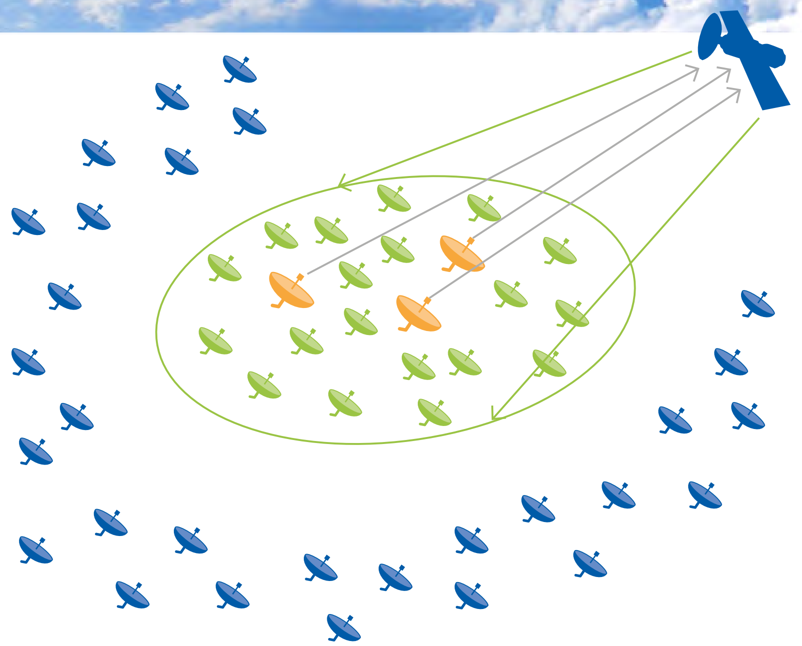
TAKING A NEW LOOK AT SPACE

A radar system keeps an eye on the objects orbiting Earth

By Markus Peichl

For some time, the stars have shared the night sky with an ever-increasing number of artificial satellites orbiting Earth. One prominent addition is SpaceX's Starlink constellation, which attracted attention last year as its satellites gleamed in the darkness overhead like a string of celestial pearls. However, the physical condition of individual satellites often remains unknown; their status data tell us nothing about whether a piece of the solar panel has broken off, or if the satellite bus has been dented by a chunk of space debris – and operating companies often only learn that their satellite is defective when the subsystems fail. To continuously document the condition of space objects and identify failures at an early stage, DLR researchers are developing a new concept comprising multiple transmitter and receiver units, with the aim of creating a system capable of maintaining continuous, high-quality surveillance of these new celestial bodies.



Sender
Monostatic receiver
Bi-/multistatic receiver

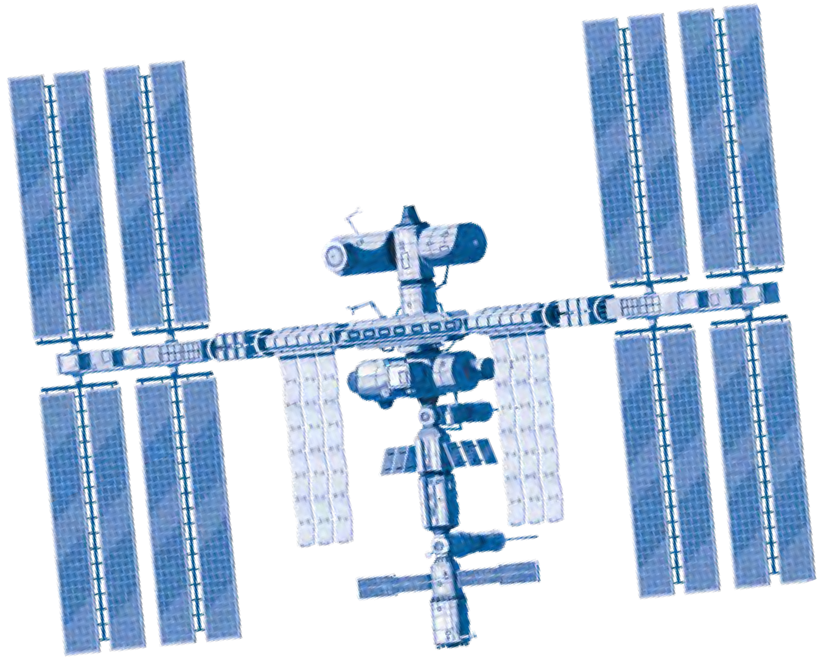
The IoSiS concept consists of a networked radar system with distributed antennas, comprising a few transmitters (in orange) with small antennas of a few metres in diameter and many distributed receivers (green and blue) with very small antennas measuring around one metre across. The green receivers are positioned so close to the transmitting antennas that they can capture monostatic images, while the more distant blue receivers can record multistatic radar images.

