Array Antenna Activities at RUAG Space

An Overview

Joakim Johansson, Per Ingvarson
RUAG Space
Gothenburg, Sweden
joakim.johansson@ruag.com

Abstract—**The demanding requirements that apply to space-borne antennas result in various trade-offs for array antennas. The paper describes some of the constraints, and presents some array systems developed at RUAG Space.**

***Index Terms*—space antennas, array antennas**

I. Introduction

Array antennas provide the possibility to very accurately control antenna patterns and to provide multiple beam functionality, all from a compact mechanical envelope. All kinds of antenna elements are possible to arrange in arrays, but some types have crystallized into being more popular than others, especially in space applications where extreme requirements are legion.

Slotted waveguide antennas have been successfully used in airborne early warning systems in rotodome (*e.g.* AN/APY-1/2 'AWACS') and phased array (*e.g.* ERIEYE) versions, for space-borne synthetic aperture radars (*e.g.* ERS-1) and scatterometers (*e.g.* ASCAT), *etc.* The early popularity of the slotted waveguide approach was due to the fact that very good models were developed that enabled fast synthesis and very accurate analysis even with computer capacities that would be considered useless today. The antenna type still remains popular for high performance systems. The main disadvantage is the rather complicated mechanical build-up, especially if dual polarization is needed.

For ground-based and airborne arrays one can afford the luxury of using antennas with dielectric materials, *e.g.* microstrip arrays. These antennas are easier to manufacture with standard photo-lithographical methods, but the materials have to have close tolerances to achieve good performance. Diluting the antenna with air can improve the performance in terms of tolerances and losses, and *e.g.* mobile communication base-stations arrays can use thin low-cost PCB substrates without much penalty. However, when moving into space-borne array systems, dielectrics now turn into a problem. The antenna is by necessity mounted exterior to the satellite, and is thus fully exposed to the harsh environment in space. Apart from the obvious thermal and UV irradiation issues, there is a serious problem with electrostatic discharges. Charged particles will irradiate and become lodged within the dielectric, essentially creating an electret. With sufficient charge densities, the electrostatic field strength becomes large enough to produce breakdown. In a passive antenna this is not necessarily

في الفضاء الخارجي الهوائيات تتعرض لعوامل خارجية كثيرة منها الأشعة
فوق بنفسجية والعزل يصبح مشكلة، فالأشعة فوق بنفسجية تولد كهرباء ساكنة
ومع ازديادها تتحول إلى كهرباء ومع ازدياد كثافة شحنة الكهرباء بشكل كبير
تسبب فشل النظام.

destructive *per se*, but a noise pulse will be generated that could lead to a drop-out in communications. Hence, all-metal antennas with no directly exposed dielectrics are highly desirable. One way to mitigate ESD problems would be to use doped dielectrics where charges are bled away. However, another requirement would discourage such materials, namely passive intermodulation (PIM). PIM is produced when multiple high power carriers are illuminating non-linear parts of the antenna, and the interference requirements can be extremely demanding (–150 dB levels are common). Metals in imperfect contact with each other or semi-insulators (*e.g.* doped dielectrics) are thus to be avoided.

Satellite-based cellular systems require a multitude of independent beams that cover separate areas to provide multiple access through frequency re-use. Multiple fixed beams can be produced by an array antenna with a suitable beam-forming network (BFN), *e.g.* a Butler matrix. The complexity and the number of elements will be daunting if small cells are required from geostationary orbit, and thus direct radiating arrays (DRA) would be at a disadvantage. One attractive way to produce the required beams on ground is to have a large deployable reflector system that is fed by a focal plane array. The feed element size would match the illumination needed for a given focal length, and is typically 1 to 2 wavelengths. Space systems will impart severe requirements on mass, power handling (heating and multipactor breakdown), polarization purity, *etc.*

Array systems generally require that the elements are placed close enough to avoid grating lobes. This will mean 0.5 – 1 wavelengths depending on off-axis scan angle. However, certain systems can relax this requirement. The angle subtended by Earth as seen from geostationary orbit is ±9 degrees. Apart from the gain losses that would result from radiating into grating lobes, one could thus use significantly larger elements and inter-element separations to alleviate the array 'real-estate' problems encountered at the higher frequency bands.

