibility on TX side in order to transmit arbitrary waveforms as well as an advanced error correction strategy. Both output signals of the AWG are coherently generated and fed to an IQ modulator. Then the signal is amplified, filtered, and transmitted. On the RX side the functional concept is similar, except the signal conditioning part before digitization using the HDA providing a sampling rate of 8 GS/s. Hence, in order to fulfill the Nyquist criterion with some safety margins, the maximum analogue IF bandwidth is 3 GHz resulting in a maximum RF bandwidth of 6 GHz using IQ modulation and demodulation at a center frequency of 11GHz.

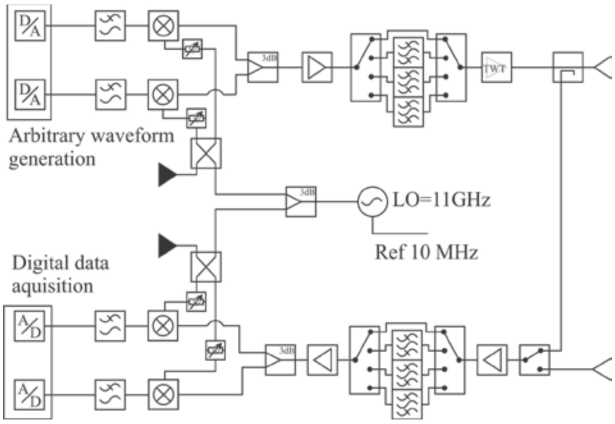

Fig. 1. Simplified GigaRad block diagram.

Especially the IQ circuit parts require proper error correction in order to achieve the desired image rejection of the second sideband as described in the next section. Another very important issue for very high-resolution SAR applications is the maintenance of sufficient coherence and therefore stability of the local oscillators. In case of GigaRad the implemented phase-locked source offers excellent low phase noise and spurious performance and can be additionally locked on an external ultra-stable oscillator connecting both the digital and the frequency conversion sections.

A photograph of the basic radar hardware setup is shown in Fig. 2. The single units are arranged in a 19" rack. The high-power and low-noise amplification sections are excluded to allow a bi-static and high-power operation via optical transmission [5].

Due to the large complexity of the system, the different filter constellations, the error correction, and the required timing accuracy especially for the IoSiS mode, an EPLD and a micro controller are used to control the whole instrument via appropriate clocks. Following the signal path of the block diagram in Fig. 1 the original signal is generated in the AWG, followed by frequency conversion, and conditioning in the TX section. Then the signal can be optional routed via an optical link to the extension modules shown here in the lower part of the rack. Also the time sensitive control signals for duty cycle modulation of an optional HPA, and the receive gate switches are connected via a high-speed real-time bus. This extension modules and the connection are the basis for many application were a significant separation of the antennas, or between the radar electronics and the antennas, is necessary.

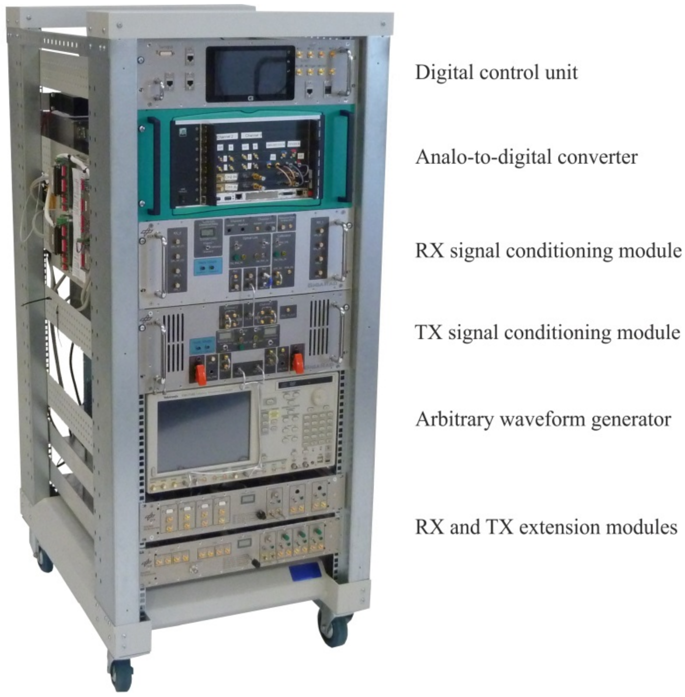

Fig. 2. Photograph of the basic radar hardware setup of GigaRad including the extension modules, all being installed in a mobile 19'' rack.

III. RF ERROR CORRECTION AND ABSOLUTE CALIBRATION

As mentioned earlier the proper rejection of image frequencies, error correction, and absolute calibration is necessary for high-quality SAR/ISAR images. Therefore in a first step the error correction for the IQ sections is performed. In Fig. 3 the main strategy is illustrated. First of all the local oscillator signals are adjusted with manual phase trimmers to exactly 90° phase difference at the mixer diodes of the TX and RX sections (path 1).