The decade prior to 2021 saw a record-breaking number of satellite launches. While the number of satellites in orbit initially climbed slowly following the launch of Sputnik 1 in 1957, almost 700 satellites were launched into space in 2010, and 2020 saw the launch of over 1200. This exponential growth shows no signs of stopping and has been spurred on by the increasing privatisation and commercialisation of space – the 'New Space' era. For decades, spaceflight was largely the preserve of a few state institutions with predominantly scientific and military interests. However, more and more companies and start-ups are now staking their claim to space for the civilian market. The range of applications is broad, covering everything from Earth observation to broadcasting, communications and navigation. Space has been transformed into an economic sector, and now hosts critical infrastructure. This is particularly noticeable in low Earth orbit (LEO), the region of space reaching up to an altitude of 2000 kilometres. Around 7000 artificial objects have been put into LEO so far, most of which are still there. Space transport has brought with it countless pieces of contaminating debris. There are thought to be 100 million pieces of space debris orbiting Earth, measuring between one and ten millimetres in size – an increasingly serious problem.

Monitoring more than debris

Space Situational Awareness (SSA) is all about keeping a watchful eye on both space debris and functioning satellites. SSA is as old as spaceflight itself and instruments for this purpose were developed at the very early stages of our forays into space, as monitoring flight trajectories from the ground during rocket launches or locating objects in orbit was necessary from the very beginning. Today, we monitor the situation in space using optical systems and radar instruments that detect space objects, track their paths, and provide information about their size, design, composition and possible rotation (via radar imaging). Leading systems include HUSIR (devised by the US Air Force and the Massachusetts Institute of Technology), the German GESTRA (German Space Agency at DLR) and TIRA (the Fraunhofer Institute for High-Frequency Physics and Radar Techniques), and GRAVES (the French Air and Space Force). All use very large antennas – usually around 30 metres in diameter – and low-frequency microwaves. Depending on their size, they can identify objects at a range of up to a few thousand kilometres. With the exception of GRAVES, they are also exclusively monostatic, with the transmitter and receiver located in the same place.

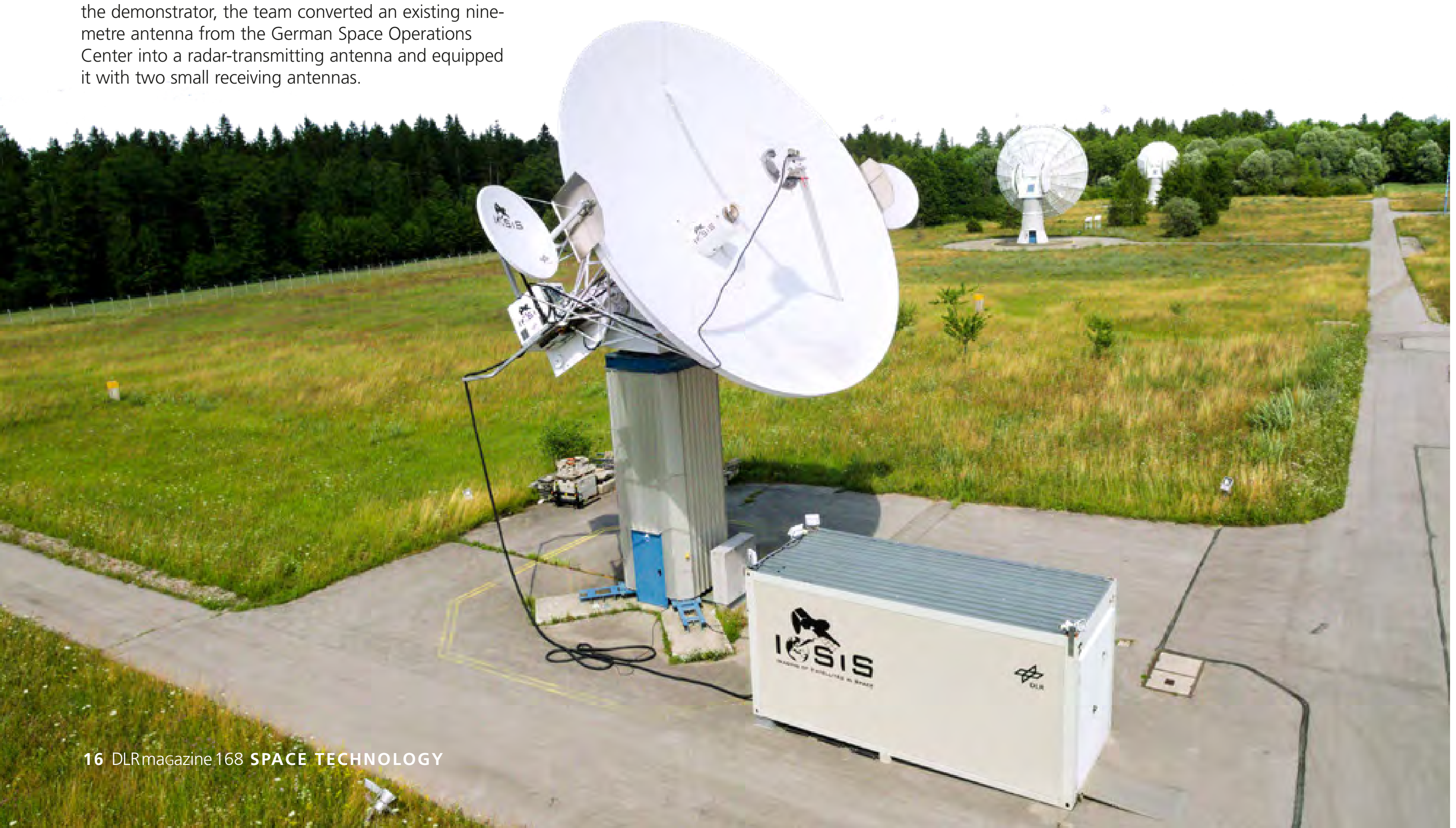
In addition to our urgent need to detect and determine the trajectory of space debris, in future active space objects will also need to be identified, classified and monitored with high precision. This would allow changes in flight behaviour or signs of ageing to be detected, and functional failures predicted in good time. This is particularly relevant for the concept of Responsive Space (see article in DLRmagazine 166), which aims to detect and replace defective satellites as quickly as possible – ideally within a few days. Given that it currently takes years to replace satellites, this would be truly revolutionary for the space sector. In the future we may also be faced with an increasing number of (intentionally) unknown space systems, which we must bear in mind when developing new ways for professional SSA to pinpoint their position and function.

