GESTRA-TECHNOLOGY ASPECTS AND MODE DESIGN FOR SPACE SURVEILLANCE AND TRACKING

H. Wilden[(1)], C. Kirchner[(1)], O. Peters[(1)], N. Ben Bekhti[(1)], R. Kohlleppel[(1)], A. Brenner[(1)], T. Eversberg[(2)],

[(1)] *Fraunhofer FHR, 53343 Wachtberg, Germany,* helmut.wilden@fhr.fraunhofer.de,
[(2)] *German Space Agency DLR, 53227 Bonn, Germany ,* thomas.eversberg@dlr.de

ABSTRACT

On behalf of the Federal Government the German Space Administration (DLR RFM) commissioned the Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR) in 2015 to design and develop a phased–array based radar for monitoring the low Earth orbit. This so-called German Experimental Space Surveillance and Tracking Radar (GESTRA) will support the German Space Situational Awareness Centre to generate a catalogue of orbital data for all objects with a minimum radar cross section (RCS) at altitudes of less than 3000 km.

1 INTRODUCTION

The strong dependency of human society on infrastructure in space demands for continuous space surveillance activities. Considering potential sensor technologies, operational radar-based space surveillance systems play an important role in detecting debris objects in the earth orbit. On behalf of the Federal Government the DLR Space Administration (DLR RFM) commissioned the Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR) in 2015 to design and develop a state-of-the-art phased – array radar to monitor the low Earth orbit. This so-called German Experimental Space Surveillance and Tracking Radar (GESTRA) will support the German Space Situational Awareness Centre to generate a catalogue of orbital data for all detected objects at altitudes of less than 3000 km. Incorporating most challenging phased-array technologies, the concept of the GESTRA radar system will provide high quality data sets. This radar sensor gives the basis for future scientific investigations within the cooperation frame of the contributing nations.

2 REQUIREMENTS OF THE RADAR SENSOR

Monitoring the low Earth orbits up to an altitude of 3000 km and assuring the detection of all objects with a certain minimum radar cross section can only be achieved with a radar system based on phased-array principles and newest module and beamforming technologies. Once, space objects have been detected, special track-while-scan- radar modes focus energy and timing in order to improve the data quality and information about the object orbit parameters (see *Figure 1*). Due to the main orbit trajectories, the strategy for space surveillance is to form and monitor a wide angle fence of closely separated transmit beams and to detect all objects passing this fence.

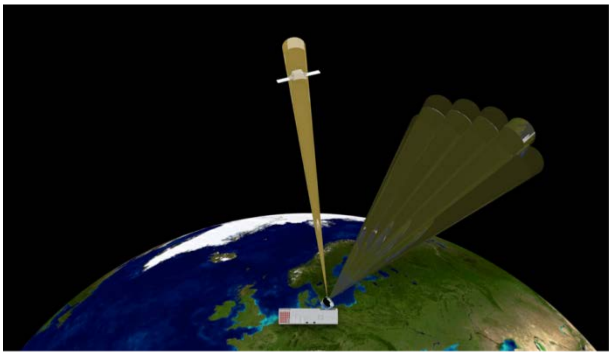

Figure 1 Beam strategy for track-while-scan mode

The partly mobile radar sensor is developed to allow an experimental operation for 12 years. This long term operation explains the detailed requirements defined by DLR-RFM concerning high standards in product assurance and quality management, documentation and verification, which were derived from the ECSS standards of the European space agencies.

3 DEVELOPMENT OF THE GESTRA SYSTEM AT FHR

The subsystem complexity and the high transmit power lead to the design of a close-monostatic pulsed phased-array radar in L-band (1280-1400 MHz).

The transmit subsystem and the receive subsystem are integrated individually in large-size shelters of 18 m x 4 m x 4 m being separated by about 100 m. In order to extend the field of view beyond the scan area of the array, each array antenna is mounted on a 3-axes positioner with wide angle mechanical rotation features (see *Figure 2*). Integrated scissors lifts allow to move the antenna frontends from transport position into operational position within the 5 m-radome on the shelter roof.