In a second step I and Q paths are aligned separately using different filters for the upper and lower side band (paths 2 and 3). Since the signal is sufficiently rejected in the unwanted frequency range by the filters, only one channel of the arbitrary waveform generator has to be used to compare the sampled signals in I and Q channels for amplitude and phase differences in the demodulation part. A similar procedure is used for proper alignment of both AWG output channels.

In a third step the frequency response in the TX (H_{TX}) and RX (H_{RX}) chains is measured with respect to phase, group delay, and amplitude (orange path), using the internal calibration path (H_{Cal}). This transfer function in conjunction with the external calibration 4) determines the overall frequency response of the system. In this step especially the response of the antennas, the waveguides and the antenna feed systems are characterized in two transfer functions (H_{ANT_TX}, H_{ANT_RX}). The external calibration is performed using a point target e.g. a trihedral reflector in the far field having the known transfer function (H_{target}). Knowing the distance to the antennas, the free-space transfer function (H_{space}) is determined. Using these calibration measurements the unknown target function

$H_{unkonwn\_target}$ is calculated using the internal and the external correction function H_{corr_int} and H_{corr_ext} as measured before:

$$H_{unknown\_target} = \frac{S_{data} H_{corr\_int} H_{corr\_ext}}{S_{chirp} H_{space}}$$

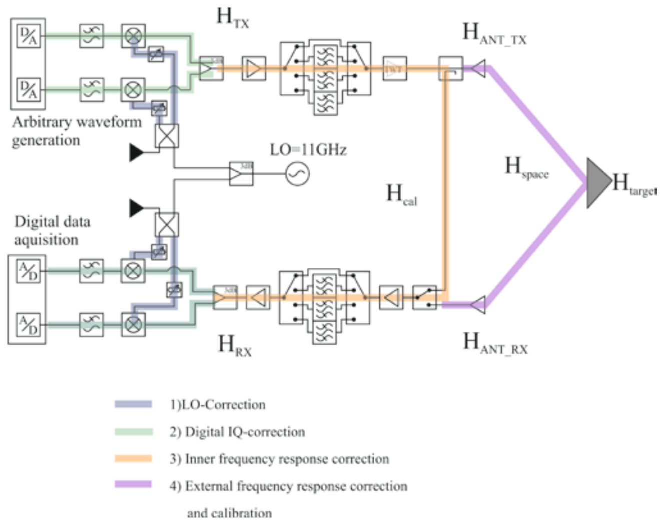

Fig. 3. Block diagram explaining the system correction strategy 1): phase adjustment for the local oscillator signal in IQ modulation and demodulation, 2): amplitude and phase correction of the modulation/demodulation sections, 3): amplitude and phase correction of the RX and TX units, 4) amplitude and phase correction of the overall signal path including the antennas and waveguides.

IV. APPLICATIONS

Using GigaRad, several measurement campaigns in different remote sensing application areas were performed. Two applications showing the system capability and flexibility are illustrated next. The first application in a bi static arrangement is shown in Fig. 4. The measurement in a turntable configuration allows high-resolution imaging of objects located on a slowly rotating platform. By corresponding ISAR processing the azimuth resolution is chosen the same as the range resolution [7]. Because of the very high spatial resolution, sufficient signal-to-noise ratio, and adequate clutter suppression, the radar image of a bicycle in Fig. 5 appears quite similar to an optical image, allowing a high potential of feature extraction capability. Many details are visible like the wheels, the frame, one pedal, the seat, and the suspension fork. The processed aspect angle for this image was chosen to 100° so that different parts reflecting only at certain observations angles are visible in the image

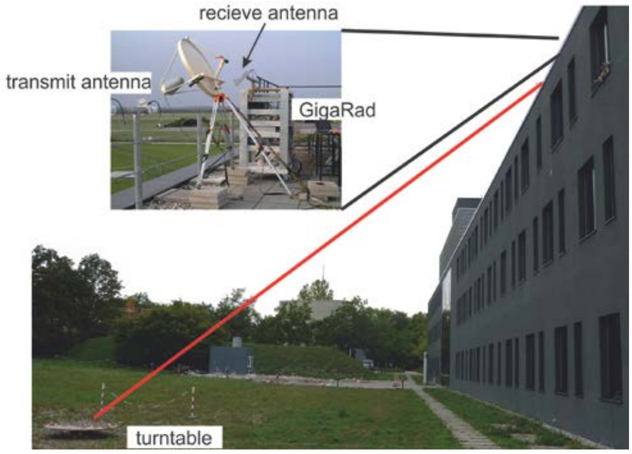

Fig. 4. Measurement configuration of the tower-turntable arrangement used for ISAR imaging.