II. RUAG Space Experience

RUAG Space (historically Saab Ericsson Space) has a long history in terms of involvement with design, manufacturing and testing of arrays and array elements, and this paper will present some highlights.

978-88-907018-1-8/13/$31.00

A. Slotted Waveguide Arrays

Historically, the company has designed and measured large slotted waveguide arrays for SAR and scatterometry at C-band since the eighties. The large ERS-1 antenna (launched in 1991) necessitated the construction of a planar near-field antenna test range, see the figure below.

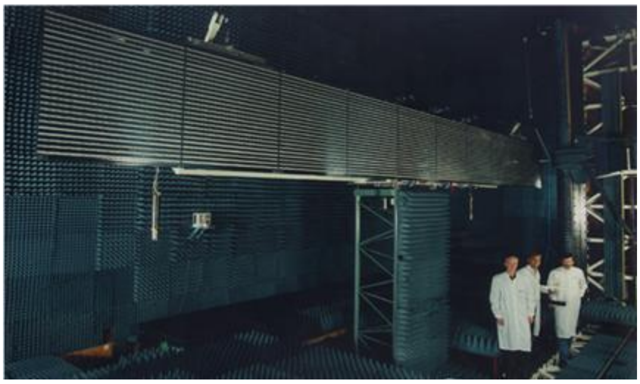

Figure 1. The ERS-1 SAR slotted waveguide array under test.

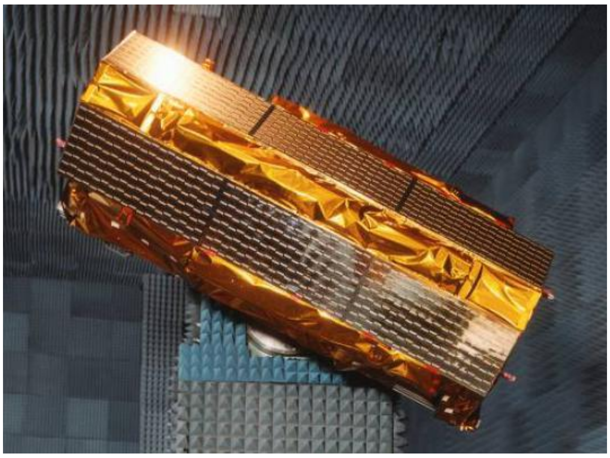

Figure 2. The ASCAT scatterometer slotted waveguide arrays under test.

The demands on dual polarization capabilities are increasing within the area of remote sensing, as much more information can be extracted from HH/HV/VV measurements. However, the integration of such capabilities into slotted waveguide systems is not straightforward. One innovative solution to the problem is shown in the figure below, where a folded ridge type waveguide with broad wall slots is combined with a waveguide with narrow wall slots. In this case, wires are used to properly perturb the field.

More recently, work has continued within ESA studies that aim at developing scatterometer slotted waveguide arrays for future MetOp missions.

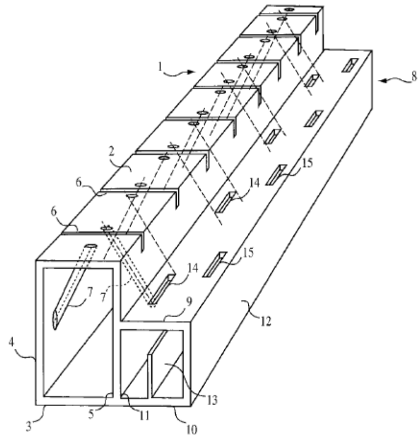

Figure 3. A method to realize dual polarizations in a slotted waveguide array (U.S. patent No. 5831583).

