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

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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 or 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

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 11 GHz.
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.

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 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_{\text{unknown target}} is calculated using the internal and the external correction function $H_{\text{corr int}}$ and $H_{\text{corr ext}}$ as measured before:

$$H_{\text{unknown target}} = \frac{S_{\text{data}} H_{\text{corr int}} H_{\text{corr ext}}}{S_{\text{data}} H_{\text{space}}}$$

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.

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.
V. CONCLUSION

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