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The History of Antennas in Sweden

from the EuCAP 2013 historical workshop, Gothenburg

Carl-Henrik Walde (editor)

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ARTHUR artillery hunting radar, ERIEYE airborne early warning system, stealth ship HMS Visby

Editorial comments

This publication covers papers presented in the workshop ”The History of Antennas in Sweden” at EuCAP 2013, the 7th European Conference for Antennas and Propagation, Gothenburg, 8-12 April.

The workshop had nine papers, many of them referring to Swedish defence antenna projects. The conference organisers and the authors have kindly allowed us to publish these in an FHT booklet.

Carl-Henrik Walde, editor of this FHT publication, has written a synthesis for the IEEE Magazine of Antennas and Propagation, volume 55 (2013), issue 4, pp. 298-306 (ISSN: 1045-9243). In the author's original formatting, this article has been included as an introduction, the author taking advantage of the (American) language refinements kindly suggested by its editor Dr Ross Stone.

The author

Contents (page numbers suppressed)

FMV Printcenter, Stockholm, 2013

The History of Antennas in Sweden

Carl-Henrik Walde, *Secretary, Swedish URSI Committee*

SWEDEN has a long tradition of radio and antenna projects and Gothenburg is one of the most important regions for antenna competence in Europe. It was not a coincidence that the 7th European conference on antennas and propagation took place in Gothenburg, Sweden, 8-12 April, 2013. Under the chairmanship of Claes Beckman, nine historically-oriented papers were presented in a workshop covering antenna developments in Sweden from the Grimeton radio station SAQ (a Unesco World Heritage) to spin-off companies based on successful research performed in the region.

Joakim F Johansson, RUAG Space AB, presented ***The early days of radio in Sweden, Ernst F. W. Alexanderson and Grimeton radio station SAQ***. [1]

Ernst Alexanderson (Fig. 1), a lesser known Swedish wireless pioneer, emigrated to USA in 1901 and got a position at General Electric in Schenectady, finally becoming Chief Engineer at GE and RCA. In 1919 he became the second recipient of the IEEE Medal of Honor (Marconi being the third in 1920). He was awarded many US patents, his 345th in 1973 at the age of 95! In 1905 he filed a patent application for a VLF 'alternator', a continuous wave transmitter.

Figure 1. Ernst F.W. Alexanderson (1878 – 1975).

At Grimeton near Varberg, the VLF station SAQ for direct communication from Sweden to New York was ready for operation in December 1924. The transmitters were two Alexanderson electro-mechanical alternators; the antenna comprised six free-standing towers 127 m tall with top cross-members 46 m wide. The total antenna length was 2 km, electrically small for the 17 km wavelength. The top-wire system is a transmission line; the radiators six vertical lines connected to variable inductors (Fig. 2).

The antenna efficiency would normally be very low. However, by combining several radiators in Alexanderson's multiple tuned antenna, the efficiency increased significantly to reach above 10 % which is considered good for this type of system.

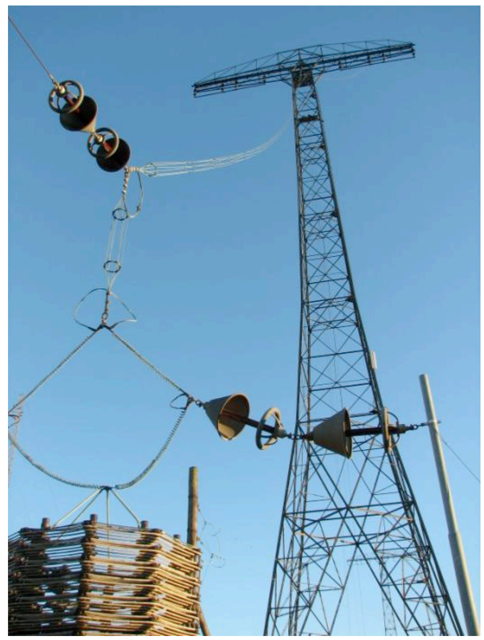

Figure 2. One antenna tower with the cage type vertical radiator and tuning coil visible (Wikimedia Commons).

Joakim Johansson called this radio system "the internet of the twenties". (The information transmitted from Grimeton in 1936 was 1.8 million words, i.e. around 10 Megabytes.)

Already at the time when SAQ opened for traffic, vacuum tube electronics and short-wave communications could provide this service more efficiently. However, the Royal Swedish Navy needed SAQ for communication to submerged submarines and the station, well maintained and in almost mint condition, has survived into our days. In 2004, SAQ was listed as a UNESCO World Heritage. It goes on air on "Alexander Day" (a Sunday in June/July), on United Nations Day and on Christmas Eve. All similar radio stations have been decommissioned.

A Beverage antenna has very good directivity along the wire away from the feed point. However, as the receiving station SAK in Kungsbacka, between Varberg and Gothenburg, was close to the sea, it was impossible to have it in the desired direction. Therefore, the antenna for America was run in the opposite way on 9 m tall telephone poles along a 13 km stretch inland with a balun device at the far end. Nothing is left of this antenna today.

[ü] Manuscript received July 08, 2013.

Swedish Radio Astronomy was presented by Hans Olofsson, Director of Onsala Space Observatory (OSO) at Chalmers. [2]

Swedish radio astronomy research and its development are synonymous with the formation and development of OSO that grew out of the ionospheric research activities of professor Olof Rydbeck. Radio interference in Gothenburg led to a donation of land on the Onsala peninsula which made it possible to create a radio astronomical observatory in the late 1940s. The first significant step came when Rydbeck bought five German WW2 radar antennas (7.5 meter Würzburg Riese) from Norway and brought them to Onsala.

In collaboration with the Scandinavian telecommunication authorities a 25.6 m telescope was erected in 1963 to detect the weak signals from cosmic molecules. OSO had to invest in extremely low-noise amplifiers, based on maser technology. This was a risky, but successful project that also led to the first very long baseline interferometry (VLBI) observations. The telescope is still used for these observations.

A radome-enclosed 20 m telescope for mm-wave observations was inaugurated in 1976 and it was the world's largest such telescope for about a decade. A wealth of radio astronomical successes has been achieved with this telescope and it laid the ground for OSO's international expansion.

In the early 1980s, the observatory looked towards shorter wavelengths and a different site had to be chosen. This lead to SEST, the 15 meter Swedish-ESO Submillimetre Telescope in Chile. This was a successful and rewarding project, which ended in 2003 when the telescope was moth-balled. SEST was followed by the Atacama Pathfinder Experiment (APEX) project in Chile, a 12 m sub-mm telescope at 5100 m of altitude. The excellent telescope and site will enable THz observations.

It then became clear that long-wavelength radio astronomy would be needed for studying a number of astrophysically very important questions. A Dutch project, the Low-frequency Array (LOFAR), was a step towards a more ambitious project, the Square Kilometre Array (SKA). To technologically and scientifically prepare for SKA, OSO joined the international LOFAR project; a station at Onsala was built in 2011 (Fig. 3).

Figure 3. The LOFAR station at Onsala (OSO).

Simultaneously with the radio astronomical activities, OSO has become increasingly active in the field of geodesy. The central activity here is geodetic VLBI, where some of the most distant objects are used to measure the positions of the radio telescopes at increasing accuracy over the years. The next phase is aimed to reach an accuracy of 1 mm; OSO will install two fast 12 m radio telescopes at Onsala and equip them with modern VLBI instrumentation.

Gudmund Wannberg, Wannberg Radar Consulting AB, presented ***The EISCAT antenna systems for Swedish and international ground-based space radio science***. [3]

An incoherent-scatter radar (ISR) is an extremely powerful remote sensing technique, but it comes at a very high cost because of the extreme weakness of the scattering resulting in signal-to-noise ratios well below unity. ISR systems operate in high VHF or low UHF bands where spectrum space is scarce.

The initiative to establish a powerful ISR system in northern Scandinavia for studying the physics and electrodynamics of the ionosphere was taken by three scientists: Bengt Hultqvist (Sweden), Olav Holt (Norway) and Juhani Oksman (Finland).

EISCAT, European Incoherent SCATter scientific association, came into being in December 1975 and built the world's first UHF and VHF ISR stations in Tromsø in Norway, Sodankylä in Finland and in Kiruna, Sweden (headquarters).

The UHF fully steerable, wheel-on-track 32-m Cassegrain dishes were supplied by TIW, Inc., and commissioned in 1978.

The VHF antenna is an offset-fed, parabolic trough reflector (Fig. 4), designed by a young Per-Simon Kildal, and submitted as his PhD thesis at NTH, a starting point of a long and distinguished career.

Fig. 4. The EISCAT VHF antenna in Tromsø (Lars-Göran Vanhainen).

In the 1990s, a second-generation, 500-MHz dual antenna ISR system was built on Spitsbergen in Svalbard. This system, operational in 1996, is of special interest to the Swedish antenna community as its first antenna was constructed by a Swedish company. It is a fully steerable, moving-head, doubly shaped 32-m Cassegrain dish incorporating many features that make it well suited to the harsh climate of Svalbard.

KAMFAB had never before built a big antenna, but had been the main contractor for a number of scientific and high-tech programs. Acceptance tests with 500 kW of RF power run into the antenna for 20 hours showed no problems and the EISCAT Svalbard Radar was officially inaugurated on August 22, 1986, four days short of the twenty-fifth anniversary of EISCAT UHF. The antenna is electrically small (32 λ at 500 MHz), but delivers very good efficiency and low-noise performance. The second antenna, a fixed, field-aligned 42 m dish, was supplied by Alcatel of France in 1998.

A study for a third generation system (EISCAT_3D), an order of magnitude better than the old systems, has recommended a phased-array VHF system with a central transmit/receive core, comprising upwards of 10^4 elements and a number of receive-only arrays, 100-300 km distant from the core. The project is on the ESFRI Roadmap for Scientific Infrastructure and currently in a "Preparatory Phase" supported by the EU 7th framework program.

EISCAT, the world leader in incoherent scatter research, has been an important asset to Swedish scientists and engineers for antennas as well as receiver and signal processing hardware.

Concluding, Wannberg raised a frequency management issue as mobile phone systems now take over EISCAT frequencies. Due to article size limitations we cannot cover this extremely important issue here. It may suffice to say that EISCAT already have coped with the problem and modified systems to be able to continue the research activities on other frequencies. Thus, the 32-meter Kiruna UHF dish has recently been converted to prime-focus feed for operation at 224 MHz. It is the biggest operational reflector antenna in Sweden.

Swedish space antenna projects was presented by Per Ingvarson, RUAG Space AB. [4]

At LM Ericsson's MI Division in Mölndal, created to develop radars for the Swedish defence, the development of satellite antennas started in the early 1970s. The group has remained, but with new names, new owners and a new location within the Gothenburg area; today it belongs to RUAG Space AB. It has been responsible for an overwhelming number of antennas; some of them are highlighted here.

The first ESA satellites had low data rates, so that wide coverage antennas could be used. The first projects, GEOS and ISEE-B, used thin slotted waveguide arrays in S band, GEOS also had a VHF turnstile array. Later, it was clear that a standard antenna was needed, giving isotropic radiation. Two conical quadrifilar helices were selected and first delivered to Exosat. Further developments of this antenna type, protected by many patents, gave a variety of coverages and applications at L, S, C and X band. Overall, more than 250 flight helix antennas have been delivered.

For somewhat smaller coverages, the patch excited cup (PEC) antenna was developed. It has been and is being used for high performance GNSS applications. Low mass, metal-only design, and low back and crosspolar radiation makes them competitive and they are also used for arrays.

