IMPROVEMENTS OF GESTRA — A PHASED-ARRAY RADAR NETWORK FOR THE SURVEILLANCE OF RESIDENT SPACE OBJECTS IN LOW-EARTH ORBIT

M. Albrecht, C. Reising, D. Behrendt, M. Thindlu Rudrappa, P. Müller, M. Gilles, M. Käske, and C. Knauf

Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, 53343 Wachtberg, Germany, Email: marcus.albrecht@fhr.fraunhofer.de

ABSTRACT

The usage of phased-array radars for space situational awareness offers the advantage of electronic beam steering and digital beam forming, allowing rapid switching between different tasks, such as forming search fences and target tracking. With the German Experimental Space Surveillance and Tracking Radar GESTRA such a system has recently been constructed at the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR. Phased-array radars like GESTRA, consisting of a separate receiver and transmitter, enable both quasi-monostatic and bistatic modes of operation. This approach inherently offers the possibility of expanding GESTRA into a network of multiple, cooperating transmit and receive units. Such a system results in a variety of opportunities to improve the performance of space surveillance but also increases the methodological challenges in view of signal processing and operational modes. We discuss some of our recent and ongoing investigations on phased-array radar networks for space surveillance and report on upcoming realisations of such a system on the basis of GESTRA.

Keywords: space surveillance; space situational awareness; space debris; radar; phased-array radar; radar networks; GESTRA; LEO; signal processing; object characterisation.

1. INTRODUCTION

The use of space assets in low Earth orbits (LEO) for communication, Earth observation, navigation and other services plays a growing role in our modern society. As the number of active satellites in LEO increases, so does the danger they are exposed to from a growing number of inactive satellites, rocket stages and other debris of various sizes. Accordingly, there is great interest in an improved space situational awareness (SSA) in view of, e.g., collision avoidance, space traffic management, fragmentation detection and re-entry prediction.

Radar is an important sensor for the surveillance of objects in LEO. This is due to its capabilities with respect to accurate range measurements, operations independent of weather and daytime, searching comparatively large volumes, tracking, and providing instantaneous information on direction and radial velocity.

Phased-array radars provide an enhanced surveillance flexibility by their inertia-free electronic beam steering and digital beam forming. This allows a multi-modal operation by, e.g., setting up search fences, tracking modes and combinations of these. At the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR we have been commissioned by the German Space Agency at the German Aerospace Center (DLR) to design and construct the German Experimental Space Surveillance and Tracking Radar GESTRA (Sec. 2). The radar comprises separate autonomous transmit and receive sub-systems integrated in two partly mobile shelters. This design and the operational flexibility provided by the combination of electronic and mechanic beam steering inherently offers the possibility to expand the system into a network of cooperative radars for space surveillance (Sec. 3). Such a phased-array radar network consists of a set of transmitters (Tx) and receivers (Rx) in different possible configurations (Sec. 3.1). It offers a variety of advantages compared to a single (quasi-)monostatic phased-array system due to an increase of the amount and diversity of the information to be gathered for the observed objects (Sec. 3.2).

The performance of a radar system is strongly dependent on the mode of operation and the quality of the signal processing. The usage of a radar network for SSA poses some special challenges regarding its operation. This includes centralised control, data transmission between remote systems, synchronisation of the systems, and high accuracy of the position and orientation of the radars. The aspired performance gain through multistatic signal paths also requires a more complex signal and data processing. In this paper, we briefly report on some recent investigations and simulations done at Fraunhofer FHR on performance improvement by networks (Sec. 3.2). This includes the possibilities of an enhanced object characterisation with phased-array radar networks (Sec. 3.3). We discuss some aspects of the required operation modes and signal processing (Sec. 3.4).

In view of the realisation of a phased-array network for SSA in combination with GESTRA, the construction of the additional receiver GESTRA EUSST is currently under way at FHR (Sec. 4.1). The receiver will provide an improved performance and functionality. To establish the required cooperation between GESTRA and GESTRA EUSST, the project GESTRA Networks is currently developing the required interconnection as well as a precise synchronisation of time, phase and frequency between these systems (Sec. 4.1). This includes an adaptation and optimisation of the software, and algorithms for network operation. To realise a very precise time synchronisation and highly stable frequencies of the applied oscillators, the usage of sets of atomic clocks is being developed. The alternative usage of Global Navigation Satellite System (GNSS) services does not provide the required precision for such applications. Moreover, the ongoing project GESTRA TX2 includes the design and development of an additional transmitter (Sec. 4.2). An enhanced transmit power by up to a factor of two compared to the original GESTRA transmitter will be achieved using new GaN-based semiconductor technology. The enhanced power requires a newly developed cooling based on the pulsating heat pipes technology. When combining all these systems, i.e. GESTRA, GESTRA EUSST and GESTRA TX2, the resulting network will provide a significant increase of the detection capabilities. Depending on network geometry, sensor orientation and operation mode it will be able to detect three to four times smaller targets compared to GESTRA alone [13].