B. Feed Elements for Mobile Communication

Large deployable reflector systems with focal plane feed arrays can provide cellular communications at L- and S-band. The patch excited cup (‘PEC’) is an antenna type that can provide dual circular polarization with high isolation, low loss, excellent PIM performance, and high power handling, while also maintaining a low mass as well as a low manufacturing and assembly cost. Several thousand PEC array elements have been delivered through the years (ICO, Thuraya, MSV, *etc.*).

Figure 4. PEC elements in the ICO direct radiating S-band arrays.

The generic PEC element design is comprised of a metal cup, an all-metal patch tower, a distribution network that also constitutes a backing structure, and four feed probes between the network and the lowest patch. Variations on the theme exist, depending on the specific application.

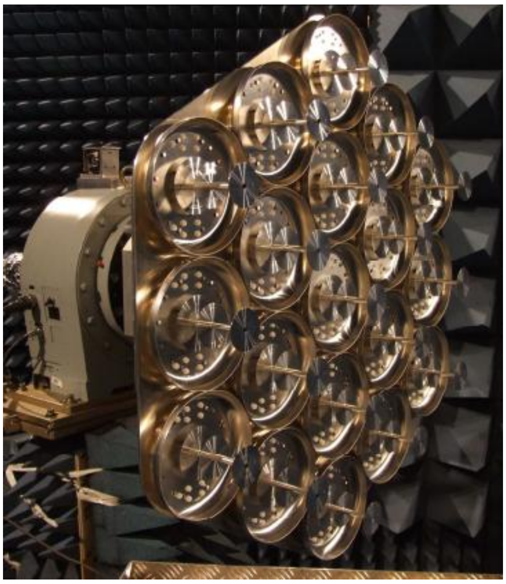

Figure 5. Testing of L-band patch excited cup (PEC) feed elements in an array environment.

The PIM properties are verified in a dedicated PIM test facility where the antenna under test can be irradiated with high power carriers, while under thermal cycling.

Figure 6. PIM test facility at RUAG Space.

PEC array elements with associated filter components were design and built within an ESA study, where the focus was on the S-band systems S-UMTS and S-DMB [1]. The S-UMTS element shown in the figure below had the following features:

- RX frequency band: 1980 – 2025 MHz
- TX frequency band: 2160 – 2200 MHz
- Size 1λ (≈140 mm)
- Dual circular polarization
- Integrated diplexers
- High isolation, low loss, low mutual coupling, and excellent PIM performance
- 2 × 100 W (multipaction tested to 400 W)
- Low mass, low manufacturing and assembly cost

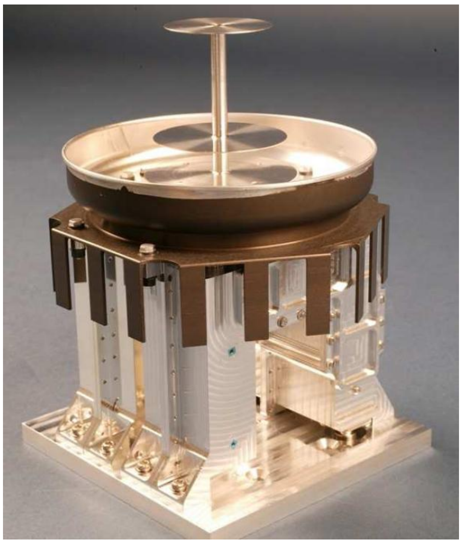

Figure 7. The S-UMTS element including diplexer.