By the end of the 1970s, there was a large interest for direct-TV satellites. A novel astigmatic offset Cassegrain reflector concept was developed, used by The TELE-X satellite.

For the Swedish ODIN satellite (Fig. 5) a very stable technology was developed with CFRP (carbon-fiber-reinforced polymer) honeycomb, invar inserts, superinvar moulds and extremely precise manufacturing. The RF design was done at Chalmers.

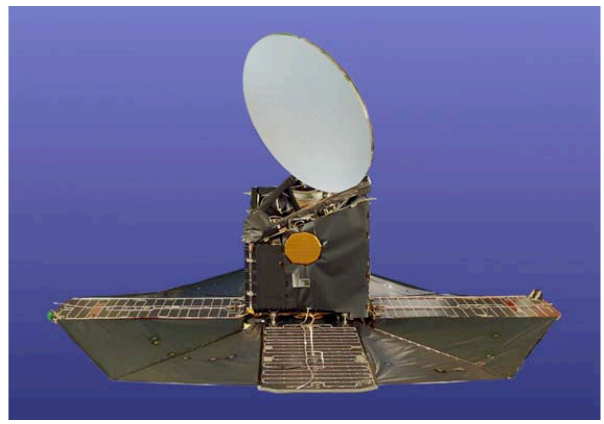

Figure 5. The ODIN satellite.

Slotted waveguide arrays for ERS-1 and -2 were designed with inhouse software. They were used for remote sensing with SAR (synthetic aperture radar) and scatterometers. The SAR antennas were 10 meter long and deployable. Further developments have been made, e.g. with dual polarisation.

Mobile communication initially used single-beam antennas, later multibeams. An array covering the earth with a number of beams from a geostationary orbit was developed in the 1970s and early 1980s. However, even smaller beams were required, and small arrays feeding a reflector and using the patch excited cup (PEC) technology were delivered to the Artemis and EMS satellites. More than 3000 S band elements were delivered to Hughes (now Boeing).

The design methods have changed significantly during the 40 years covered here. At the beginning, computers were slow. memory limited and software simplified. Engineers had to understand the problem well enough to be able to make the correct simplifications. From the 1990s, commercial softwares became more powerful. The extraordinary development of computers and software is the most important change for the antenna design work.

The space antenna group has kept the links with Ericsson and Saab and has formed strong relations with academia. It played an important role in ACE (the European Antenna Centre of Excellence) and in the creation of EurAAP (European Association of Antennas and Propagation), and its yearly antenna conference EuCAP.

Lars Josefsson, Lars Microwave (retired from Ericsson) presented ***Radar antenna R&D in Sweden***. [5]

Like the group at RUAG, Ericsson built an overwhelming number of antennas; some of them are highlighted here.

Already in 1939 radar experiments were under way in Sweden. During the war Ericsson developed radar equipment (‘echo radio’) for the Swedish Navy (with moderate success). Later Ericsson got contracts for license production of search and fire control radars for the Swedish Army and Air Force.

For aircraft Draken (the ‘Dragon’, delivered 1959), the first version J 35A was equipped with a radar from CSF. For J 35B and D, the first all-Swedish airborne radar was made by Ericsson. This antenna had a parabolic reflector front fed by a rotating circular waveguide feed (conical scan). The antenna platform had 3 axes for steering and stabilizing the antenna beam. A new antenna was needed in the more advanced radar for the J 35F version; with a Cassegrain antenna the wide angle sidelobes were drastically reduced.

In 1968 Ericsson and Chalmers University (the latter with support from Ericsson) embarked on a joint four year R&D program in the field of phased array antennas: ESA = Electronically Scanned Antennas. The results of this effort included several doctor degrees at Chalmers.

Ground based long range radars have limited coverage and are vulnerable and have limited mobility. The advantage of airborne solutions is apparent and several studies had been undertaken in this area since the 1960s. The system finally arrived at was Erieye (Fig. 6) – the Swedish Airborne Early Warning System, an S band active phased array antenna mounted on a small turboprop aircraft. The dorsal unit has two 8 meter long slotted waveguide arrays, one on each side, with about 200 solid state transmit/receive modules. Today the system is operational in many countries.

Figure 6. The ERIEYE radar mounted on a Saab 340 turboprop aircraft.

ARTHUR stands for Artillery Hunting Radar. By electronic steering of the antenna beam both in azimuth and elevation it can detect projectiles before impact and calculate the launch site with high accuracy. In ARTHUR, the vertical aperture slotted ridge waveguides are more than 2 m long.

Ericsson’s business has traditionally been telecommunication. The radar unit in Mölndal provided the basis for an expansion into other applications. The technical spinoff between these activities has contributed greatly to the proficiency and knowhow of the Ericsson Antenna Department.

For years, FMV (Swedish Defence Material Administration) has taken an active part in the technical development. Another important contributor has been FOA/FOI (Swedish Defence Research Agency). Collaboration between Ericsson and other companies as well as several technical universities should also be remembered, e.g. in the area of conformal antennas.

Claes Beckman, Royal Institute of Technology (KTH), told ***The story of Allgon: HF, VHF, cellular and microwave antennas during almost 60 years***. [6]

In 1947, Torbjörn Cramner and his wife Veronica founded “Antennspecialisten” in Stockholm producing citizen band and FM car antennas. In 1951, they moved to Åkersberga, north of Stockholm. In the late 1960s, the couple went separate ways leading to a split of the company. Torbjörn continued with HF antennas under the name of Allgon; Veronica named her part Carant (short for ‘car antenna’).

Carant was successful in its field, in 2000 being acquired by Smarteq which also bought the car antenna and application division of Allgon; that joined two parts of Allgon that had been separated for some 30 years. Today Smarteq develops a number of antennas for vehicles, some of them produced in Hungary by a company named Carant.

In the 1970s Allgon initiated a new product area: antennas for the Swedish defence. The reflection free directional broadband and lightweight antenna RFD707 for combat net radio systems was internally referred to as the ‘Hallén antenna’.

Allgon made some HF rotating logperiodic antennas (Fig. 7), developed by Erland Cassel. They were designed for transmitters up to 250 kW carrier and 100% AM modulation over the frequency range 6-30 MHz. The boom was tiltable allowing for beam shaping to optimize the communication. They were 25 m long and weighed several tons. Several of these are still in use.

In 1974 Allgon went bankrupt, mainly due to the enormous effort put into the development of the logperiodic antennas. The company was aquired by Hjalmar and Jonas Kämpe and renamed Allgon Antenna AB (Allgon AB).

From then on there were many mergers, company splits as well as changes of brand names and production facilities, too numerous to be described here.

Figure 7. An Allgon log-periodic antenna in Switzerland.

In 1981, the Nordic telecoms launched NMT 450 (1G), the world's first fully automatic mobile phone system introducing handover and international roaming. Allgon produced car mounted antennas for NMT and also base station antennas for NMT 900. Later, dual polarization was included for diversity, reducing the size of the base station installation. Similar products were built for GSM (2G) and 3G systems. With the introduction of the pocket size mobile phone, Allgon invented the extractable terminal antenna which combined a quarter wave antenna with a helix at its bottom. At the end of the millennium, Allgon was probably the world's second or third largest antenna company, producing around 100 million terminal antennas per year.

In 2005, the brand name of Allgon was gone and most of the employees had left. The story of Allgon could have ended here, but the Kämpe family started a new antenna business, CellMax, designing high gain base station antennas for 3G and 4G, producing them at Allgon's former subcontractor Gelab.

Allgon was throughout a world leading antenna house in an environment filled with entrepreneurial spirit with managers like the Cramner and Kämpe families, supported by gurus like Ulf Saldell and Erland Cassel and engineers like Bo Karlsson, co-author of Beckmans paper.

The story of the hat-fed reflector antenna for the global microwave-link market was presented by Tomas Östling, Arkivator AB. [7]

Professor Per-Simon Kildal invented the hat antenna in 1986. Then, he had already worked with designing primary feeds for reflectors and had become interested in characterizing feeds for improved aperture efficiency of the reflector.

The hat feed is a result of a theoretical formulation of the radiation from the line feeds of the radio telescope in Arecibo in 1986. The first published feed had very narrow bandwidth and couldn't be used at all, but adjustments of the geometry gave a good radiation pattern and return loss. In the beginning of the 1990s Ericsson got interested in the patented invention.

The story of COMHAT started at an antenna conference in Gothenburg 1997 (*Antenn 97*). Per-Simon Kildal had worked with Ericsson and they had decided to use the hat antenna in the new antennas for the "Mini-Link¨ microwave radio; the entrepreneur Bengt Gustavsson was looking for new business. Their joint idea was to market, develop and manufacture hat antennas to the global microwave radio link industry. Kildal wanted the name to describe the technique, the hat antenna, and Gustavsson combined it with communication, thus COMHAT. In 2000, they celebrated the first contract: 100 pcs 1.2 m antennas to Viking Microwave.

COMHAT sold filters, couplers, antennas and measurement systems to customers all over the world. A very successful Master thesis was written during this time: Martin Denstedt managed to increase the bandwidth almost by a factor 3 to over 30%. He was awarded 'Lilla Polhemspriset' for the best Master thesis in Sweden in 2007.

In 2007 Arkivator acquired COMHAT. Now the antenna and filter products were a part of a bigger company, giving access to a large and efficient production facility. A demand for a new size of antennas was growing among the customers: 0.9 m antennas. With focus on production costs, Arkivator decided to develop a new antenna that has been well received by the customers. Shortly afterwards Arkivator also developed E-band antennas in the sizes 0.2, 0.3 and 0.6 m (Fig. 8). Today, more that 93,000 antennas have been manufactured.

Figure 8. COMHAT 0.3 m and 0.6 m antennas.

The story of the hat antenna shows how long time it can take from invention to series units reaching the market: 15 years. Today, after producing the hat antenna for about 12 years, Arkivator has started to sell the next generation of hat antennas by adding new ideas resulting in antennas with much better performance at lower cost. The first to be launched was the 0.6 m with the 1.2 m shortly afterwards. The 0.3 m will be added in a year.

Charlie Orlenius, Bluetest AB, presented ***The Bluetest story: the 12 years from a crazy idea to commercial success***. [8]

The idea was simple, yet revolutionary: to build a compact antenna measurement instrument based on a reverberation chamber, preferably small enough to be placed on the antenna designer's own desk. The idea was created by professor Per-Simon Kildal and patented.

In the 1990s, mobile phone antennas needed to be designed in short time. To use reverberation chambers for measurements of small antennas and mobile phones was essentially an answer to the industry's demand for faster, simpler, and less costly solutions. These chambers, mode-stirred chambers as they are sometimes called, were not new; they were well known in the area of Electromagnetic Compatibility (EMC).

The company Bluetest was founded in the Autumn of 2000 as a way to explore the idea in a tight and still active relationship with Chalmers. Bluetest has been focusing on the industrial development, whereas Chalmers has focused on the academic aspects leading to several Master, licentiate, and PhD theses.

There have been other collaborating parties e.g. the Swedish labour union TCO, previously known for their successful quality certification of computer monitors, that wanted to introduce a "quality label" for mobile phones.

Size of the chamber was an important parameter, and the company envisaged chambers so small that they could be placed on a desk. At least one such prototype chamber (Fig. 9) was produced for Bluetooth antennas, also the origin of the name Bluetest. The relatively small chambers meant a challenge in terms of accuracy. With improvements, the chamber was capable of measuring parameters such as radiation efficiency, impedance mismatch, Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS).