2. GESTRA

The German Experimental Space Surveillance and Tracking Radar GESTRA is a quasi-monostatic, pulsed phased-array radar at L-band [18] [12]. It is specifically constructed for the surveillance of LEO with orbit altitudes between 300 and 3,000 kilometres. GESTRA is quasi-monostatic in the sense that it consists of two containers, so-called shelters, which have a size of 18×4×4 meters and a weight of 90 tons each. The shelters are divided into separate areas for the transmitter or receiver system, air conditioning and an operation room. The antenna plates of the transmitter and receiver subsystems both consist of 256 modules. Each transmitting module is capable of generating over 1,000 Watts of transmit power. In addition to the inertia-free electronic beam steering, a three-axes positioner enables mechanical steering of the antenna plates, providing an enhanced surveillance flexibility. Moreover, the positioners enable a rotation of the antenna plates around their own axes to change the spatial orientation of the linear polarisation. The transmitter provides a single and the receiver a dual linear polarisation.

Basically, GESTRA can be regarded as a software-defined radar. As such it provides a multitude of operation modes with a freely programmable sequence of beam directions and pulses per beam. Important for the detection of objects is the generation of fence-like search volumes by sets of scanned radar beams. The search volumes can be adjusted to provide the required field of view (FoV) or sensitivity, i.e. probability of detection for a given radar cross section (RCS). Initially seven different operation modes are planned which will span different search fences in space. The pulses per beam direction are generated such that any LEO object with a sufficient RCS is detected at least three times while crossing the search fence. Because of this, larger FoVs are typically associated with a lower number of pulses per beam direction and hence lower sensitivities, and vice versa. Operation modes with tracking capabilities will also be implemented. Moreover, it will be possible to initiate a track-while-scan mode, which uses idle times for tracking while maintaining the search fence. As a software-defined experimental system, GESTRA offers a great flexibility for other operation modes or further system adaptations.

Another unique feature of GESTRA is the fact that it is partially mobile. The shelters were designed and built in a way that they can be moved to and installed at different locations. This has already been proven by their transport from the assembly site at Fraunhofer FHR in Wachtberg, Germany, to the current location near Koblenz, Germany.

Currently, test and trial measurements are being carried out with GESTRA in its real operational environment [12]. In this process, the operational measurements are already fully tested: GESTRA is remotely commanded with measurement tasks that are then carried out by the system on site independently and without personnel present. That means that the transmitting shelter transmits, according to the selected operation mode, and the receiving shelter receives simultaneously. The data obtained is then processed, which is currently done offline. The experiments performed so far are within the expected results with respect to the performance of the system in essential parameters such as detection performance or velocity estimates. Variation in the signal to noise ratio (SNR) are within expectations due to rotation of the regarded objects.

The current work concentrates on the future real-time capabilities, further robustification of the overall system and increased remote operability. GESTRA funding is provided by the German Space Agency at the German Aerospace Center (DLR) with funds from the German Federal Ministry of Economics and Climate Action (BMWK). In future, the radar system will be operated by the German Joint Space Situation Centre, which is financed by the BMWK and the German Federal Ministry of Defence (BMVg). The final handover of the experimental system to the German Space Agency is planned for the end of 2023. In addition, this national research and development expertise in radar technology and signal processing is to be linked with a capable commercial enterprise in the future.

3. COOPERATIVE PHASED-ARRAY RADAR NETWORKS

Currently a comprehensive analysis of performance improvements, operation modes and signal processing algorithms for phased-array networks of different configurations is conducted. The overall objective is a theoretical and simulation-based investigation in view of optimising spatial coverage, sensitivity and accuracy of orbit determination. A part of theses studies is done in collaboration with the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE, and is funded by the German Federal Ministry for Economic Affairs and Climate Action. In order to ensure the most efficient use of radar networks, an important new aspect is the development and analysis of a dynamic radar resource management (RRM). This includes adaptive methods and algorithms for automated planning of the time sequence of the tasks assigned to the network depending on the current observational situation and the general requirements. Recent results on RRM can be found in [15]. In the following we briefly discuss some aspects of our investigations on radar networks for SSA.

3.1. Radar network configurations

Phased-array radar networks for space surveillance can be categorised into different types with respect to a variety of criteria (e.g. spatial coherence, type of data fusion; see [4]). Considering the distances between the subsystems (or nodes) that make up the network, i.e. phased-array transmitter, receiver or both, we here distinguish between three different kinds: local networks, networks of medium extent and global networks [5].