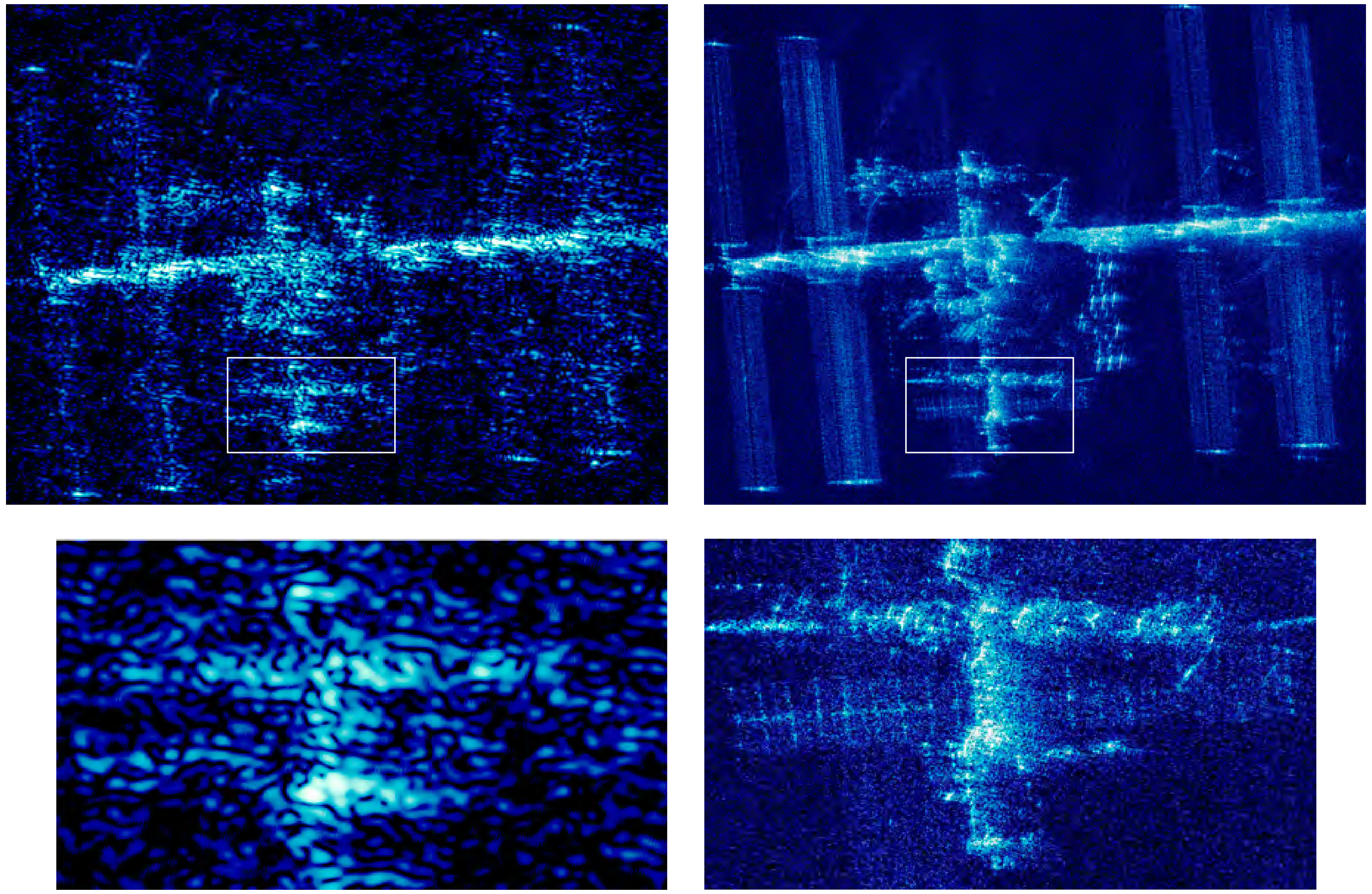


An agile antenna swarm

As current observation systems can only be expanded upon or improved to a limited degree, DLR is developing the new 'Imaging of Satellites in Space' (IoSiS) concept for future radar-based space situational awareness. Unlike today's systems, IoSiS is an experimental system concept in the form of a multi-instrument network. Instead of large, individual antennas, the researchers rely upon a 'swarm' of transmitting and receiving systems. One or more transmitters with an antenna measuring less than 10 metres across will be combined with a number of distributed receiving antennas, each with a diameter of around one metre. In contrast to their predecessors, these systems operate at a significantly higher frequency of around 100 Gigahertz and, in theory, can achieve a spatial resolution of just a few centimetres. As all the transmitters and receivers work together, the system can create both truly monostatic three-dimensional images – using transmitters and receivers located close together – and multistatic images – using transmitters and receivers spaced further apart to allow for a wide-angle view of an object. Multistatic images reveal structures that are often hidden from monostatic radar.

DLR's Weilheim site is home to the IoSiS radar system demonstrator, which operates in the X-band. To create the demonstrator, the team converted an existing nine-metre antenna from the German Space Operations Center into a radar-transmitting antenna and equipped it with two small receiving antennas.





In 2017, IoSiS had a resolution of 50 centimetres (left); today, this has improved to five centimetres (right). The width of the upper images corresponds in reality to about – the length of the ISS of about 110 metres – and the enlarged areas (bottom row) are about 25 metres wide.

Having a system with thousands of receivers has many other benefits, too. For one, the large quantity of antennas required makes them suitable for industrial series production. Current SSA systems tend to be highly specialised and custom-made products, but IoSiS has greater flexibility. Depending on the financial circumstances, the overall system can be expanded piece by piece, with each addition increasing overall performance. If a receiver fails, it can easily be replaced. And advanced or novel hardware can be integrated directly into every new receiver. Current systems are rather