Figure 9. Early prototype chamber for Bluetooth measurements showcased at the IEEE International Symposium on Antennas in 2000.

The big breakthrough of reverberation chambers came just after 2010 when multiport antennas were introduced in mobile handsets to mitigate fading effects. As the chamber supports a multipath fading environment, it was very straightforward to measure diversity antennas. One could easily switch between active and passive measurements as well as between single and multiport antennas and quickly access the parameters.

With the introduction of 4G, the concept of MIMO in handsets gained a significant interest. The reverberation chamber was well prepared for this, and Bluetest was able to deliver the first functional measurement system in December 2009. With the introduction of 4G and MIMO, the industry shifted towards using data bit throughput as a parameter instead of using antenna radiation efficiency or receiver sensitivity. Today, more than 140 test systems have been delivered.

In hindsight it is interesting to see how it all started with a simple, yet revolutionary, idea and then it went on to become a dominating technology for this specific type of testing. All in all, the next decade for reverberation chamber research has the promise of being just as exciting as the previous one.

The final speaker was Carl-Henrik Walde who told us about ***Erik Hallén and his integral equation, Swedish defence activities, the ANTENN conferences, stealth craft Smyge***. [9]

Gunnar Petersson, who worked closely with Erik G. Hallén (Fig. 10) and is familiar with his theories, has been kind to submit the part on Hallén, professor of Electromagnetic theory at the Royal Institute of Technology in Stockholm (KTH). Hallén's main interest became antenna theory, in which area he is internationally famous, especially for the distribution of the current on a metal rod antenna, Hallén's integral equation.

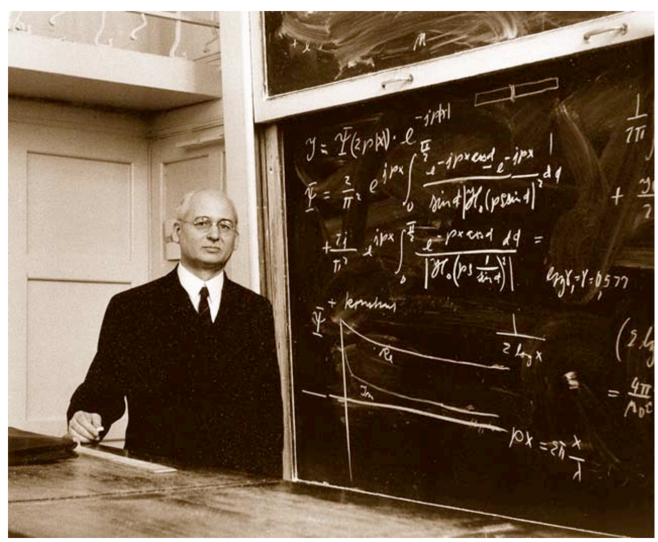

Figure 10. Erik Hallén (1899 – 1975) at KTH (Unknown photographer).

Another area of great importance at that time was reflection-free antennas. Although a pure theorist he was very keen on testing his theoretical results with experiments. One of his students, Erland Cassel, measured amplitude and phase of the current along the antenna, the first time this was done. Based on Hallén's theory, an army wire antenna för 30-80 MHz was made by Allgon and widely deployed.

In the 1950s, Carl-Henrik Walde, the author of this article, was one of the few students of *Teknisk Fysik* (Engineering Physics) in Sweden, at that time available only at KTH. Hallén was a radiant teacher in electromagnetic and field theory, his book was good and we grasped what he said or at least believed so, but he was as feared as his final oral examination. However, when the number of students increased, Hallén was forced to change his exam to a written, but a very unusual one. In the author's own words:

– I was one of those taking part in the premiere. Sitting at our desks, professor Hallén greeted us by declaring "You have got five hours. If you cannot address all eight problems, I suggest you leave and do something else". After three hours Hallén reentered, loudly saying: "Those who are ready may approach and I will check your solutions". These words came as a shock, but not for two of my most brilliant classmates, Karl Johan Åström and Torsten Bohlin who early became control theory professors at Lund University and KTH, respectively. Åström was awarded the IEEE Medal of Honor in 1993.

The author joined the navy in the 1950s and one of his first jobs was to procure a broadband vertical antenna for 100-160 MHz, the frequency band for short-haul communications within the Royal Swedish Navy. Allgon Antennspecialisten made an antenna based on a patent by its managing director Torbjörn Cramner. It had the form of a thick cylinder with thick counterpoise rods, the radiating elements made of copper nets, rigidity reinforced by plastics. The prototype is in the navy historical collections, the series units are still in use.

A well-known way of research, development and series manufacture of military equipment and systems is called *The Swedish Model*. It is based on close cooperation between defence staffs, defence procurement offices, universities, research institutes, industry with consultants and telecom operators, and – very important – the users. In that spirit and to bring industry and users together, the army people invited to the first *Antenna* meeting in May 1974. Present were Lars Höök and the late Curt Norell; they became the driving force.

In 1982 FMV, the Swedish Defence Materiel Administration, reorganised and established a joint radio division with Walde as chief engineer and manager. The antenna meetings continued under the new command and *Antenn 85*, in Arboga, gathered almost 200 participants.

On that occasion, 'P', Per-Erik Ljung at FOA, delivered an almost shocking talk on radar targets of naval ships, in essence meaning that these were poorly designed. Commander (E) Lars Salomonsson, later raising to rear admiral, became upset and said to P: "Now you go with me to Karlskrona shipyard and I will tell you why we cannot design in another way." They went there and P was pushed into the drawing office. Salomonsson returned some hours later expecting rough talk, but found the gentlemen sketching, saying: "We are designing a new ship."

That became HMS Smyge, our first stealth ship. Navy people from all over the world went to Karlskrona to have a look. Based on Smyge, the Visby corvette (Fig. 11) was launched in June 2000. USS Zumwalt, due for delivery in 2014, has similar features, but with a formidable price tag.

Figure 11. HMS Visby in a Swedish archipelago (Kockums AB).

At the end of the workshop, Ninva Shamoun and Michael Andersson were awarded the ***Microwave Road Award*** for their Best Master thesis in Antenna and/or Microwave Technology (Fig. 12). Microwave Road, an association of microwave companies in the Gothenburg area [10] sponsored this prize.

Figure 12. Ninva Shamoun (left), Ingmar Andersson representing Microwave Road and Michael Andersson (Jan-Olof Yxell Chalmers).

Ninva and Michael will perhaps enter the stage at an antenna conference 50 years from now and tell the history of today.

ACKNOWLEDGMENTS

I thank the conveners Per-Simon Kildal, Claes Beckman and Per Ingvarson for organising the workshop and the authors for letting me cut and paste. Giuseppe Pelosi and Piero Mazzinghi have kindly given the speakers "A Wireless World", a book commemorating the centenary of the Nobel Prize in Physics that was awarded to Guglielmo Marconi in 1909 [11]. Thanks are also due to Karolina Partheen at Chalmers for early help and to Juan Mosig and Per-Simon Kildal et al. for inviting me as a guest. Kildal also kindly suggested a reference list.

FHT, Försvarets Historiska Telesamlingar (Swedish Defence Historical Collections) will probably publish a booklet with the full papers (including references) of the EuCAP 2013 historic workshop [12].

References

[1] J. F. Johansson, "The early days of radio in Sweden, Ernst F W Alexanderson and Grimeton radio station SAQ, Unesco World Heritage", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013.

[2] H. Olofsson, "Swedish Radio Astronomy", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013.

[3] G. Wannberg, "The EISCAT antenna systems for Swedish and international ground-based space radio science", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013.

[4] P. Ingvarson, "Swedish space antenna projects", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013.

[5] L. Josefsson, "Radar antenna R&D in Sweden", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013 .

[6] C. Beckman, B. Karlsson, "The story of Allgon: HF, VHF, cellular and microwave antennas during almost 60 years", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013.

[7] T. Östling, "The industrial story of the hat-fed reflector antenna for global microwave-link market: The 25 years from invention via Comhat to mass production in Arkivator", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013.

[8] C. Orlenius, Bluetest AB, "The Bluetest story: the 12 years from a crazy idea to commercial success", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013.

[9] C.-H. Walde, and G. Petersson, "Erik Hallén and his integral equation, Swedish defence activities, the ANTENN conferences, stealth craft Smyge", EuCAP 2103, Gothenburg, Sweden, 8-12 April 2013.

[10] www.microwaveroad.se/

[11] K. Grandin, P. Mazzinghi, N. Olander, G. Pelosi (Editors), “A Wireless World”, Royal Swedish Academy od Sciences and Firenze University Press, 2012 (ISBN 978-91-7190-178-1).

[12] (TBA) C.-H. Walde (Editor), “The historic workshop at EuCAP 2013”, Stockholm: FHT, Försvarets Historiska Telesamlingar (Swedish Defence Historical Collections, www.fht.nu).

Carl-Henrik Walde graduated at KTH in 1958 and spent all his professional life in the Swedish Armed Forces Administration. He is secretary of SNRV, the Swedish National Committee of URSI, and of NRS, the Nordic Radio Society foundation. With callsign SM5BF he is honorary member of SSA, the Swedish league of radio amateurs.

The Early Days of Radio in Sweden, Ernst F.W. Alexanderson and Grimeton Radio Station SAQ, UNESCO World Heritage

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

Abstract—The Grimeton radio station is a still operational pre-electronic era VLF transmitter system. Created a UNESCO World Heritage in 2004, it also serves as a testimonial to the impressive productivity of the Swedish-American inventor E.F.W. Alexanderson.

Index Terms—radio history, VLF

I. THE EARLY DAYS OF RADIO IN SWEDEN

Sweden was at the beginning of the 20th century transforming into an industrialized nation. Rich in natural resources such as iron ore and hydro-electric power, and having a working force of relatively high literacy, Swedish companies such as LM Ericsson, ASEA, SKF, Alfa Laval, *etc.* grew into multinational giants. However, within the area of wireless communications, the Swedish success story would still have to wait until the last decades of the century. At the time, the great powers of wireless were Great Britain and Germany.

Early on, the main stakeholder in wireless communications was the Royal Swedish Navy (*cf. e.g.* [1]). The utility of wireless was obvious, and work began to equip the navy with the needed equipment. Negotiations with Marconi were unsuccessful, and thus the main supplier would be Telefunken in Germany.

Major spark transmitters were commissioned in Karlsborg (the “backup capital” of Sweden), at the naval port of Karlskrona, and in the merchant port city of Gothenburg.

Sweden had by tradition good contacts with Germany, and it was common for Swedish engineering students to study in Germany. In the electrical engineering field, the *Königliche Technische Hochschule* in Charlottenburg, Berlin was generally considered as the most prestigious university. Hence, the few Swedes that made an impression in the wireless field at that time, notably Ragnar Rendahl and Ernst Alexanderson, had that *alma mater* in common.

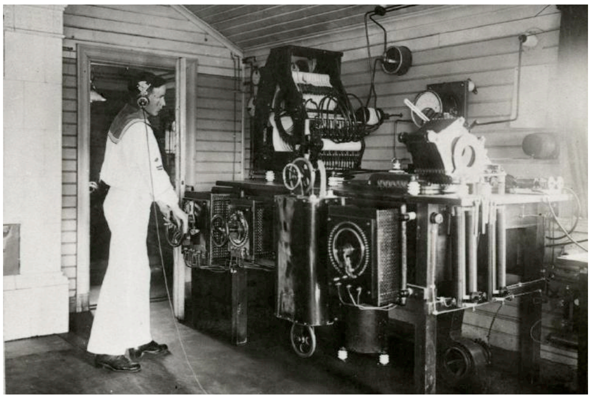

Figure 1. Interior from the Karlskrona spark transmitter 1914 (call sign SAA).

