45 YEARS OF ANTENNA R&D: HIGHLIGHTS AND SOME LESSONS LEARNED

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ABSTRACT

Highlights of 45 years of Antenna Engineering, of which 35 with ESA, are reviewed with emphasis on R&D and innovation. The paper focuses on some new concepts that were successfully demonstrated, developed in industry and used for real projects. Conclusions include some possible lessons learned and trends for the future.

INTRODUCTION

Antenna engineering is a wonderful field to work in because of its renewed diversity. This is particularly true in space: antennas are key to the success of most space missions and each new spacecraft generally requires very specific, different and complex antennas.
In this context, excepted maybe for generic modelling and test techniques where there can be some R&D continuity, innovation is constantly needed to meet new antenna mission requirements and the success of antenna R&D is not easily predictable.
In this paper some innovative antenna concepts that the author was involved with since the mid sixties are briefly reviewed. Some have now been widely used for decades and some have not yet made it into space.

SOME SIMPLE R&D FROM THE SIXTIES

1.1 Log-periodic antennas

Frequency independent antennas were introduced by Rumsey and Duhamel in 1957. The author was involved at UC Berkeley in the development of a low profile EM coupled slot array of this type (see fig. 1) for which good performance was demonstrated from 2.8 to 5.9

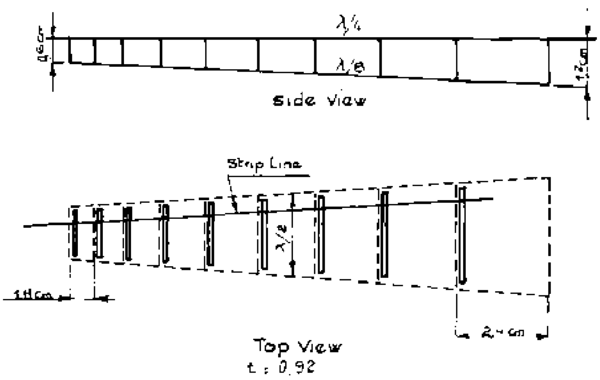

Fig.1 - Strip-line fed log-periodic slot array [1]

GHz on a breadboard model [1].
Log-periodic antennas are a good example of a successful “blue sky research” concept proposed in Academia 50 years ago, supported and used until now mostly for defence and with new perspectives for ultra wideband communications and radio-astronomy.

1.2 Circularly polarised broadcast antenna

In 1967, circular polarisation was introduced for FM broadcasting in the US and, within months, manufacturers had to come up with a CP omni-directional antenna. The author proposed a design inspired from the Lindenblad antenna but simplified by using two inclined V’s facing each other with a central coaxial feed integrated in their support (fig.2).

Fig.2 – JAMPRO’s Circularly polarised FM broadcast antenna “Penetrator” [3][4]

The antenna was modelled using the precursor of the Method of Moments of K.K. Mei [2] and a breadboard was built. It was then further developed and patented in 1970 by JAMPRO Antenna Company [3][4].
With over 4000 antennas in operation worldwide today, it has become an industry standard.
This is a good example of fast and close to market innovative R&D resulting within 3 months in a product that has been leading the market for nearly 40 years.

R&D IN SPACE ANTENNA ENGINEERING

1.3 Radiating element technology

In 1974, ESA started an R&D effort on active multiple beam arrays [5][6]. This has included the development and prequalification of radiating elements at L-Band (fig. 3) which has been the seed at Ericsson (now Saab Space) of a very successful development for export.

As an example Fig. 4 shows measurement of a satellite antenna feed system in the anechoic chamber of the DTU-ESA Spherical Near-Field Antenna Test Facility at the Technical University of Denmark, a world standard for antenna measurement accuracy, also used for the delicate SMOS antenna testing.

The feed system consists of 128 individual antenna elements which were designed and manufactured by Saab Ericsson Space. Similar elements have been flown by ARTEMIS and EMS and thousands have been and continue to be exported to the US for Boeing GEO-mobile programmes.