Proc. 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office
Ed. T. Flohrer & F. Schmitz, (http://spacedebris2017.sdo.esoc.esa.int, June 2017)

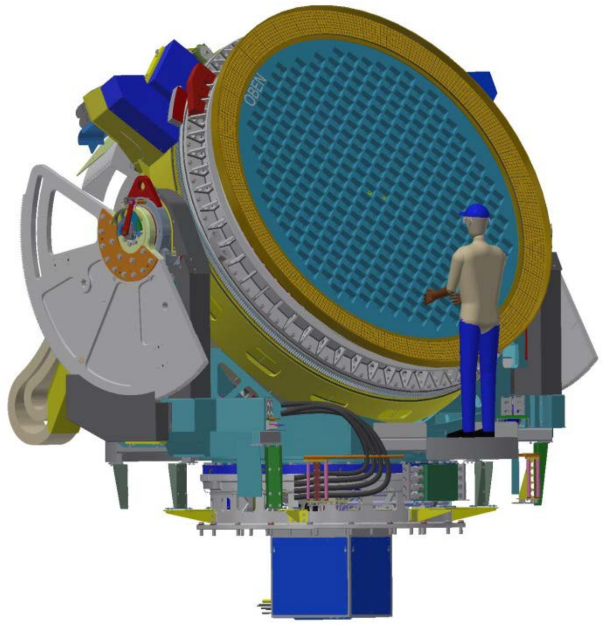

Figure 2 Mechanical model of the antenna with 3-axes-positioner

Both antenna apertures consist of 256 active cavity-backed stacked patch antennas distributed on a triangular grid of the planar circular array. The transmit elements excite a linear polarization and the receive elements are designed for dual polarization in order to cope with ionospherical wave propagation effects (Faraday Rotation). The mechanical model of the antenna with positioner is shown in *Figure 2*.

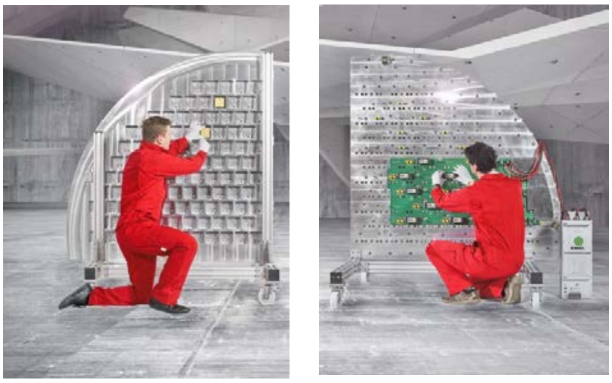

Figure 3 Demonstrator of an antenna quarter, a) front side b) backside with large backplane PCB

On the backside of the antenna plate the element outputs are connected to the corresponding modules for receive and transmit respectively. For maintenance reasons the modules of both antennas are arranged on so-called plank structures enabling liquid-cooling and power supply to the modules. The planks form the least replaceable units additionally accommodating decentral power supplies and the necessary control units. The mass of all planks summarizes to nearly 2 tons for each of the two subsystems being carried by the antenna plate.

4 TRANSMIT SYSTEM

Due to the high radiated average power needed to meet the range requirements of the radar, a separate transmit subsystem is mandatory. Each high power single radiator is connected to a transmit module with high efficiency.

The solid state transmit modules developed at FHR are designed to deliver a pulsed output power higher than 1000 W with a duty cycle of maximum 25%.

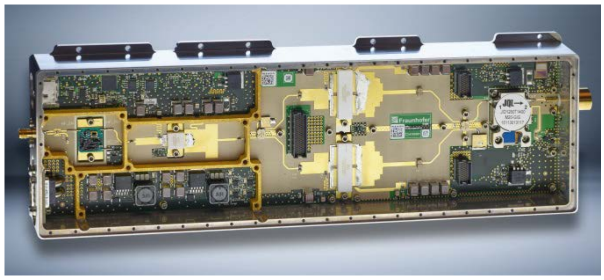

Figure 4 Transmit module

The transmit module shown in *Figure 4* depicts the 3-stage structure of the amplifier design. Several programmable features in the transmit path allow the output pulse to be compliant with ITU concerning out of band spectrum. Assuring mode-adapted pulse length large buffer capacitors mounted on the planks store the necessary electrical energy. By means of 6 bit-phase shifters the beam shape is switched from beam broadening in surveillance mode to pencil beam in track mode.

5 RECEIVE SYSTEM

To guarantee a low system noise figure independent of the ambient temperature the receiver system utilizes the same liquid-cooling system as the transmit system. The receiver is based on the so-called “software defined radio” principle with the received signal being sampled by each element on the carrier frequency. The associated receiver module (see *Figure 5*) contains two identical analog microwave pre-amplifying paths having adjustable gain and filter centre frequency. A 12-bit dual-channel A/D converter digitizes the dual-polarized received signal, which is fed into the central FPGA. A firmware was developed that implements digital downconversion, baseband filtering and the first-level beamforming. Thus the radar frequency can be switched from pulse to pulse enabling flexible waveforms.