II. E.F.W. ALEXANDERSON

Every nation has its answer to the question of “who invented radio”. Scientist such as Braun, entrepreneurs such as Marconi, and mavericks such as Tesla all made important contributions. However, such complex technical systems would not work without practical solutions to numerous detail problems, and thus the inventorship is by nature collective.

One of the less known pioneers of wireless technology is the Swedish-American engineer Ernst F.W. Alexanderson (*cf. e.g.* [2] for an authoritative biography). Alexanderson was born in Uppsala in 1878. After studies at the Royal Institute of Technology in Stockholm and year in Berlin, he emigrated to the U.S.A. in 1901. After some shorter employments he ended up at General Electric.

Alexanderson finally managed to get a position at the prestigious testing department of GE in 1903. The testing department was a must if aiming at higher positions in the company. Being “the best graduate course in electrical engineering in the world”, it was considered essential for “Americanizing” European engineers.

With help from his mentor C.P. Steinmetz, and with the management attention his invention of the self-exciting dynamo got, his career took off, and he finally became Chief Engineer at GE and RCA.

Figure 2. Ernst F.W. Alexanderson (1878 – 1975).

Alexanderson was a prolific inventor, and was awarded at least 345 US patents. A General Electric advertisement campaign featuring Alexanderson had the title "An Invention Every Seven Weeks". His last patent was awarded 1973, at the age of 95!

He contributed to a wide variety of fields, such as control engineering (the amplidyne), color television, radio facsimile, power electronics, power engineering, navigation, *etc.*

Even though Alexanderson is less known today, it is evident that he was recognized as a major player in electrical engineering in the first decades of the century. In 1919 he became the second recipient of the IEEE Medal of Honor (Marconi being the third in 1920).

Alexanderson made inventions of main importance to the early trans-oceanic communication systems [3]. The simplicity of spark transmitters made them popular for naval applications, even though they created damped waves that covered a wide spectrum. However, for reliable long-range high-speed communications, high power continuous wave transmitters were essential. In 1905, Alexanderson filed a patent application for a high-frequency alternator that filled that need. In the following years, he made important inventions for key components of a complete wireless communications system:

- Transmitter (High-Frequency Alternator);
  U.S. Patent No. 1008577
- Modulator (Magnetic Amplifier);
  U.S. Patent No. 1206643
- Multiple Tuned Antenna;
  U.S. Patent No. 1360168
- Receiver (Selective Tuning System):
  U.S. Patent No. 1173079

Through these (and other) inventions, RCA became independent of the Marconi and de Forest patents.

Alexanderson recognized system aspects early, and is quoted as stating that – "*The problem of radio engineering is to establish the relation between kilowatts input and words output*", which is a nice condensed version of information theory.

III. The Grimeton Radio Station

A. *Rationale and Location*

One of the first acts of war of *The Great War* in August 1914 was when a British cable ship severed the German telegraph cables in the North Sea [4]. Later raids essentially left Germany isolated in terms of wire telecommunications The German Empire had to rely on detours via neutral nations (*e.g.* the "Swedish Roundabout") and the wireless capabilities of its *Grossfunkstation Nauen*.

The potential future consequences of the alleged Swedish complicity in the relaying of the "Zimmermann Telegram" (the failed attempt to instigate a Mexican declaration of war against the then neutral U.S.A. [5, 6]) is likely to have motivated the Swedish authorities to acquire a reliable wireless back-up system for transatlantic communications.

A reliable transatlantic wireless communication system would be based in the VLF (3 – 30 kHz) band. The theory of the propagation of RF surface waves over an imperfect conductor had been pioneered by Sommerfeld and Zenneck before WW1, and it was understood that the lower the frequency, the lower the signal attenuation. High conductivity soil or, even better, high-salinity water would improve the propagation. The ability to generate high power was also easier at lower frequencies, but lower antenna efficiency and a limited available bandwidth would be limiting factors.

A quick glance at a map shows that a location in the Varberg area on the west coast of Sweden would yield a great circle path towards the U.S. east coast that would pass almost entirely over sea water, clearing both the north tip of Jutland and the southern tip of Norway. Other boundary conditions were the vicinity to a reliable AC power grid and being not too far from the Swedish governmental telegraph facilities in Gothenburg. All these factors converged to a dual facility solution with a receiving station in Kungsbacka and a transmitting station in Grimeton outside Varberg (see the map below).

The Grimeton radio station was ready for operation in December 1924, and the official inauguration was held on 2 July 1925 in the presence of King Gustaf V.

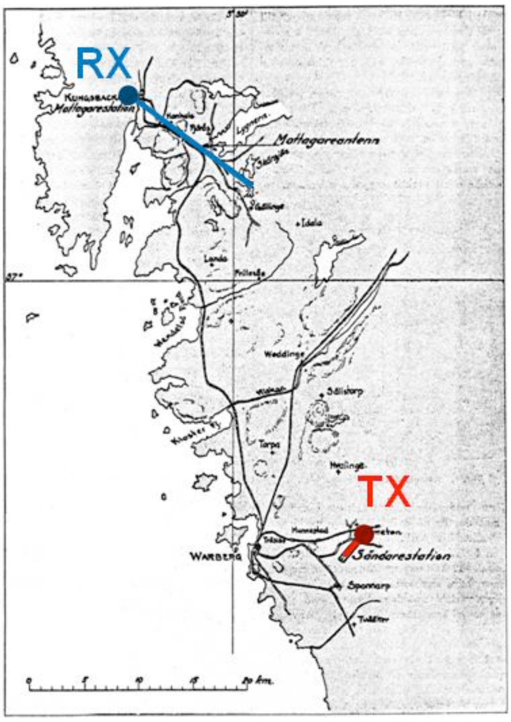

Figure 3. The location of the receiving and transmitting stations on the west coast of Sweden.

B. The Receiving Station Design

The receiving station used quite an interesting approach. The Beverage "wave" antenna [7] achieves a very good directivity in the direction along the wire away from the feed point, and the longer the wire, the better. However, the station in Kungsbacka is close to the sea, and thus it would not be possible to have a long antenna in the desired direction. The problem was solved by running the antenna in the opposite direction. Two wires were mounted on 9 m tall telephone poles along a 13 km stretch inland. By mounting a balun device at the far end, one could now use the two-wire common mode as a Beverage antenna with its feed at the far end, and then use the differential mode as a transmission line back to the receiving station.

Nothing is left of the receiving antenna system, but the station building in Kungsbacka remains, now as an apartment building.

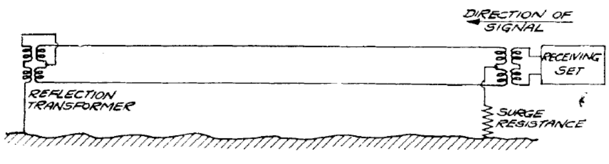

Figure 4. The principle of the two-wire Beverage antenna [7].

C. The Transmitting Station Design

The schematic of the Grimeton transmitting station is shown below. The design is the standardized General Electric one, and the main parts are described below [8].

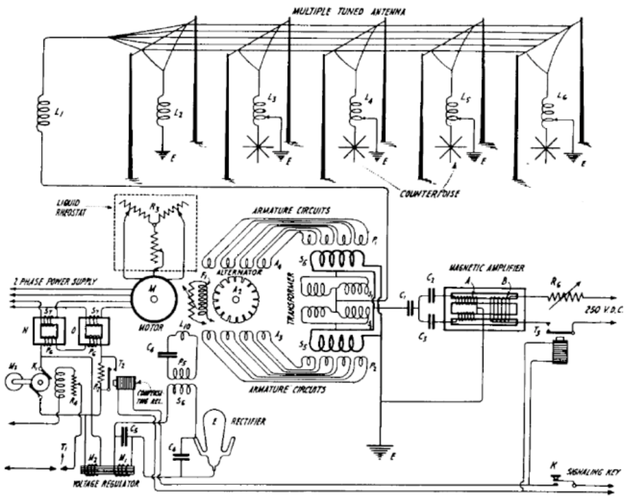

Figure 5. The schematic of the General Electric alternator based design.

1) The Alternator

The alternator is in principle comprised by three parts: a motor, a gearbox, and the high frequency generator, comprising a 50 ton unit, see the figure below. The motor is a 370 kW 2.2 kV 50 Hz asynchronous motor which has quite a unique wiring, with a 2-phase stator and a 3-phase rotor connected by slip-rings to external liquid resistors. The proximity to a stable power grid that was provided by the early hydro-electric power generating capabilities in Halland County was essential to the Grimeton radio station.

The gearbox provides a final rotation speed at 2115 rpm, and the peripheral speed of the 1.6 m diameter rotor disk is 638 km/h (177 m/s). The mechanical issues encountered when having a 1.5 ton disk spinning at such speeds, while providing a 1 mm air gap to maximize the RF coupling, are by themselves quite difficult problems. Alexanderson solved several of these problems and patented *e.g.* a self-adjusting bearing system.

The steel rotor of the alternator has 488 teeth that are filled with non-magnetic brass to improve the aerodynamics. The nominal frequency of the Grimeton alternator is thus 488*2115/60 = 17.2 kHz. The GE alternator gearbox was manufactured in three versions, and the number of poles in the drive motor could be selected to cover a frequency range of 12.5 – 28.5 kHz.

The stator has 64 armature windings, each providing 30 A at 100 V, that are combined in the transformers in the RF switchyard.

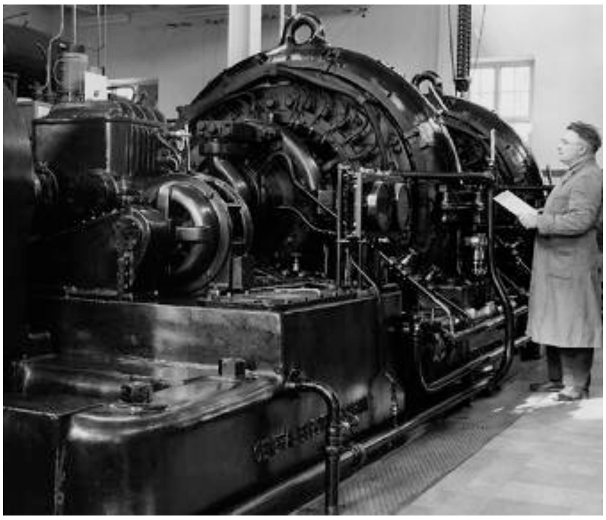

Figure 6. The Alexanderson alternator at Grimeton (World Heritage Grimeton).

The RF switchyard comprises two transformers with32 primary winding and one secondary winding each, lightning arresters, switch-gear, and a variometer (variable inductor) for tuning. An additional winding is used for modulating through a magnetic amplifier comprising two transductors and six capacitor banks. The transductors have an RF winding for which the inductance can be changed by a DC current. By keying the DC current, it is thus possible to modulate the RF inductance, and thereby the resonance conditions and the RF coupling. The RF carrier leakage in the key-up case is about 20 dB below the key-down case.

The transmitter has quite ingenious systems to maintain the carrier frequency versus variations in power grid voltage and frequency. Also, the keying results in a variable load for the alternator. The inertia of the rotor will dampen some of this variation, but slower variations in duty cycle of the keying have to be compensated. The above-mentioned liquid resistors (filled with NaOH) are used for regulation of the drive motor asynchronous slip, and thereby the frequency.