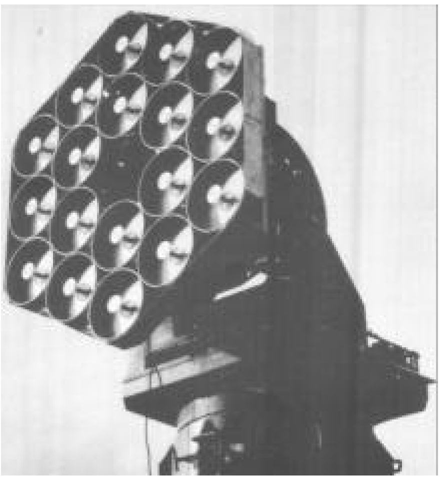

Fig.3 – L-Band Multibeam Array Model MAM

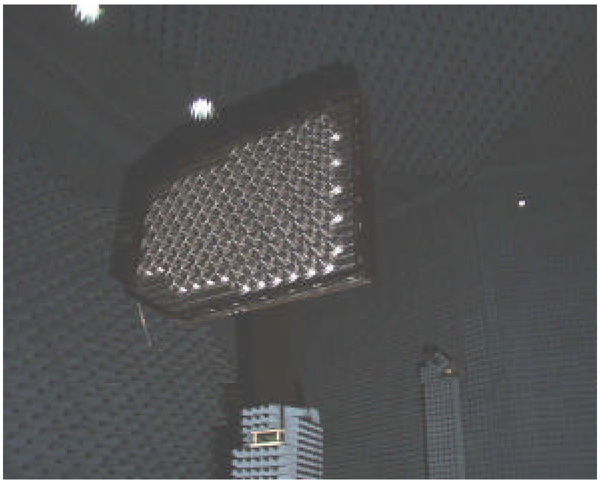

Fig.4 – Saab-Space L-Band feed array for export in the DTU-ESA Spherical Near-Field Antenna Test Facility

This is an example of very successful ESA R&D but with an effective time to market of over 15 years.

1.4 Semi-active multiple beam antennas

The semi-active multi-matrix feed concept was introduced by the author in 1989 in support of the ESA ARTEMIS L-band payload design [7][8] and extended later to conformal and planar arrays [9]. The idea is to insert hybrid butler-like matrices between the power amplifiers and the radiating elements.
By proper phasing of signals from each beam at the power amplifier inputs, the beam power can be moved in the focal plane of a reflector or around a conformal array. This allows to reconfigure multiple beams and the traffic to beams with all amplifiers operating at nominal level and therefore with optimum efficiency. The principle is illustrated in fig. 5 for the ARTEMIS mobile application, and further described in [7] and [8]. This reflector feed architecture and its derivatives have been selected and flown for several mobile missions: including ARTEMIS, Italsat EMS, INMARSAT III and IV series and are being studied for future missions, also

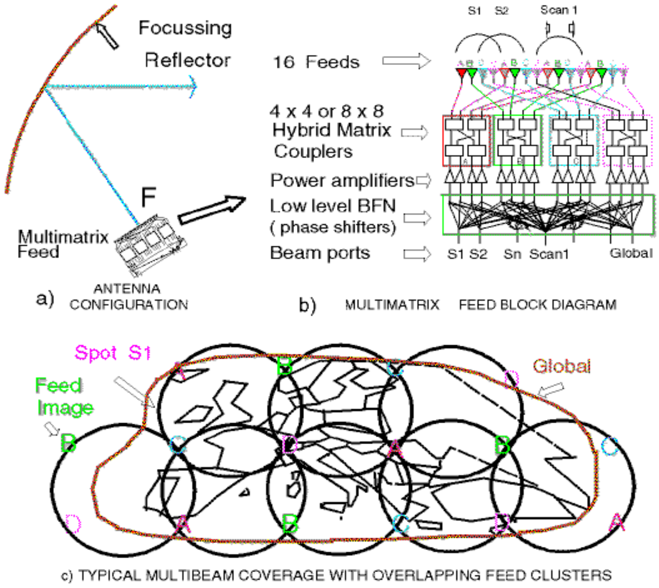

Fig.5 – Semi-active multi-matrix feed concept [6]

in other bands, such as EUTELSAT S-band mobile TV.