The optical digital outputs are combined using adapted beamforming units. These units allow to arbitrarily shape multi-beam pattern of the receiving antenna. Only this digital beam processing in combination with a beam

Figure 5 Dual polarized Digital Receive Module

broadening array weighting on transmit allows to meet the requirements of high speed space surveillance. To improve the sensitivity of the radar system for given transmit power and noise figure, multiple radar pulses are combined with a sophisticated high-performance radar processor, having a thermal power loss of 40 kW.

6 MODE DESIGN OF THE RADAR

In order to facilitate the operation of space surveillance, several operational modes are implemented with different scan strategies. Due to the main orbits of the space debris the beam directions form of a fence with up to 90° coverage, either formed in azimuth or in elevation. Once an object has been detected, a track beam is fixed to the object and tracks it within the area of the antenna beam coverage. The resulting object path information is improved by the increased observation time. The detection performance enhances, if a-priory orbit knowledge of the observed object is taken into account, based on catalogue information.

After system delivery to the contractor the GESTRA system will be remotely controlled by the German Space Situational Awareness Centre in Uedem. This makes it necessary to monitor the status of vital subsystems and processes permanently, as well as of all system components. More than 2000 sensors measure moisture levels, air and water pressures, flow rates of the coolant, and currents in both GESTRA shelters to ensure safe operation.

In total the shelters weigh more than 90 tons each.

7 OUTLOOK

In November 2016 the Fraunhofer FHR successfully completed the critical design review of the GESTRA system. Thus all of the subsystems will now be built and tested. Algorithms as well as firmwares will be further optimized. Starting in March 2017 all of the subsystems will be integrated into the shelters. After the final verification, the system will be handed over to the German Space Situational Awareness Centre in Uedem.

8 ACKNOWLEDGMENT

The work presented in this paper was performed on behalf of the German Space Agency with funds of the German Federal Ministry of Economic Affairs and Technology under the grant No. 50LZ1401.

The authors deeply appreciate and thank for the tremendous support of the development team consisting of up to 34 members. Additionally, special thanks are devoted to the main sub-contractors Kniel (development of the adapted power supplies), MBM/AlpinaTec (development of the 3D-positioner), innovatek (development of the antenna fluid cooling system) and Weiss Umwelttechnik (chiller and shelter climate) for their precious component optimization activities, interactive concept discussions and very helpful contributions to the development of this innovative surveillance and tracking phased-array-radar.

9 REFERENCES

1. J. Ender, L. Leushacke, A. Brenner,and H. Wilden, “Radar techniques for space situational awareness”, Proceedings of 2011 International Radar Symposium (IRS) (2011)

2. M. Sciotti, P. Besso, T. Flohrer, H. Krag,“Low Earth Orbit objects tracking and orbit determination from ground-based phased array radar systems”, Proceedings of 2011 International Radar Symposium (IRS) (2011)

3. E. Brookner, “Phased-array and radar astounding breakthroughs-an update”, Proceeding of 2008 Radar conference (2008)

4. H. Krag, H. Klinkrad, T. Flohrer, and E. Fletcher, “The European Surveillance and Tracking system-Services and Design Drivers”, Proc. of SpaceOps 2010 Conference, Huntsville (US) AIAA-2010-1927, (2010)

5. H. Wilden, C. Kirchner, O. Peters, A. Brenner, J. Vera, J.M. Hermoso, J. Torres, M. Sciotti, P. Besso ,“Low-cost Radar Receiver for European Space Surveillance”, Proceedings of IET Radar 2012, International Conference on Radar Systems, Glasgow, UK (2012)

6. M. Mendijur, M. Sciotti, P. Besso, “Management of radar resources for space debris tracking,” Proc. of SPIE2012 ”Defence, Security, and Sensing Symposium”, Baltimore, USA, (April 2012)

7. H. Wilden, C. Kirchner, O. Peters, N. Ben Bekhti, A. Brenner, T. Eversberg, “GESTRA- A phased array based surveillance and tracking radar for space situational awareness”, Proceedings of 2016 IEEE International Symposium on Phased Array Systems and Technology (PAST 2016), Boston