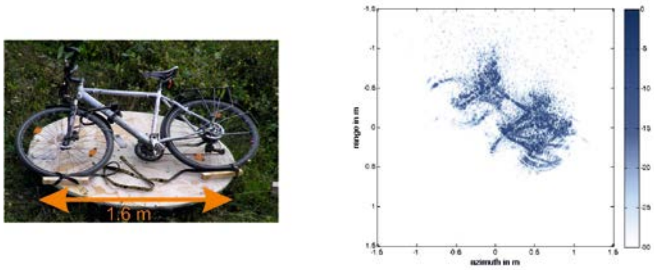

Fig. 5. ISAR-measurement of a bicycle in a turn table arrangement. Left: photography of the scenario; right: focused image with 6 GHz bandwidth.

In a second project called IoSiS [4] the radar shall be used in a system for high-quality imaging of satellites in space as illustrated in Fig. 6. For this very challenging application the radar was connected and synchronized to a steerable 9 m multi-dish antenna system. The antenna was modified to meet the requirements for the application in that way that a traveling wave tube amplifier (TWTA) and the two extension modules described above are mounted behind the main dish. Additionally two small receive antennas are mounted besides the TX antenna. The main radar system GigaRad is located in a container close to the positioning system.

Fig. 7 shows a processed ISAR image of the International Space Station ISS at a range and azimuth resolution of approximately 40 cm, demonstrating the capability of the GigaRad instrument for the IoSiS application and especially allows proving the coherency and timing performance.

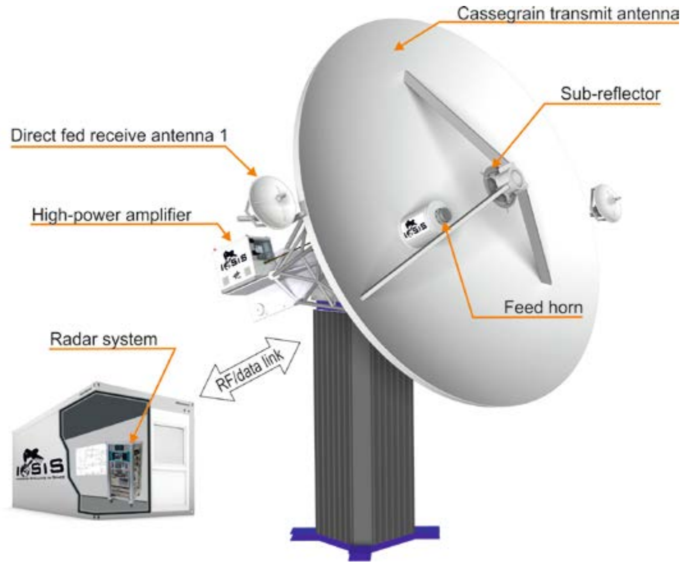

Fig. 6. Sketch of main components of the IoSiS system.

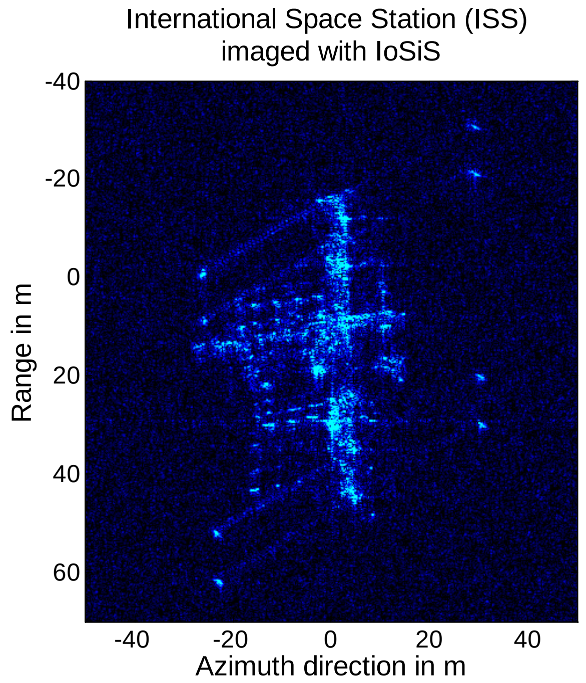

Fig. 7. ISAR image of the International Space Station (ISS) with a spatial resolution of 40x40 cm created with IoSiS and the GigaRad system.

V. CONCUSION

In this paper the new multi-purpose and high-resolution ground-based radar instrument GigaRad operated in X- and Ku band was presented. The broadband system characteristics, the flexible setup, the multi-channel capability, and the high degree of digitization allow a multitude of applications. In order to achieve the expected high performance, the system has been extensively characterized and an appropriate error correction scheme has been implemented. The absolute calibration using a reference target has been investigated. A verification of the system performance, i.e. the high-resolution imaging capability and the validity of the error correction algorithms have been exemplarily shown by ISAR imaging of a bicycle. Additionally the very challenging application of imaging satellites in space has been shown for the ISS.

VI. REFERENCES

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