In local networks, the individual sub-systems are located at distances between each other of a few 100 metres, i.e. still separated significantly with respect to the wavelength. In this configuration the sub-arrays are operated as part of a common quasi-monostatic system. This type enables spatially coherent integration for detecting particularly small objects.

Alternatively, networks of medium extent consist of subsystems with distances of several 100 kilometres. The FoVs of the individual sub-systems overlap to a considerable extent, so that bi- or multistatic signal paths can be used. A fusion of the data from different viewing directions leads to an improved performance in view of detection as well as position, velocity and subsequently orbit parameter estimates. In this paper we focus on medium extent networks for the surveillance of LEO objects.

Finally, in global networks the individual nodes are distributed around the Earth and so far apart that the FoVs do not overlap significantly for LEO objects, or the SNR for overlapping areas is very small. Accordingly, the nodes of such networks are operated independently of each other as individual monostatic radars. Global systems can be optimised to significantly improve the buildup and maintenance of an object catalogue in view of timely updates of the orbit parameters of a large number of objects and the coverage of a large orbit parameter space, especially with respect to inclination. Such systems may itself include local or medium extent networks as sub-systems, and thus can benefit locally from the immediate enhancements of cooperative distributed radar configurations.

3.2. Advantages of radar networks

Cooperative phased-array radar networks of medium extent may in principle provide a variety of advantages compared to a single (quasi-)monostatic system [5]. The advantages are due to a gain in the amount and diversity of the obtained information. Depending on the concrete realisation, they may include benefits that are described in the following.

A network enables the utilisation of bi- and multistatic signal paths. According to the number of Tx and Rx, more backscattered signal energy can then be used for detection and tracking. When all nodes of the network are equipped with Tx/Rx pairs, the number of signal paths increases quadratically with the number of nodes. If the distances between the nodes are sufficiently large, a network provides the possibility to observe objects simultaneously under different aspect angles. In the typical case of a fluctuating radar cross section (RCS) due to the rotation or tumbling of an object, this has the advantage that a temporal minimum of the RCS according to one signal path might be compensated by higher RCS values from other signal paths. The corresponding smoothing-out of the fluctuations in the data fusion process can then lead to a SNR gain. Accordingly, an improved detection performance is achieved, i.e. objects with a lower RCS and correspondingly a lower size can be detected as compared to using a single monostatic system.

The improvement in detection performance depends on the data fusion in the network. If all multistatic paths are used, objects with lower RCS values can be detected than in a monostatic operation of the network. In the latter case a receiver only processes the back-scattered signal of the transmitter in its own node, while in the former case it processes the signals from all transmitters in the network. Figure 1 shows a simulation of the minimum detectable RCS for both cases, i.e. monostatic and multistatic operation, achieved by a network of three nodes, each containing a Tx/Rx pair. A multistatic operation with several transmitters requires to imprint the transmitted radar waves with the information from which transmitter they originate. This is necessary to clearly separate the interfering signals at the receivers in the signal processing. The usage of different frequency bands for different transmitters is not efficient for this purpose as this would require a too broad frequency spectrum. Instead code division multiplex and Doppler division multiplex techniques are used to provide orthogonal waveforms for the separation of the signals.