Extension of the semi-active concept to arrays [9] has also been successfully demonstrated.
Fig. 6 shows a semi-active conformal array developed by Thales Alenia Space [10] and which uses innovative ESA patented 3x3 hybrid couplers derived from [11].

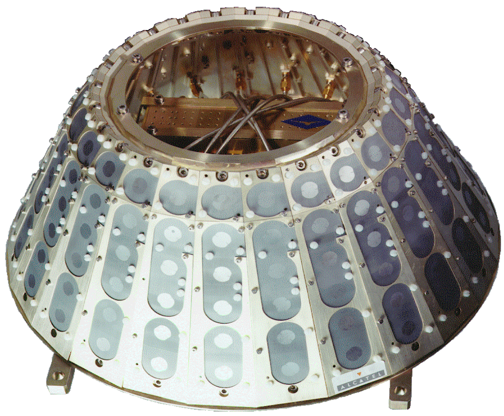

Fig. 6 – Semi-active conformal array demonstrator [10] (Thales Alenia Space – ESA)

A semi-active conformal array architecture has been selected for ESA's GAIA data transfer antenna.

Semi-active multi-matrix antennas are an example of innovative R&D using readily available constituents with, as a result, reliable modelling and fast utilisation.

1.5 Reflector technology

ESA has pioneered with success novel reflector technologies for contoured and multiple beam space applications which are widely used today.
Leading work by Westcott on reflector shaping [12] was supported by ESA in the early eighties and shaped reflectors have been widely used in the last 30 years in

Europe and beyond. Fig. 7 shows multiple contoured beam shaped reflectors for an INTELSAT mission.

Fig. 7 – Shaped reflectors for INTELSAT contoured beam coverage (Courtesy H. Wolf Astrium-D)

Beam reconfiguration by sub-reflector shaping has been looked into repeatedly at ESA [13][14]. An innovative reconfigurable design by Thales Alenia Space with a shaped and rotatable dual reflector system has been flown successfully on several EUTELSAT Satellites but true sub-reflector shape reconfiguration is still under study.

ESA has also contributed to the development of gridded reflectors to improve polarisation purity and to separate feeds in each of two orthogonal linear polarisations.

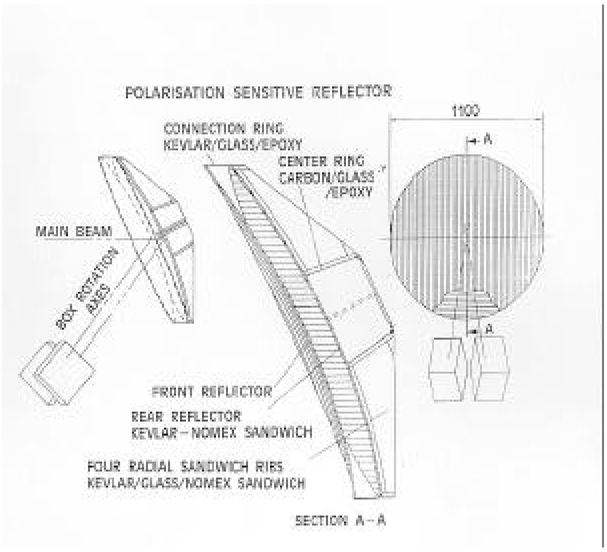

Fig. 8 - Polarisation sensitive reflectors with identical shells rotated around bore-sight [13]

One particular innovation was to use gridded reflectors rotated in opposite directions around the system bore-sight to allow the use of identical front and back reflectors from a single mandrel instead of two [15].

Fig. 9 - Polarisation sensitive shaped reflector: thin gridded Kevlar front skin + CFRP rear dish + intermediate stiffening structure (courtesy Astrium I)

This approach was then used for parabolic and shaped reflectors for several EUTELSAT missions. Fig. 9 shows a shaped gridded reflector developed by Astrium. ESA has also successfully supported from 1980 at Alenia Spazio, the development of reflectors and feeds for Ka-band multiple beam antennas [16].

The resulting thin sandwich reflector technology was used for the Casini high gain antenna and the feed technology for Italsat and subsequent Ka band satellites. Overall, the multibeam antenna R&D at ESA has mostly been successful in areas where it was directly driven by specific market needs.