inflexible and have only a limited capacity for technological upgrades. Additionally, approval procedures for the location of the IoSiS antennas, which measure around one cubic metre, are simpler than for the large antennas of current systems, which can measure over 30,000 cubic metres. In addition, it is virtually impossible for the entire system to fail at once.

Surveying space from Weilheim

A team at the DLR Microwaves and Radar Institute in Weilheim has set up an initial demonstrator of the IoSiS concept, comprising a transmitter and two receivers currently operating at around 10 Gigahertz (for technical reasons). The radar system maps objects in LEO at a very high resolution and can process almost any type of signal. The demonstrator was first used to image the International Space Station (ISS) in 2017, and the team has been continuously developing its hardware and software since. Whereas four years ago the images had a spatial resolution of 50 centimetres, today the system produces radar images at a five-centimetre resolution. This not only allows very small objects to be examined, but also makes it possible to record signs of degradation in larger structures.

IoSiS can also observe larger objects, such as disused rocket stages. These are relatively easy to detect but require precise condition monitoring. The larger an object the faster it degrades, as it is more likely to collide with something and be damaged. To assess the situation accurately, it is important to determine when a large object has broken into two smaller pieces of space debris.

A multifaceted concept

The DLR team is currently working on the concept for the next generation of IoSIS (IoSiS-NG), and thus on improving the system's spatial resolution and three-dimensional imaging capabilities. Three dimensional images of Earth's surface can be created using conventional radar interferometry methods. Here the third dimension is calculated using the phase differences of two partial images. However, this method reaches its limits with very complex objects such as the ISS. The multistatic receivers of the IoSiS system, on the other hand, can receive information from different perspectives, enabling researchers to create a real three-dimensional image.

The experimental IoSiS system is currently only in use in Weilheim, but plans are underway to gradually roll it out across Germany.

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