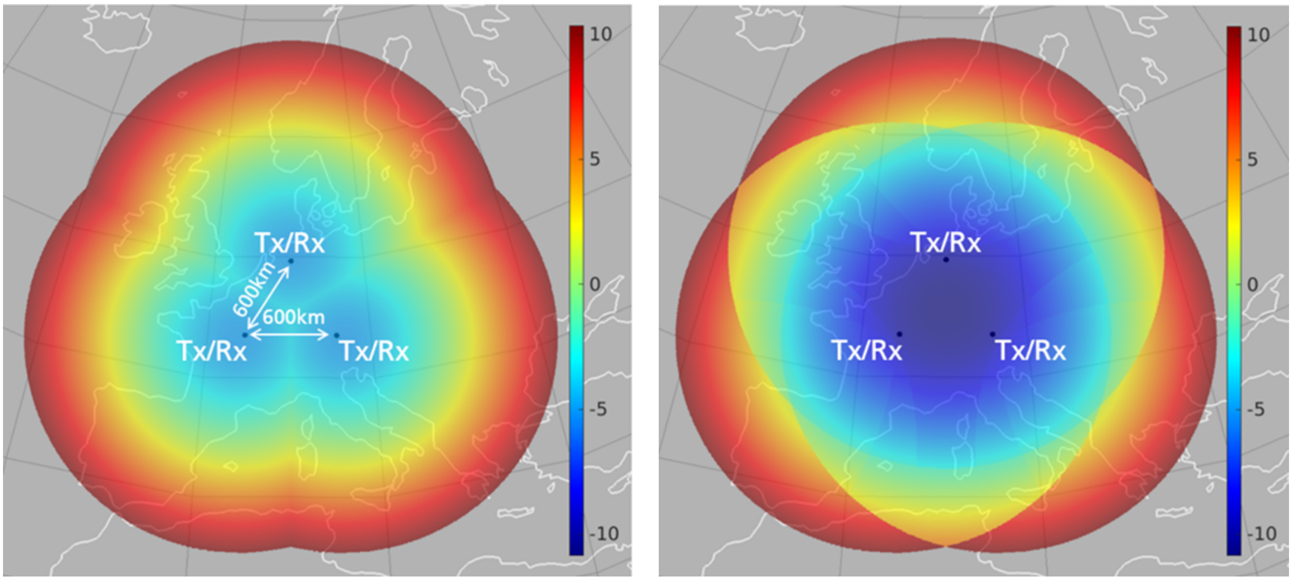

Figure 1. Simulation of the detection performance for a radar network. The network consists of three nodes with a Tx/Rx pair each in a triangular geometry and a distance between the nodes of 600 km. The colour code shows the minimum detectable RCS in dBm^2 at an altitude above Earth's surface of 1000 km. **Left:** *Monostatic operation.* **Right:** *Multistatic operation. In multistatic operation lower RCS values can be detected and the distribution is more homogeneous. The sharp cutoffs in this case originate from the fact that signal paths are disregarded if they degrade the results. As an effect, the outer regions in both cases show equal values.*

The fusion of direction of arrival (DOA) and range information from distant nodes in a network leads to an increased precision in the estimation of the object positions. This is due to the fact that for a single node, i.e. in the monostatic case, the position accuracy in the cross-range direction is much smaller than in the down-range direction. Accordingly, the error ellipsoids, which describe the probability distribution of the positions, are oblate and their intersection in the data fusion process results in a more confined position estimate. Figure 2 gives a simplified delineation of this principle.

The observation of objects with a network allows to obtain Doppler and hence radial velocity information from different viewing angles simultaneously. As a result, an instantaneous determination of the velocity vector is possible if the object is simultaneously observed along at least three lines of sight (LoS) with a sufficient distance between the nodes. By differentiation of the velocity vector it is also possible to derive the acceleration vectors if observations at consecutive time steps are available.

An improved determination of position, velocity and eventually acceleration leads to an estimation of the orbit parameters with higher precision [8]. This has the effect that the required update rate of the parameters in a catalogue is lower and resources are freed for other tasks.

The aforementioned effects come into play when the network is run cooperatively in the sense that all nodes simultaneously observe the same volume in LEO. Alternatively, a network including multiple Tx/Rx pairs at its nodes can be used to increase the FoV and hence the surveillance volume in search mode, with no or only a

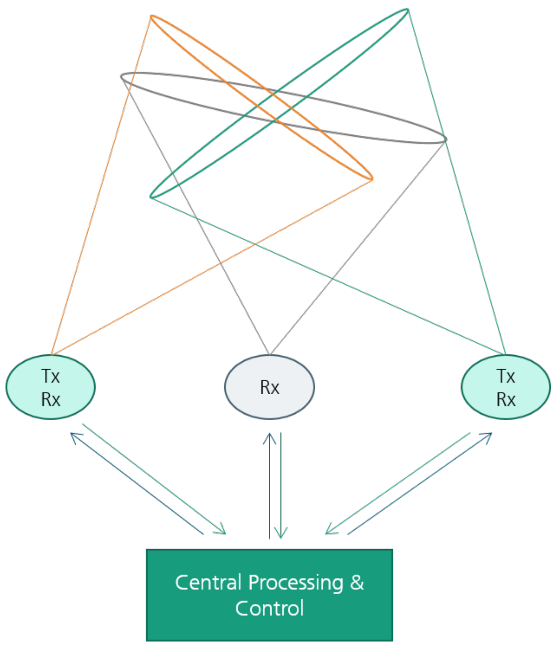

Figure 2. Improvement of the position estimation in a radar network by data fusion. The intersection of the ellipses, which depict the oblate error ellipsoids, result in a higher precision of the position estimate.