1.6 Reflectarrays

Reflectarrays were introduced in the 1960's for radar. A feed illuminates a generally planar array where each element receives, optimally phases or delays and re-radiates the incoming microwave power.

The advantage over regular phased arrays is the simplicity, low cost and low loss of the power distribution scheme. Main limitations are the bandwidth due to path differential, the direct reflection of part of the incident power and the single beam capability.

To evaluate direct reflection and the scan potential, investigations in the 60's included the modelling of finite arrays of waveguide (see fig. 10) and the control of scan blindness effect by adding periodic screens that would now be called EBG structures [17].

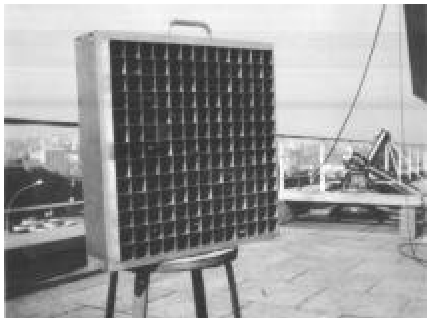

Fig. 10 – Reflectarray used in the 60's to validate finite array modelling [17]

Reflectarrays have been used for radars with limited instantaneous bandwidth but not yet in space.

Recent work by Encinar et al. [18], sponsored by ESA, has led to multilayer designs (fig. 11) that might compete with shaped reflectors for contoured beam applications with moderate bandwidth.

Fig.11 – Multilayer Reflectarray (Poly. U. of Madrid & Thales Alenia Space)

Extension of reflectarray bandwidth by approximating a curved shape with flat panels (fig. 12) might help use this low cost technology for space based radar [19].

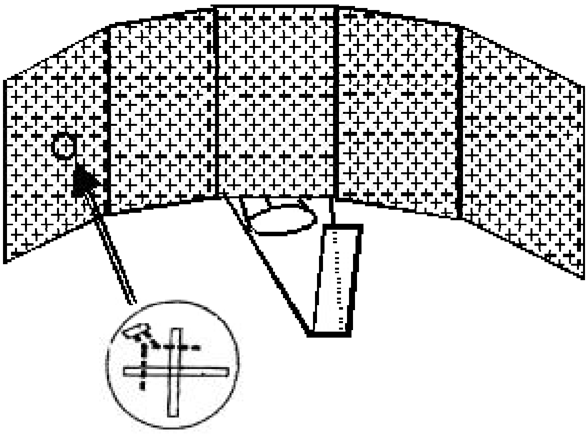

Fig.12 - Reflectarray in flat panels approximating a parabola and with polarisation rotation and phase-shift [19]

1.7 Other technologies

Previous sections focused on some of the innovative ESA R&D where the author has made contributions.
ESA has pioneered and supported the development of many other successful antenna technologies and techniques ranging from reflector antenna analysis to near field and compact test ranges. They have been presented over 35 years at the 29 Antenna Workshops organised at Estec, at AP2000 in Davos, in Antenna COST actions and at the EuCAP conferences.

CONCLUSIONS AND LESSONS LEARNED

After nearly 45 years of involvement in antenna R&D, it seems very difficult to draw clear lessons on what to support and what to leave for others to develop.
Antenna modelling and measurement techniques can be developed further jointly with academia and specialised industry and other users. Networks of competence / excellence can help standardise interfaces and limit duplications. Space specific techniques must also be researched and supported in Estec labs.
With the progress in solid state amplifier efficiency and in digital beam forming, smart active antenna systems are finally emerging at lower frequencies for space communications and radar. This has become a quickly maturing multidisciplinary area where spin-in can be expected from defence and wireless applications and where R&D should focus on space specific requirements (reconfigurability, power efficiency, mass, thermal control, lifetime….).
With a limited market and very high development costs, very large aperture antennas have been a concern in Europe since the 1970's. Consolidation of existing designs and more innovation are required in this field.
Overall, one rule could be to strictly focus on applied and space specific R&D with a clear potential to respond much better than available technologies and techniques to specific needs of one or preferably more future space missions.

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