The transmitter also includes a lot of auxiliary systems for control, measurement, and protection, as well a water cooling system with an outdoor cooling water pond with fountains.

2) The Antenna

The antenna system is supported by six free-standing towers that are 127 m tall and have top cross-members that are 46 m wide. At the time of construction, these were the tallest (non-guyed) structures in Sweden. Each of the four inner towers weighs in at 130 tons, and the outer ones are even heavier at 160 tons. The towers are spaced by 380 m, and the total antenna length is thus around 2 km. Even at this size it is an electrically small antenna compared to the 17 km wavelength.

The antenna signal exits the building through a balanced two-wire cage type transmission line. A transition to the antenna top-wire system and the ground network is provided through a balun transformer, providing an RF voltage of 60 kV. At this point, a 50 Hz de-icing current is also injected into the antenna wires, when needed.

The antenna top-wire system is only a transmission line, and the antenna function is provided by the cage lines (see the figure below) that are connected to variable inductors at each of the six towers. The 2.7 m diameter inductors have about 75 turns of Litz wire that yield 10 mH to resonate the 50 nF antenna top capacitance. An essential, but only partly visible, part of the system is the grounding network.

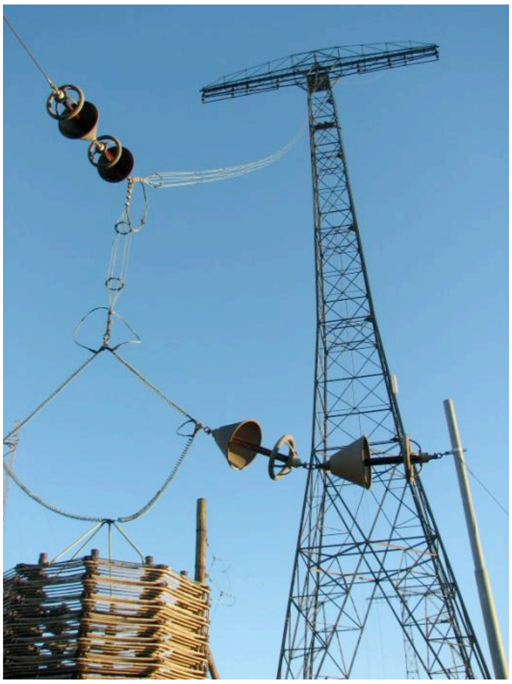

Figure 7. One antenna tower with the cage type vertical radiator and tuning coil visible (Wikimedia Commons).

The antenna height will determine the radiation resistance of a top-loaded monopole. With a height of around 0.75% of the wavelength, the result is 50 mΩ for the Grimeton antenna! Despite the advanced grounding system, the ground resistance is about 2.5 Ω, and the antenna efficiency would thus be around 2 %. However, the genius of Alexanderson stepped in again. By having several radiators he could get a multiple tuned antenna, and in theory the efficiency should be improved significantly. In the Grimeton case, the efficiency is above 10 %, a figure that is considered good for this type of system.

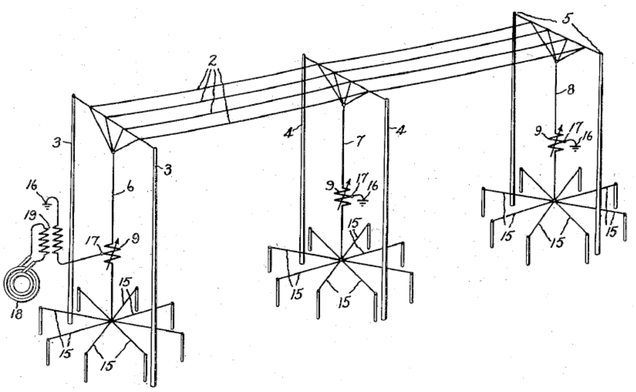

Figure 8. The multiple tuned antenna principle (U.S. Patent No. 1360168).

Figure 9. The Grimeton station building and the six antenna towers (Wikimedia Commons).

D. The Significance of Grimeton

The Grimeton station was part of a global RCA network that could be called the wireless "internet" of the twenties. The Morse code keying speed was typically 50 words per minute (wpm), but the transmitter could in principle modulate up to 150 wpm. In modern terms this would correspond to 42 baud and 125 baud, respectively. One should now consider that the contemporary submarine telegraph cables had even less capacity, typically 25 wpm.

The total information transmitted from Grimeton in 1936 was 1.8 million words, corresponding to around 10 megabytes!

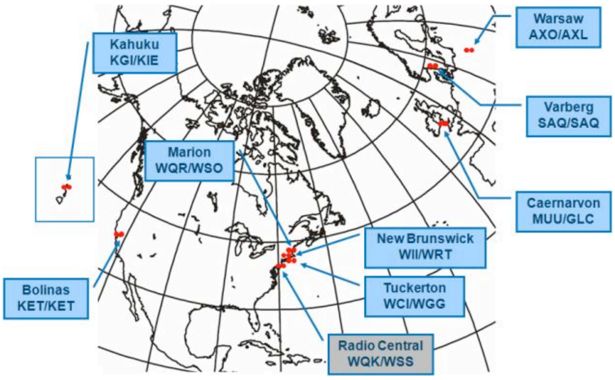

Figure 10. Node map of the RCA wireless "internet" of the twenties.

E. The Survival of a 'Dinosaur'

In a sense, the technology used in the Grimeton radio station was already obsolescent at the moment of construction. Vacuum tube electronics and short-wave communications could in essence provide the same long-range fixed communications capabilities. However, within its niche it still was more reliable due to its independence of ionospheric propagation conditions.

With the laying of the submarine telephone cables in the mid-fifties, the need for trans-oceanic telegram (text) messaging over a radio via would gradually disappear.

During WW2 it was realized that communications to submarines could be accomplished by using VLF transmitters. The range and depth penetration will be dependent on the frequency and the water salinity. Therefore Grimeton was used for early communication experiments with submerged submarines [9]. A quite unique advantage to Sweden is the brackish low salinity conditions in the Baltic, thereby allowing the LF radio station at Ruda (call sign SHR) to cover the eastern waters. However, on the west coast of Sweden, Grimeton was still needed due to the much higher salinity. Therefore the antenna system at Grimeton could survive into our days as a matter of national security.

The de-regulation of the Swedish telephone state monopoly in the late decades of the 20th century could have been the death knell to a facility such as Grimeton. The state monopoly was privatized into Telia (now Telia Sonera), and Grimeton fell under the auspices of Telia Mobile. With wise people still in high positions in the company, the towers were meticulously renovated before the station was declared obsolete. At the same time, the Swedish National Heritage Board found the architectural qualities of the station building important, and declared it a protected building heritage. With all the planets in the right positions, the radio station was now transferred to a non-profit foundation.

F. A UNESCO World Heritage

The United Nations Educational, Scientific and Cultural Organization (UNESCO) maintain a list of World Heritage Sites. Monuments such as the Great Wall of China, the pyramids at Giza, *etc.* are obvious list members.

Since Grimeton Radio Station is unique as a pre-electronic radio system, still in working order, work began to nominate it to the UNESCO list. This work was crowned with success at the UNESCO summit in Suzhou, China, and the station was added to the list on 2 July 2004. The Swedish government is now committed to preserve the radio station to future generations as a living monument of the inventions that changed the world for ever.

REFERENCES

[1] A. Ahlström, *Karlskrona Radio 1909 – 2009*, Royal Swedish Navy Historical Collections, Stockholm, 2009, ISBN 91-7942-083-4.

[2] J.E. Brittain, *Alexanderson: Pioneer in American Electrical Engineering*, ISBN 080184228X.

[3] E.F.W. Alexanderson, "Transoceanic Radio Communication", Trans. AIEE, Vol. XXXVIII , pp. 1269 – 1285, July 1919.

[4] http://en.wikipedia.org/wiki/Telconia

[5] http://en.wikipedia.org/wiki/Zimmermann_Telegram

[6] B.W. Tuchman, *The Zimmerman Telegram*, ISBN 0345324250.

[7] H.H. Beverage, C.W. Rice, and E.W. Kellogg, "The Wave Antenna – A New Type of Highly Directive Antenna", Trans. AIEE, Vol. XLII, pp. 215 – 266, Jan. 1923.

[8] *Alternatorn* (newsletter for the 'Alexander – Friends of the Grimeton Veteran Radio' society); various issues 2007-2012. www.alexander.n.se.

[9] C.-H. Walde, "Ubåtssamband och dess bakgrund" , *Audionen* (newsletter for the Radio Historical Society of West Sweden), No. 3, 2005.

Swedish Radio Astronomy

Hans Olofsson
Onsala Space Observatory, Chalmers University of Technology

Swedish radio astronomy and its development are synonymous with the formation and development of the Onsala Space Observatory at Chalmers University of Technology. The observatory grew out of the ionospheric research activities of prof. Olof Rydbeck, and his subsequent interest in radio astronomy that was stimulated during his years in the US. The increasing problems with radio interference in the Gothenburg area, eventually led to a donation of land on the Onsala peninsula, which made it possible to create a radio astronomical observatory in the late 1940:ies. This was a time when funding for research infrastructure was not easily obtained, and the first significant step came when the observatory bought five German second-world-war radar antennas (7.5 m Würzburg Riese) from Norway and brought them to the Onsala site. This made it possible to start mapping cosmic hydrogen, through the 21 cm line, in our galaxy, the Milky Way, and also to perform solar observations. The observatory was officially inaugurated in 1955, and Fig. 1 shows the installations in the late 1950:ies.

Fig. 1. The installations at the Onsala site in the late 1950:ies.

Prof. Rydbeck's interest gradually focused on astromolecules, i.e., molecules naturally occurring in the interstellar medium, but this required a larger telescope to be built at Onsala. Through collaborations with the Scandinavian telecommunication authorities a 25.6 m telescope was erected at Onsala in 1963, Fig. 3. Simultaneously, the observatory invested in the development of extremely low-noise

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amplifiers, based on the maser technique, to be able to detect the weak signals from cosmic molecules. This was a risky but eventually successful project, and it had two important consequences. The first detection of cosmic CH, an important component of astrochemical networks, and the first very long baseline interferometry (VLBI) observations in which the observatory was involved. The 25.6 m telescope is still in operation for astronomical VLBI observations.

Fig. 2. Left: The Onsala 25.6 m cm-wave telescope. Right: The Onsala radome-enclosed 20 m mm-wave telescope.

An unsuccessful attempt to get funding for a 100 m telescope, lead the observatory in a new direction, towards shorter wavelengths where an increasing number of new astromolecules was detected. A radome-enclosed 20 m telescope for mm-wave observations was inaugurated in 1976, Fig. 2, and it remained the world's largest mm-wave telescope for about a decade. A wealth of radio astronomical successes has been achieved with this telescope, and it laid the ground for the observatory's international expansion. It is still in operation for single-dish astronomical observations and for astronomical and geodetic VLBI observations.

In the early 1980:ies the observatory looked towards even shorter wavelengths, meaning that a site different than the Onsala one must be chosen. Eventually, this lead to the deployment of a 15 m mm/sub-mm telescope in the Chilean Andes (the Swedish-ESO Submillimetre Telescope, SEST, on La Silla), Fig. 3, through a collaboration between the observatory, now under the leadership of prof. Roy Booth, and the European Southern Observatory. This was a very successful and scientifically rewarding collaboration, which ended in 2003 when the telescope was moth-balled.

Fig. 3. Left: The Swedish-ESO Submillimetre Telescope on La Silla in the Chilean Andes. Right: The Atacama Pathfinder Experiment (APEX) telescope on Llano Chajnantor in the Chilean Andes.