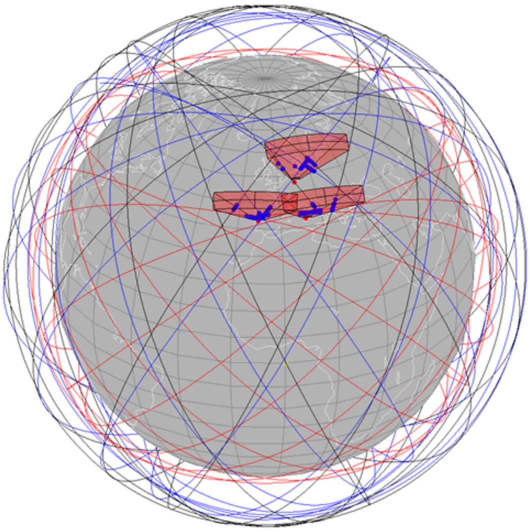

Figure 3. Simulation of detections by a radar network. The search fences are set up in a way that two of them only overlap marginally. For some orbits consecutive detections in distinct search fences are achieved.

small overlap between the different FoVs. The volumes can be set up in a manner such that objects with suitable orbit parameters can be observed at slightly different times and hence positions on their trajectories, see Fig. 3. This again enables a better estimation of the orbit parameters. In this case, it is advantageous if characterisation algorithms are applied to provide a probability that two observations at different times in fact arise from the same object (Sec. 3.3).

In general, a network facilitates the search and simultaneous tracking of multiple targets. Moreover, a network offers a higher failure safety of the entire system. If a subsystem fails or requires maintenance, the other subsystems can continue the surveillance. This also holds for the case that the required coordination and synchronisation between the nodes is temporarily not available.

3.3. Characterisation of resident space objects

The characterisation of resident space objects (RSO) by surveillance radars is an important aspect in view of improving our knowledge of the space situation. While dedicated radars like TIRA, which provide high precision imaging, are best suited to perform a detailed reconnaissance of individual RSOs, the characterisation of RSOs with phased-array radars also offers a number of advantages. An important benefit is the potential for an improved identification of target objects that goes beyond the sole identification by their orbital parameters. In this respect, a characterisation can lead to a more confined estimation of the probability that two objects observed at different times are actually identical. This enables a more reliable data assignment in object catalogues, which in turn may lead to a higher accuracy of the orbital parameters since more data belonging to one object can be used for the determination of its orbit and corresponding changes thereof.

The characterisation of RSOs with surveillance radars is based on an analysis of the back-scattered signals of rotating targets, which show components in the frequency spectrum that change in time. Typical quantities to be obtained are the rotation period, the maximum Doppler frequency and the maximum size of the object projected onto the line of sight. Obtaining more information on the rotational state of targets is also important with respect to other considerations beyond identification. These comprise future attempts of an active removal from orbit, where the rotational state is a decisive information. Knowledge on the rotational state of an object is also important for analysing the possible improvement of detection performance and estimation accuracy of orbital parameters through long coherent processing intervals. It also provides valuable information for investigations of the complex rotation dynamics owing to the influence of the atmosphere, solar radiation pressure and other factors.

Due to the fact that the time frequency distribution of the radar signals of rotating rigid bodies has sinusoidal signatures, geometric and rotation parameters can be extracted. Since the widely used Fourier transform does not provide information on time-varying frequency modulations, a joint time-frequency analysis (TFA) is required to extract rotation dynamic features [3]. Traditionally, a TFA is performed by using the Short Time Fourier Transform (STFT), which computes Fourier spectra on successive sliding windows. In this approach, the length of the window is a trade-off between time and frequency resolution, called the Gabor limit. A possibility to overcome this drawback is to combine Fourier-based spectrograms obtained with a short and a long window, or with a set of windows of varying sizes. This super-resolution technique can localise oscillation packets simultaneously in both time and frequency better than it is possible with any single spectrogram. A comparison of the effects of STFT, chirplet transformation and super-resolution wavelets on the extraction of features (rotation period, Doppler frequency and maximum size) based on the inverse Radon transform (IRT) for the monostatic case is presented by [16]. The performance of the time-frequency representation is evaluated by comparing the concentration measure as well as the Renyi entropy of the IRT output obtained for varying SNR levels in the simulations. As a result, the usage of the super-resolution technique provides a better accuracy for the estimation of the aspired parameters than STFT or chirplet transformation.

Using radar networks can improve the extraction of geometric and rotation parameters, adding another benefit in favour of networks. This is due to the simultaneous availability of information for different LoS, which in principle opens the possibility for a three-dimensional (3D) reconstruction of the shape of rotating objects. An approach is to obtain inverse synthetic aperture radar (ISAR) imaging of rotating objects, which gives the projection of the 3D target reflectivity onto the imaging