The smaller S-DMB element had the following features:

- S-DMB band (2170 – 2200 MHz)
- One circular polarization
- Small aperture: 0.8 λ (≈110 mm)
- 300 W
- Integrated with a band-pass filter

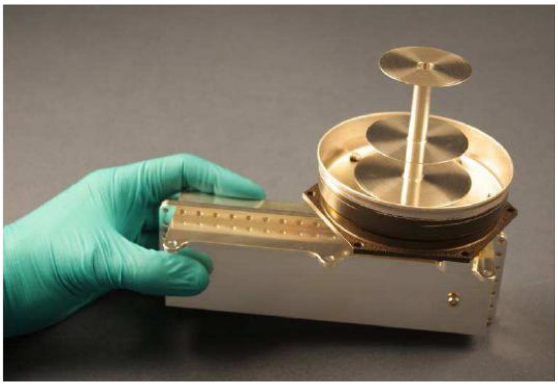

Figure 8. The S-DMB antenna element.

The PEC elements have been very successful in L- and S-band arrays, but are also used in single element applications when a medium gain antenna is required for TT&C or data downlink purposes [2].

C. *Feeds for Multi-Beam Arrrays*

Multi-beam systems with one physical feed per beam suffer from beam overlap level problems. One way to mitigate this is to utilize overlapping sub-arrays of smaller feeds. However, at high frequencies such overlapping beam forming networks would introduce undesirable losses. The integration of low-noise amplifiers (LNAs) with the feeds before beam forming was studied in 'MultiKaRa' (Multi-beam Ka-Band Receiving Antenna for future 'Multimedia via satellite, direct to home' systems).

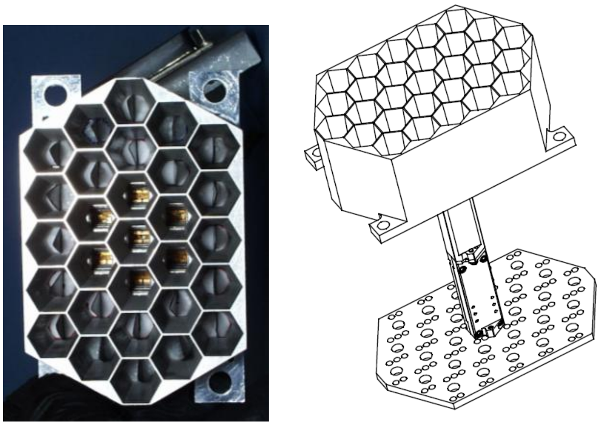

Figure 9. The MultiKaRa active feed array breadboard.

D. *Millimeter Wave Array for Radiometry from GSO*

A future multi-frequency millimetric radiometer system is envisioned for real-time sounding of the atmosphere from geostationary orbit (GSO). The system would comprise a rotating Y-shaped sparse array. A demonstrator of the central part has been built for 53 GHz to demonstrate the imaging concept with rotation, calibration, and post-processing [3].

Figure 10. The Geostationary Atmospheric Sounder (GAS) demonstrator.

E. *Microstrip Array for GPS Occultation*

The global navigation satellite systems (GNSS) do not only provide a base for terrestrial navigation. The GNSS signals can be used for satellite-based measurement of the extra phase delay caused by the atmosphere as the signal is going into occultation. Such an instrument is the MetOp GRAS (GNSS Receiver for Atmospheric Sounding), where a patch antenna array provides the desired banana-shaped lobe that will cover the GPS orbits.

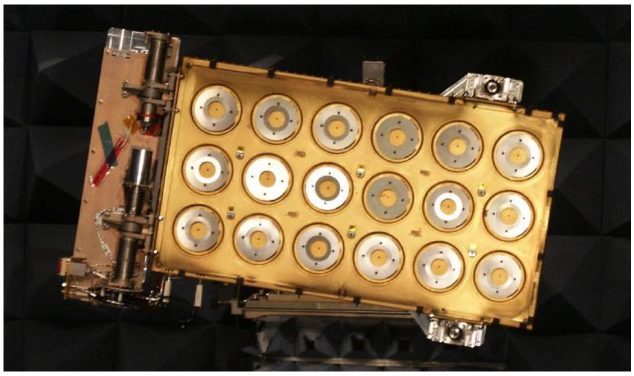

Figure 11. The MetOp GRAS radio occultation antenna.

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