In the 1980:ies the activities of the observatory had expanded to the extent that discussions to form a national facility started. They were concluded in 1994 when Onsala Space Observatory (OSO) became the Swedish National Facility for Radio Astronomy, with direct funding from the Swedish Research Council and hosted by Chalmers.

The SEST project was soon to be followed by the Atacama Pathfinder Experiment (APEX) project. This is a 12 m sub-mm telescope, a first version of the telescope which will later form part of the Atacama Large Millimeter/submillimeter Array (ALMA), located on a high (5100 m of altitude) site in the northern Chilean Andes (Llano Chajnantor), Fig. 3. Due to the excellent site, high and dry, and the high quality of the antenna surface it is even possible to perform THz radio astronomical observations with this telescope, which is operated by the Max-Planck-Institute for Radio Astronomy (in Bonn), the European Southern Observatory, and OSO since 2005. The SEST and APEX projects positioned OSO well for a substantial involvement in the 1.3 B$ project ALMA, the world’s largest mm/sub-mm radio interferometer array, presently being built on Llano Chajnantor.

At the same time as the sub-mm activities were flourishing within OSO, it became clear that long-wavelength radio astronomy would be the way to go for studying a number of astrophysically very important questions, such as the origin of large-scale structure in the universe, and the amount and nature of dark matter and dark energy. The Dutch project the Low-frequency Array (LOFAR) was paving the way for an even more ambitious project, the Square Kilometre Array (SKA) with an estimated cost of at least 1.5 B€. Consequently, to prepare technologically and scientifically for the SKA, OSO joined the international LOFAR project and a LOFAR station was installed at the Onsala site in 2011, Fig. 4. This station is now operated within the International LOFAR Telescope collaboration as well as in stand-alone mode. Since 2012, OSO is also a member of the Brittish company that is presently in charge of the SKA project.

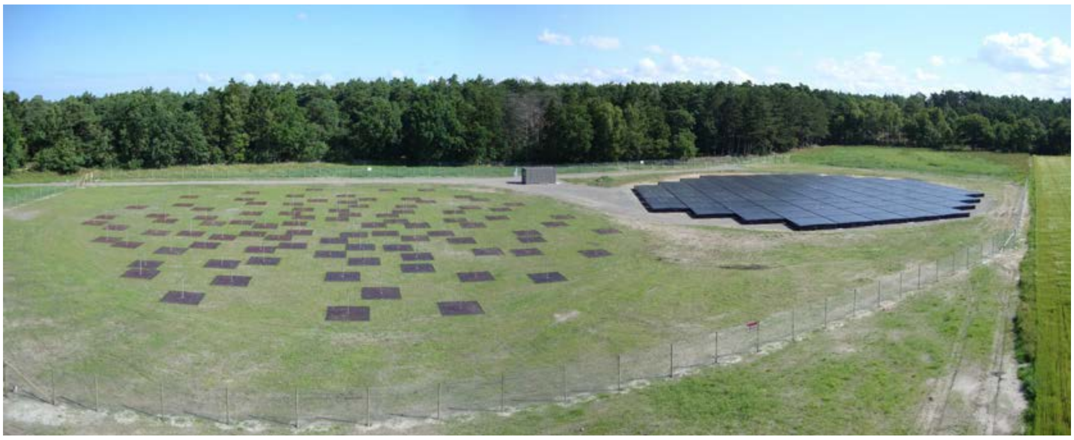

Fig. 4. The LOFAR station at Onsala.

Simultaneously with the radio astronomical activities, OSO has over the years become increasingly active in the field of geodesy. The central activity here is geodetic VLBI, where some of the most distant objects in the universe are used to measure the positions of the radio telescopes at increasing accuracy over the years. Among other things this gives information on Earth's crustal motion (i.e., plate tectonics) and, in particular, on Earth's rotation properties. The next phase is aimed to reach an accuracy of 1 mm in the position of a telescope (per measurement epoch), and to achieve this OSO will install two fast 12 m radio telescopes at the Onsala site, and equip them with modern VLBI instrumentation. The geodetic VLBI activity has over the years been supplemented with a national/international GPS station, a gravimeter laboratory with a superconducting gravimeter, tide-level gauges, and seismometers, with the aim to produce multi-method observations of the Earth's interior, crust, oceans, and atmosphere.

Thus, OSO is today an important research facility with a mission to operate its own instrumentation and to channel Swedish interests in international radio astronomical projects, as well as to promote geophysical activities that utilize radio astronomical methods.

The EISCAT antenna systems for Swedish and international ground-based space radio science

Gudmund Wannberg
Wannberg Radarkonsult AB
Duvvägen 22, SE-98137 Kiruna, Sweden
gudmund@wannbergradar.se
Formerly with Swedish Institute of Space Physics (IRF), Kiruna, Sweden

Abstract—**EISCAT, the European Incoherent Scatter Association, was formed in 1976 for the purpose of constructing and operating a complex incoherent-scatter radar (ISR) system in the auroral zone in northern Scandinavia. The paper reviews the principles of incoherent scatter radar and presents a brief history of EISCAT, with special emphasis on its radar antennas and the contributions to EISCAT antenna development made by Swedish scientists, engineers and companies. The planned next-generation incoherent scatter radar system, EISCAT_3D, is briefly discussed.**

I. Principles of Incoherent Scatter Radar

Classical physics tells us that an individual electron scatters EM radiation with a cross-section $\sigma_e = 1.0 \cdot 10^{-28}$ m^2. In 1928, Fabry suggested that this phenomenon might be used to probe the ionosphere. But three decades were to pass before radar technology had advanced to the point where it became possible: it was only in 1958 that Bowles recorded the first incoherent scatter signals from the ionosphere, using a 6 MW, 41 MHz transmitter [1].

In plasma, the electrons are loosely bound to the ions through polarization forces. The full theory of incoherent scatter shows that this coupling causes the scattered signal to contain information about a range of parameters, some directly measurable and some derived, e.g.

- electron density and temperature,
- ion temperature,
- ion composition,
- ion drift velocity,
- ion-neutral collision frequency,
- ionospheric electric fields,
- electrical conductivities and currents,
- neutral particle density,
- neutral gas temperature,
- neutral air velocity

ISR is thus an extremely powerful remote sensing technique [2]. But using it as a tool to study the atmosphere as a whole comes at a very high cost because of the extreme weakness of the scattering. In a typical experiment observing the ionospheric F2 peak, the total scattering cross section of all electrons in the measuring volume is $\approx 1...10 \cdot 10^{-6}$ m^2, so that megawatts of transmitter power and thousands of m^2 antenna apertures must be used. But even so, the received power is only about $10^{-21}....10^{-22}$ of the transmitted power - femtowatts or less, resulting in signal-to-noise ratios well below unity.

Another complication is that, for an ISR to work well, its wavelength λ_R should be at least ten times the plasma Debye length

$$\lambda_D \approx 69\ (T_e / n_e), \qquad (1)$$

where T_e is the electron temperature and n_e the electron density. When

$$\lambda_D > 0.2\ \lambda_R, \qquad (2)$$

the scatter spectrum starts to broaden and eventually degenerates into a Maxwellian with a width determined by the electron temperature. All information about the ions is then lost; this is the so-called "Debye cutoff" effect. Throughout most of the ionosphere $\lambda_D < 1 \cdot 10^{-2}$ m, but below 90 km and above 1000 km, where the electron densities are very low, it can reach $4 \cdot 10^{-2}$ m. Due to the Debye effect, ISR systems must operate in the high VHF or low UHF bands, where spectrum space is nowadays becoming increasingly scarce.

II. EISCAT

In the auroral zones, the Earth's magnetic field connects to distant parts of the magnetosphere. The field guides accelerated electrons and ions into the ionosphere, where they dump vast amounts of kinetic energy, ionize the neutral constituents, set up strong current systems, create auroral displays and trigger all manner of exotic plasma processes.

The first initiative to establish an ISR system in northern Scandinavia for the purpose of studying the physics and electrodynamics of this complex part of the ionosphere was taken by three Nordic scientists: Bengt Hultqvist (Sweden), Olav Holt (Norway) and Juhani Oksman (Finland). This group

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succeeded in obtaining support for the establishment of a joint Nordic incoherent scatter observatory from the 1969 URSI General Assembly in Ottawa. Several years of political groundwork and ups and downs followed. During this period France, West Germany and the UK decided to join the project. The EISCAT Scientific Association formally came into being in December 1975, when all parties were finally able to sign an Agreement defining EISCAT as a Swedish not-for-profit foundation, headquartered in Kiruna [3].

EISCAT now constructed a tri-static, vector-measurement-capable UHF (933 MHz, λ_R = 0.33 m) ISR system with antennas in Tromsø, Norway, Kiruna, Sweden and Sodankylä, Finland, and a high-power monostatic VHF (224 MHz, λ_R = 1.34 m) system for coverage of the lowest and highest altitudes, located in Tromsø. The dual systems configuration was adopted in an effort to avoid the Debye cutoff problem and get good coverage throughout the entire atmosphere. The UHF system was fully operational by the official inauguration of EISCAT by HM the king of Sweden on August 26, 1981 [3,4,5]. The optical performance of the giant 120x40 m VHF antenna was verified by extensive tests in 1980/1981, but the VHF transmitter, which depended on state-of-the-art technology to reach its design targets, was badly delayed, reaching operational status only towards the end of 1984 and producing the first ionospheric echoes in the summer of 1985.

In the 1990s, the Association constructed the EISCAT Svalbard Radar (ESR), a second-generation, 500-MHz dual antenna ISR system [9], on the island of Spitzbergen in the Norwegian Arctic. This system, which became operational in 1996, is of special interest to the Swedish antenna community as its first antenna, a 32-meter dish, was specified by a Swedish engineering team and constructed by a Swedish company. The second antenna, a fixed, field-aligned 42-meter dish, was supplied by Alcatel of France and accepted in 1998.

III. THE UHF ANTENNAS

The three UHF antennas, supplied by TIW, Inc., were erected and commissioned in 1978 [4]. They are fully steerable, wheel-on-track 32-m Cassegrain dishes with main reflectors and backing structures largely identical to those used in TIW's line of Intelsat I ground segment antennas, but with relaxed specifications; surface accuracy is specified at $5\cdot10^3$ m rms for wind speeds below 12 m s^{-1} but is actually estimated to better than $3\cdot10^{-3}$ m rms.

The feed system, comprising a large corrugated horn and a shaped subreflector, produces an aperture distribution that is flat to within ≈ 1 dB out to 12.6 m radius and then drops off quadratically to -6 dB at the rim. The resulting efficiency is very good, 71 %, the first sidelobe is down by -14.5 dB and all sidelobes at > 10° offset are down by better than -35 dB. The antenna temperature at 933 MHz is about 20 K. In the feedhouse behind the main reflector, the feedhorn interfaces to a waveguide orthomode transformer (OMT), rated for the full 2 MW design power of the UHF transmitter. Identical OMTs are used in all three antennas, although only the Tromsø one is used for transmitting. There, the transmitter is connected to the antenna through a ≈ 50 m waveguide run and two contactless rotary joints. At Kiruna and Sodankylä, the OMT outputs are terminated in coax transitions connecting directly to the LNA

Figure 1: The Kiruna EISCAT UHF antenna in Cassegrain configuration

systems. Low-power polarizers inserted after the LNAs match the antenna response to the polarization of the incoming wave. The Tromsø dish was initially equipped with a waveguide polarizer, intended to enable the transmission of arbitrarily polarised signals, but stable operation of the high-power duplexer could not be achieved at full power, so the polarizer was removed. The Tromsø dish is now restricted to transmitting RHC and receiving LHC.