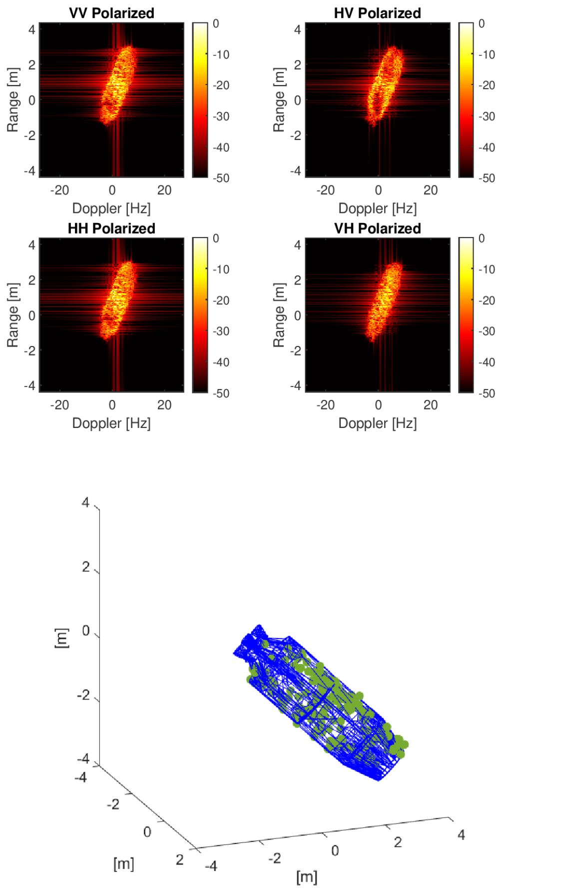

Figure 4. RSO characterisation. The four upper images show the simulated ISAR images of a rocket stage at different polarisations. H denotes a horizontal and V a vertical polarisation. The first letter gives the transmitted and the second letter the received polarisation. The lower graph shows the rocket stage model in blue and the reconstruction as green dots.

plane. The usage of multiple 2D ISAR images requires the storage and processing of a large amount of data. A possibility to reduce this is given by the application of compressed sensing (CS) techniques for the reconstruction of 2D and 3D ISAR images. This is because the ISAR image is a sparse representation of the entire ISAR data as the number of dominant scatterers is typically lower than the number of pixels in the image. An analysis of this approach by evaluating the performance of a non-uniform fast Fourier transform (NUFFT) using Gaussian gridding and varying the number of selected pulses in slow time is given by [17]. The simulations of the ISAR image reconstruction and phase recovery for 3D reconstruction are conducted for a radar network consisting of one transmitter and three receivers at a frequency of 12 GHz and a bandwidth of 1 GHz. Different objects are represented by point-scatterer models. The results exhibit that target recognition can be possible with less than 5% of the data.

Our current research is focussed on studying the effects of polarisation in RSO characterisation. Electro-magnetic scattering from objects is simulated using a physical optics method. As an example Fig. 4 shows the simulated ISAR images of a rocket stage at different polarisations for one node (Tx/Rx) of the network. Also shown is a preliminary 3D reconstruction using a network of medium extent.

3.4. Operation modes and signal processing

The basic components of a medium extent network are bistatic radars, which are combined to set up a multistatic system. Accordingly, a major topic in signal processing is related to bistatic signal paths with large baselines. In this case the intersection of transmit and receive beams, in which objects can be detected, may form relatively small volumes. The problem is known as beam scan-on-scan loss [19]. An approach to deal with this effect is pulse chasing [5, 7]. This technique time-dependently aligns the receive beam in the direction from which backscattered signals are expected according to the propagation of the transmitted pulse (Fig. 5).

Pulse chasing requires a high scan rate and can only be realised with phased-array radars. Typical cases that have been covered in the literature consider the sum of the ranges from transmitter to object and from receiver to object to be much larger than the distance between transmitter and receiver (i.e. the baseline). However, a network of medium extent may contain a baseline of several hundred kilometres while the observed LEO objects can have an orbit height as low as 300 km. To cover these situations a pulse chasing concept has been developed at FHR for the case of LEO objects and potentially large bistatic baselines in a network [5]. With this method it is possible to perform pulse chasing with multiple simultaneously active receive beams for arbitrary space surveillance scenarios.

Increasing the baselines of a medium extent network can enhance the estimation accuracy of position and orbit parameters due to a higher diversity of aspect angles. However, applying the pulse chasing method, large baselines often require a high number of simultaneously active Rx channels to cover the entire Tx beam. As the maximum number of Rx channels is typically restricted by the available hardware, this limits the maximum applicable baseline and hence the performance. To overcome this problem, a more sophisticated beam space transformation or beam former method is preferable, which reduces the required number of channels for chasing a Tx pulse. Available methods for beam space processing in multistatic radar networks have been developed for quasi-monostatic multiple-in-multiple-out (MIMO) systems, which do not serve the requirements of medium extent networks. Alternatively, they consider bistatic MIMO systems, but do not guarantee the achievement of an optimal detection and estimation performance [6]. To surmount these drawbacks, a method has been developed at FHR, which applies the eigen-beam space transformation [10, 11] to medium extent networks [6]. This eigen-beam former can provide either optimal performance or a desired performance trade-off between detection and DOA estimation, depending on the available number of channels and spatial area coverage. Moreover, the method enables a larger and more homogeneous coverage over the Tx beam with a smaller number of Rx channels compared to other methods. Given a fixed number of channels, it thus allows increasing the baseline and leads to an improved position estimation accuracy for any bistatic phased-array radar and corresponding networks.