The drive systems, comprising two DC motors for each of the two axes, can drive the 270 ton structures at up to 1.25° s^{-1}. The steering range is ± 270° in azimuth, centred on geographic north, and 2°...100° in elevation. Pointing error models are generated individually for each antenna by tracking a set of celestial calibrator sources over at least 24 hours and fitting two error correction polynomials, one for each axis, to the resulting data set. In this manner an absolute pointing accuracy of better than 0.02° can be achieved.

IV. THE VHF ANTENNA

The EISCAT VHF antenna [6] is an offset-fed, f/D = 0.45 parabolic trough reflector with its axis in the E-W direction. It was constructed between 1978 and 1980 by a consortium of three German companies: MAN, Krupp and MBB. While the consortium was responsible for the mechanical design, the electrical design and evaluation of the VHF feed and reflector system was done by a young Per-Simon Kildal, working at NTH Trondheim. His evaluation of the radiation characteristics of the antenna and the feed [7,8], submitted as his Ph.D. thesis, became the starting point of a long and distinguished career in antenna engineering.

For constructional reasons, the reflector is mechanically divided into four 30 x 40 m sections that can be independently tipped in the meridian plane between elevations 30° N - 60° S at a speed of 0.067° s^{-1}. With all sections aligned and fed in phase and the feed set up for circular polarization, the resulting beamwidth is 0.6° in azimuth and 1.8° in elevation. The broadside efficiency at 224 MHz is ≈ 0.64, corresponding to an effective aperture of ≈ 3100 m^2.

Figure 2: The EISCAT VHF parabolic cylinder antenna at Tromsø

Figure 3: Per-Simon Kildal with a 1.5 GHz model of the line feed.

The line feed comprises 128 crossed dipoles above a plane reflector, augmented by two longitudinal beam-forming rods. The design was verified by measurements on a 1.5 GHz model, performed at NTH Trondheim, and then scaled to 224 MHz.

The antenna can be operated in either of two modes. In Mode 1, one of the two 2.5 MW transmitter klystrons feeds all the horizontal dipoles and the other klystron feeds all the vertical dipoles. This allows the transmission of either linearly or circularly polarized signals and a possibility to change the polarization on a pulse-by-pulse basis. However, Mode 1 has never been fully utilized because of the unreliability of the diode duplexer and the failure of one of the klystrons. In Mode 2, which has been used exclusively for the last several years, the feed is electrically split in two halves, each half being fed by one klystron. In this mode only LHC can be transmitted. With only one klystron available, only one half of the antenna can be used for transmission but both halves can still be used as independent receiving antennas. The beam can be phase-steered into any one of 35 discrete positions between ± 21.5° in the azimuth plane by manually permuting a set of phasing cables of cleverly selected lengths, a technique suggested by Kildal. This process can take several hours; it is therefore performed only infrequently. Different schemes for implementing fast pulse-to-pulse beam-swinging, using electronic phase-shifters and/or a modular transmitter have been proposed, considered and costed, most recently last year (2012), but have so far always been judged too costly.

Figure 4: The KAMFAB ESR Antenna just before installation of reflector panels. Summer 1995.

V. ESR ANTENNA I

The ESR Phase I antenna [10] is a fully steerable, moving-head, doubly shaped 32-m Cassegrain dish. It is a one-off design, incorporating many special features that make it well suited to the harsh conditions in Spitzbergen. A very detailed performance specification for this antenna was generated by an EISCAT engineering team, led by the present author, during 1992 and 1993. After an open tender process, a bid from the Swedish company KAMFAB was selected as being the technically most attractive and also very commercially competitive. KAMFAB had never before built a big antenna, but had been the main contractor for a number of other scientific and high-tech programs, notably the 2.5 m Nordic Optical Telescope on La Palma in the Canary Islands, and got good references from all around. For the ESR project, it had engaged a number of subcontractors with long experience in RF and antenna design, notably Ticra of Copenhagen and Dielectric of Raymond, Maine, USA.

KAMFAB turned out to be a very good choice. The manufacturing proceeded on schedule, the shipping of the steel to Spitzbergen by a chartered vessel went smoothly and the on-site erection was largely completed by the end of 1994. The antenna was tested for mechanical and radiation pattern compliance in July 1995, optical and receiving performance acceptance tests were performed in October 1995, and in January 1996 500 kW of RF power run into the antenna for 20 hours with no problems; the antenna was now operational. The EISCAT Svalbard Radar was officially inaugurated on August 22, 1986, four days short of the twenty-fifth anniversary of the EISCAT UHF.

The antenna is electrically small (32 λ at 500 MHz), but delivers very good efficiency and low-noise performance thanks to a global full-wave optimisation of the reflector shapes. Somewhat remarkably, it was possible to achieve performance to within a fraction of a dB from optimum with singly curved reflector panels, a fact which translated to substantial cost and time savings in the manufacturing phase. Using celestial calibrator sources, the measured gain is 42.5 ± 0.2 dBi. The antenna temperature, including contributions from the OMT and transmit/receive switch, is < 30 K at all elevations greater than 15°. The feed comprises a waveguide

Figure 5: Overview of the EISCAT ESR site on Spitzbergen. KAMFAB 32-m antenna to the left, Alcatel fixed 42-m antenna in the foreground.

OMT, a circular waveguide pin polarizer and a Potter horn. The system is set up to transmit RHC and receive LHC. A balanced four-port PIN diode transmit-receive switch provides better than -90 dB isolation between the transmit and receive paths in the transmit state. Power reflected from the subreflector back into the horn, which can exceed 10 kW, is directed into a water load where it is dissipated. This arrangement helps to reach the desired < -30 dB cross-polarization.

With over 400 kW of drive motor power, the antenna is very fast; the maximum slew rate is 2.8^o s^{-1}. It can move a full 180^o in elevation, through zenith; when commanded to move, the antenna control unit automatically selects the shortest way to the new position. Full pointing performance (< 0.01^o wobble) is maintained at wind speeds up to 20 m s^{-1} and the antenna can drive into the safety stow position in winds of up to 27 m s^{-1} from any direction.

To prevent the main radar from illuminating aircraft in its vicinity, a standard shipboard C-band radar transceiver monitors the airspace through a pyramidal horn with a beamwidth of 10^o, installed at the apex of the main antenna subreflector tripod. The video output from the transceiver is processed in a PC equipped with a digital oscilloscope plug-in board. The main transmitter can be activated only when the aircraft warning radar is running, but whenever this detects an echo above a preset level, the main radar transmitter is disabled and an alarm is triggered.

VI. Adapting the UHF antennas for 1420 and 224 MHz

In 1981, the entire 918 - 948 MHz frequency band was made available for use by EISCAT. For many years, passive interplanetary scintillation (IPS) observations of the solar wind were made with the Kiruna and Sodankylä antennas using the full 30 MHz bandwidth and a square law detector, producing excellent quality data. However, the 918 - 948 MHz band was not protected - it had been allocated for "fixed-to-mobile communications", i.e. mobile telephony, by the ITU already in the 1970s but not taken in use for that purpose yet; the Norwegian P&T had simply let EISCAT "borrow" the band under the assumption that the EISCAT program would terminate around 1990. From that time onwards, cellphone services gradually started to appear in the band, leading to increased interference and receiver non-linearity problems. In 2001, the Finnish EISCAT site lost all spectrum except the 929.0 - 930.5 MHz slot to a new GSM operator. The remaining 1.5 MHz was barely enough to keep the radar measurement program running and totally insufficient for good IPS measurements.

It was then decided to provide the Kiruna and Sodankylä dishes with receiving capabilities in the 1410-1427 MHz protected radio astronomy band [11]. To match the existing corrugated horns at 1400 MHz, a two-section, circular waveguide Chebyshev transformer was designed and constructed by EISCAT Headquarters and Kiruna site staff. With the transformer connected directly to the horn aperture, better than -20 dB reflection was achieved over the 1420-1427 MHz band; the -3 dB beamwidth was 0.44^o and the first sidelobes about -17 dB down, roughly consistent with a slightly under-illuminated aperture and ≈ 0.65 aperture efficiency. Overall system noise temperature using uncooled HEMT preamplifiers was measured at about 65 Kelvin. The G/T at 1400 MHz was thus comparable to that at 930 MHz using the cooled front end. This action saved the IPS program from premature termination, giving it an extra 10 years.

But recently, things got really bad. In 2010, Sweden and Finland ratified a EU directive to open the 900 MHz band to third-generation mobile telephone services using the so-called UMTS 900 standard. As soon as the first UMTS 900 bases in the vicinity of the Kiruna and Sodankylä sites started up in 2011, the UHF receivers were swamped with in-band interference. It looked like EISCAT's unique capability to generate vector data had been lost for good.

However, already in 2010 the EISCAT user group at the Swedish Institute of Space Physics had submitted a proposal to EISCAT Headquarters, showing that at least some vector capability could be retained if the UHF dishes were adapted for VHF reception by replacing the subreflectors with prime-focus feeds and suggesting a Kildal-Skyttemyr dipole-ring-disk feed [12] as a suitable candidate. In 2012, EISCAT finally went ahead with this plan. Two Kildal feeds were constructed and installed in the antennas, and on November 1, 2012, the very first tri-static VHF experiment was successfully run.

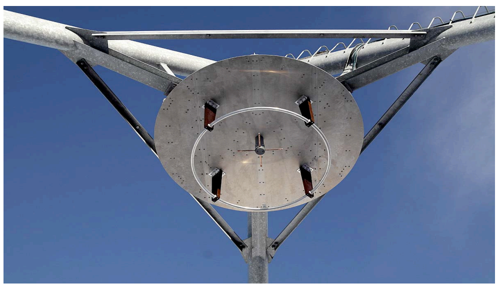

Figure 8: 224 MHz Kildal-Skyttemyr feed in Kiruna UHF antenna

At the cost of the total loss of the 1420 MHz capability, EISCAT can now continue to supply the community with vector velocity data at least until the end of 2014, when the operating permit for the VHF transmitter elapses.

VII. EISCAT_3D

From 2003 to 2009, a multi-party feasibility and design study for a third generation EISCAT system with the working name EISCAT_3D, an order of magnitude more capable than the old VHF and UHF, was carried out under EISCAT leadership with financial support from the EU FP6 program. The final report from the design study [13] recommends the construction of a multistatic phased-array VHF system with a central transmit/receive core, comprising upwards of 10^4 elements and a number of outlier, receive-only arrays, 100...300 km distant from the core. The EISCAT_3D project is now listed on the ESFRI Roadmap for Scientific Infrastructure and is currently in a "Preparatory Phase" with support from the EU 7th framework program. Continually updated information is available from the project website, www.eiscat3d.se

VIII. Summary

The establishment of EISCAT resulted in the construction of the largest reflector antennas ever built in Norway and Finland. Both are still in full operation after more than 30 years. Also, the 42-meter antenna on Spitzbergen is the second-largest in Norway, surpassed only by the Tromsø VHF. After the decommissioning of the two 32-meter Swedish Telecom (Televerket) Intelsat dishes in Tanum, the 32-meter Kiruna UHF dish remains as the biggest operational reflector antenna in Sweden. In its original Cassegrain configuration it has been operated at 930 MHz, 1296 MHz and 1420 MHz, but has recently been converted to prime-focus feed for operation at 224 MHz.