For the design of a radar system for SSA and the corresponding signal processing methods it is decisive to understand the dynamics of the observed objects [9]. For RSOs, several representations of the dynamic state can be applied, each useful for different purposes. The state can be captured by orbital elements (e.g. Kepler parameters). Alternatively, a state description in Cartesian or polar coordinates centred at the radars phase centre is a natural choice from the viewpoint of the sensor. A mixed representation of the state using a Cartesian position vector, but giving the velocity via orbital elements, allows to easily define a target position relative to the radar while simultaneously preserving the capability to relate the velocity of the target to the eccentricity of its orbit. Such an approach makes it possible to regard all orbits that pass through some point relative to the radar and define some maximum eccentricity for determining radar design or control parameters. This method has been applied to a bistatic setup, so that it can be used with respect to radar networks for SSA [14]. The method determines the velocity of an RSO at a given angle and range towards the receiver from its orbital parameters of eccentricity, longitude of ascending node and argument of periapsis. It has been applied to derive the maximum duration of the coherent processing interval (CPI) for a bistatic radar pointing to a given direction. The CPI is of great interest for SSA as longer CPIs allow detecting smaller objects [1]. Both the limits determined by range as well as Doppler resolution can be derived. The data from the simulations suggest that it is advantageous in view of the CPI to line up Tx/Rx pairs of a bistatic radar into the direction of beams that, e.g., constitute a search fence [14].

A major challenge in space surveillance is the detection and tracking of objects which have low SNR values and high velocities resulting in high high range migration. While conventional radars follow a track after detect approach, methods of simultaneous detection and tracking, so-called track before detect (TBD) methods, have been analysed [2]. For this purpose particle filters (PF) and coherently integrated target reflections are used. The method does not only provide tracks but also gives the probability of the presence of a target in a given frame. Along with the convential PF method, a feedback-based approach has been analysed. The method is currently being adapted for use with radar networks.

4. FOLLOW UP PROJECTS GESTRA EUSST AND TX2 – GOING FULLY DIGITAL

The buildup of radar networks for space situational awareness is a topic of current research [5] (Sec. 3). Using some results of this research, the German Space Agency at DLR commissioned Fraunhofer FHR to develop and construct two additional radar units GESTRA EUSST and GESTRA TX2. The GESTRA EUSST system is an additional radar receiver and its construction is funded by the EU SST program. The project is strongly connected to the GESTRA Networks project, that is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK). The main purpose of the GESTRA TX2 project is to update the GESTRA amplifier technology to state-of-the-art transistor technology. All of this follow up projects focus on the switch to fully digital array technology and are presented in the next sections.

4.1. GESTRA EUSST and Networks

The GESTRA EUSST receiver is very similar to the GESTRA receive unit. Several improvements that simplify maintenance and transport are implemented in the construction and buildup. For example, the lifting table has changed from a scissors lift table to a spindle lift system, thus the whole antenna can be fully retracted into the shelter to drastically simplify the transport of the system. From a radar perspective, the main changes are the implementation of a different beam forming technique and a very precise time synchronisation.

4.1.1. Beam forming

The GESTRA system provides the ability to generate a set of 16 different receive beam positions simultaneously [18]. For use in a multistatic phased array radar network, this number of simultaneous beams is very limiting [6]. To overcome this limitation, it is planned to drastically increase this number by the use of GPU capabilities for beam forming. In addition, new techniques for a more adaptive beam forming can be tested and implemented much easier. Nevertheless, the upcoming data rates submitted to the radar processor are very challenging and are a topic of development.

4.1.2. Precise synchronisation of spatially divided radar systems

For the sensor data fusion of both receive units, a very precise time synchronisation between the radar systems is necessary. Reducing the errors in time directly leads to increased radar performance, thus the use of optical pumped atomic clocks is planned to synchronise the spatially separated radar units.

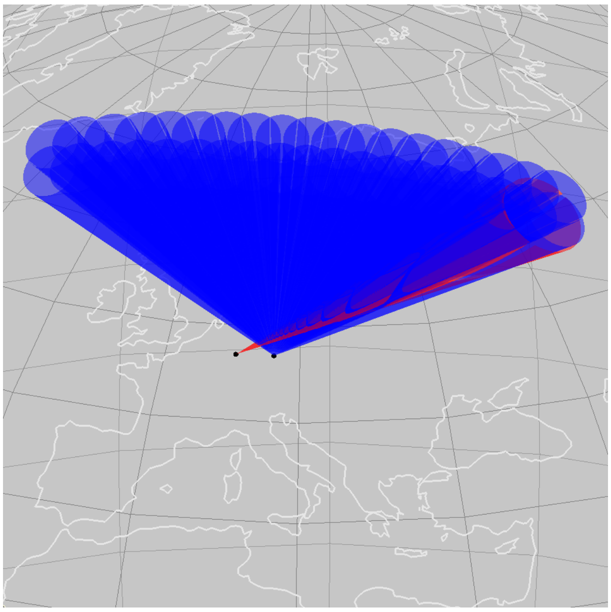

Figure 5. Beam forming. The transmit beam is shown in red and the required receive beams to chase the pulse while it travels along the transmit beam are show in blue.

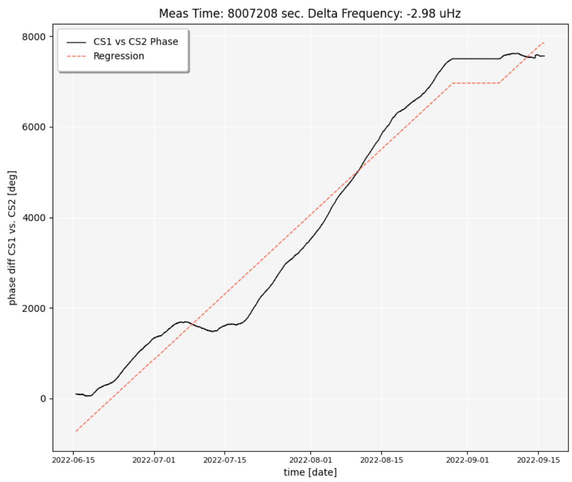

Figure 6. Long-term measurement of atomic clocks. The graph shows the phase shift between two Caesium clocks (CS1 and CS2) as a function of time.

Figure 7. Reference System. The system consists of (currently) two parabola antennas for the investigation of new synchronisation techniques.

First measurements of phase and time drift in a usual laboratory environment indicate a coupling between clock stability and climate conditions. An example of the phase drift is shown in Fig. 6. Additionally the clocks must be protected against any kind of vibrations and electromagnetic disturbances. As a result, the clocks will be placed apart from the radar shelter in an additional container that is completely decoupled from the environments inside the radar system.

Another concept to synchronise the radar receivers will be the use of extraterrestrial objects. This can be done either by use of radar reflections of well-known passive sources like satellites or with active sources like active satellites or astronomical sources. The correlation of spatially separated receivers and measurements of time differences is part of ongoing research at Fraunhofer FHR. For this purpose a reference system was set up and is currently used for first investigations of this approach (Fig. 7).

4.2. GESTRA TX2

In order to further expand the currently planned GESTRA radar network, another more powerful transmitter unit, called GESTRA TX2, is being designed. This development mainly includes four areas of improvement: transmitter module, cooling system, signal generation and networking.

When the first GESTRA transmitting unit was built, laterally-diffused metal-oxide semiconductor (LDMOS) transistors were used, because they were state-of-the-art technology at that time. In the last years the transistor technology has continuously evolved. The new transmitting modules will use final stage transistors on the basis of gallium nitride (GaN), which are able to generate substantially increased transmit power with a higher efficiency. In a first step a concept will be developed and evaluated for a new amplifier chain based on prototypes. The aim is to increase the transmit power by a factor of up to two compared to the original GESTRA transmitter.

The resulting additional thermal load in the transmitter module requires a redesign of the cooling circuit. Together with the Fraunhofer Institutes for Physical Measurement Techniques IPM and for Machine Tools and Forming Technology IWU, a much more efficient cooling concept using pulsating heat pipes is being developed. Again, the first step is an evaluation of the new system on the basis of a prototype.

The signal generation will also be improved. Compared to the original GESTRA transmitter unit, a decentralised signal generation is planned. For this an independent signal is generated in each of the 256 channels by using a multi-channel arbitrary waveform generator (AWG). This results in principle in 256 independently definable waveforms. This enables techniques like beamforming on transmit and digital synthesis. In addition, the backplane of the antenna plate will be simplified, as only reference clocks, which are required for signal generation, have to be distributed. A challenge that remains is the necessary synchronisation of signal propagation times.

One of the essential tasks is to build up a network with the other GESTRA systems. The goal is a synchronous operation of both GESTRA transmitters. At this point, the challenge is the required time, phase and frequency synchronisation of the distributed systems. The network will be designed in a way that it can be continuously expanded to include more GESTRA-like systems in order to increase the network and subsequently improve the surveillance performance for LEO.

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