Since its beginning in 1976, the EISCAT project has been a very important asset to Swedish scientists and engineers, who have made important contributions to the development and evolution of the EISCAT antenna systems, notably the UHF and ESR I antennas, and to receiver and signal processing hardware. 32 Ph.D. degrees in Space Physics, wholly or partially based on EISCAT ISR data, have been awarded and well over 100 articles have been published in refereed scientific journals. Swedish scientists have also been very active in developing new radar codes, e.g. [14], and have introduced several innovative obsrvational techniques, e.g. the so-called high-power, large aperture (HPLA) radar method for meteor head echo studies [15,16].

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Lars-Göran Vanhainen and Ingemar Wolf, two EISCAT oldtimers who have been with the Association from the very beginning in 1976 until the present, have contributed greatly to the preparation of this paper by volunteering to share their memories and photos from the early days with me. Photos illustrating the model VHF feed work have been kindly supplied by Professor Per-Simon Kildal.

References

[1] Bowles, K. L., Observations of vertical-incidence scatter from the. ionosphere at 41 Mc/sec, Phys. Rev. Lett. 1, 454–455, 1958.

[2] Rishbeth, H. and P.J.S. Williams, The EISCAT ionospheric radar: the system and its early results, Q. Jl R. astron. Soc. 26, 478-512, 1985.

[3] Hultqvist, B., History of EISCAT - Part 1: On the early history of EISCAT with special reference to the Swedish part of it, Hist. Geo Space Sci. 1, 1-7, 2011, doi:10.5194/hgss-1-1-2011

[4] Folkestad, K., T. Hagfors and S. Westerlund, EISCAT: An updated description of technical characteristics and operational capabilities, Radio Sci. 18, 867-879, 1983.

[5] Baron, M., The EISCAT facility, J. atmos. terr. Phys. 46, 469-472, 1984

[6] Hagfors, T., P.S. Kildal, H.J. Kärcher, B. Liesenkötter and G. Schröer, VHF parabolic cylinder antenna for incoherent scatter radar research, Radio Sci. 17, 1607-1621, 1982.

[7] Kildal, P.-S., Radiation characteristics of the EISCAT VHF parabolic cylindrical reflector antenna, IEEE Transactions on Antennas and Propagation, AP-32, No. 6, 541-552, 1984.

[8] Kildal, P.-S., Aperture efficiency and line feed phase center of parabolic cylindrical reflector antenna, IEEE Transactions on Antennas and Propagation, AP-32, No. 6, 553-561, 1984.

[9] Röttger, J., U.G. Wannberg and A.P. van Eyken, The EISCAT Scientific Association and the EISCAT Svalbard Radar Project, J. Geomag. Geoelectr., **47**, 669-679, 1995.

[10] Wannberg, U.G. et al., The EISCAT Svalbard Radar, a case study in modern incoherent scatter radar system design, Radio Sci., **32**, 2283-2307, 1997.

[11] Wannberg, G., Vanhainen, L.-G., Westman, A., Breen, A. R., and Williams, P. J. S.: The new 1420 MHz dual-polarisation inter-planetary scintillation (IPS) facility at EISCAT, Proc. Union of Radio Scientists (URSI) 2002, 1144-1147, 2002

[12] Kildal, P.-S. and S.A. Skyttemyr, Dipole-disk antenna with beamforming ring, IEEE Trans. Antennas. Propagat., Vol. AP-30, No. 4, 529-534, 1982.

[13] Wannberg U. G. et al., EISCAT_3D - A next-generation European radar system for upper atmosphere and geospace research, Radio Science Bulletin, No 332, 75-88, 2010.

[14] Wannberg, G., A. Westman, J. Kero, C. Szasz, and A. Pellinen-Wannberg, The EISCAT meteor code, Ann. Geophys. 26, 2303-230li9, 2008.

[15] Pellinen-Wannberg, A. and G. Wannberg Meteor observations with the EISCAT UHF incoherent scatter radar, J. Geophys. Res. 99, 11397-1390, 1994.

[16] Wannberg, G., A. Westman, and A. Pellinen-Wannberg, Meteor head echo polarization at 930 MHz studied with the EISCAT UHF HPLA radar, Ann. Geophys. 29, 1197-1208, doi:10.5194/angeo-29-1197-2011, 2011.

Swedish Space Antenna Projects

Per Ingvarson
Retired, formerly RUAG Space AB
Mölndal, Sweden
per.b.ingvarson@gmail.com

Jan Zackrisson
RUAG Space AB
Göteborg, Sweden
jan.zackrisson@ruag.com

Abstract—**During the last 40 years, the space antenna group, first with LM Ericsson and now RUAG, produced a large variety of antennas delivered to most of the satellite prime contractors. This paper gives an overview of what has been achieved, and how it was achieved.**

Index Terms—space; antenna; history

I. BACKGROUND

At LM Ericsson's MI Division in Mölndal, the development of antennas for satellites started with the GEOS and ISEE-B projects in the beginning of the 70ies. The MI Division was created to develop radars for the Swedish defense, including advanced shaped reflectors for search and fire control radars. The strong theoretical rf competence paired with good material and manufacturing capability gave a good basis for antennas for space applications.

Space applications are demanding, especially for antennas which have to be mounted outside the spacecraft, due to:

- High-energy cosmic radiation, limiting the possible materials
- Low-energy charged particles giving electrostatic discharge
- UV-radiation destroying many materials
- Atomic oxygen, eroding any carbon-based material
- Vacuum or low pressure combined with high power giving risk for multipaction and corona
- Large ratio transmitted/received signals, giving problems with passive intermodulation for multichannel applications
- Very high cost for launch, giving extreme requirements on performance per mass unit
- No possibility to repair, giving extreme requirements on reliability

The space antenna group formed at Ericsson has remained, but with new names, new owners and a new location. LM Ericsson MI division became Ericsson Radio Systems and later Ericsson Radar Electronics. 1992 Saab Ericsson Space was formed, and later became Saab Space, RUAG Aerospace Sweden and now RUAG Space AB.

The first 25 years saw an increasing work and in the late 90ies we participated in a large number of planned projects, such as Teledesic and many for mobile communication. Most of these projects disappeared with the IT crisis and after year 2000 the market for space antennas has been relatively constant.

This paper will cover the main antenna work done at RUAG, but many studies, performed there or at other places will be omitted. Also only antennas used for communication, navigation, radar and radiometry will be included, not antennas doing direct measurements of the fields in space. There has also been some space antenna hardware activities in Sweden done by other entities, however this work is not described further here.

II. WIDE COVERAGE ANTENNAS

The first ESA satellites had low data rates, so that wide coverage antennas could be used. The first projects, GEOS and ISEE-B, used thin slotted waveguide arrays in S-band, Fig.2a. GEOS also had a VHF turnstile array. Later, it was clear that a standard antenna was needed, giving isotropic radiation. Two conical quadrifilar helices were selected and first delivered to Exosat. Further developments of this antenna type, protected by many patents, gave a variety of coverages and applications at L- S- C- and X-band, Fig. 1a-d. Overall, more than 250 flight helix antennas have been delivered. The helix arms are usually fed by a stripline network, but for X-bend they are fed directly from a waveguide.

For somewhat smaller coverages, the patch excited cup (PEC) antenna was developed. It has been and is being used for high performance GNSS applications, Fig. 2f. Low mass, metal-only design, and low back and crosspolar radiation makes them competitive, and they are also used for arrays, see below.

For higher frequencies, similar patterns are obtained with a family of pipe radiators (open-ended waveguides), Fig. 1e.

American customers often require toroidal patterns. Based on a slotted circular waveguide with flanges and an internal polariser, several antennas up to 30 GHz have been made, Fig. 2b-c. They have the special advantage of two redundant ports per band without switches or loss.

For Ku and Ka-band, a family of horns was developed, including corrugated, potter and rectangular types, Fig.2d-e.

III. REFLECTOR ANTENNAS

By the end of the 70ies, there was a large interest for direct-TV satellites. We studied shaped offset reflector antennas extensively in the Nordsat study and the ESA H-sat

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study. A novel astigmatic offset Cassegrain reflector concept was developed. Finally, the TELE-X satellite was realized with these antenna types and with a new patented rf sensing mode coupler for off-boresight tracking, Fig.3b. The reflectors were built in cooperation with Aerospatiale in Les Muraux, giving Ericsson an advanced CFRP technology. This was reused for the SOHO and the Columbus KBS Ka-band antennas, Fig. 3c.

The Swedish ODIN satellite, Fig. 3d, looking at interstellar clouds and limbsounding the earth's atmosphere used frequencies up to 575 GHz. An in-orbit accuracy better than 10 micrometers was required, and we developed a very stable technology, using CFRP honeycomb, invar inserts, superinvar moulds and extremely precise manufacturing. The rf design was done at Chalmers.

The ESA deep space probes ISPM, Fig. 3a, looking at the sun's poles, and GIOTTO, looking at Halley's comet, needed large reflector antennas. We did the rf design and testing, and design and manufacturing of the feeds. The latter were working at X- and S-band. For ISPM, we used a coaxial feed, with the S-band radiating from a coaxial line surrounding the offset X-band horn to achieve conical scanning. For GIOTTO, we used an array of crossed dipoles surrounding a potter horn. The deep space probe ROSETTA, now on its way to a comet, had a 2.2 m reflector, with a dichroic subreflector reflecting at X-band and transmitting at S-band, Fig. 4a. We were responsible for the complete antenna, and introduced cyanate ester in the reflector manufacturing, giving less water absorption and microcracking than epoxy.

For the Sirius 2 satellite, we developed a compact Gregorian reflector system. The support structure was a CFRP conical tower, and the reflectors used the cyanate ester technology from Rosetta and the ODIN technology for high accuracy. This gave the most accurate commercial reflectors on the market, and the thermal stability meant the thermal protection could be minimized. This concept was reused for several other satellites, such as Eutelsat W4, AMC9, Star One, AMC23, Fig. 4b. The feed systems included waveguide filters, OMTs and corrugated horns, all built for high performance, high power and low passive intermodulation.

Large X-band antennas were developed for the German SAR Lupe project. 5 antennas with 3.3 m x 2.7 m reflectors and with the feed on a deployable boom were delivered, Fig. 4d. An improved reflector concept, giving low mass, low cost and short delivery time while keeping high accuracy has recently been developed, and a 2.4 m x 2.6 m EM has been manufactured and tested, Fig. 5a.

The technology for extremely accurate reflectors where also used for the ASTRA 1K rf sensing antenna and for the Cryosat Siral antennas, Fig. 4c. The latter were used to measure ice thickness, and consisted of two antennas, forming an interferometer and an altimeter. The stability requirements were extreme, any small change from the qualification measurements would give an error. The antennas were centrefed Cassegrain antennas with invar feed assemblies, and they were mounted on a very stiff CFRP plate. A final example is the main data link antenna on the James Web Space Telescope (JWST), Fig. 5d, to be delivered but with the design already fully verified.

In a major development for ESA, a large (1m) dichroic subreflector was developed, transmitting 10.7-11.7 GHz and reflecting 12.5-12.75 GHz with low loss, Fig. 5b. The dichroic design software was obtained from Chalmers and the rf testing was done by FOA. Another dichroic subreflector for S and Ka-band for a planned data relay satellite (DRS) was manufactured and tested, but the DRS project was cancelled.

Dual grid reflectors are conventionally made by etching on dielectric surfaces. A novel patented design was recently developed by RUAG using CFRP vanes, Fig. 5c. It gives lower losses and much better thermal stability and power handling capability.

IV. ARRAY ANTENNAS

The first array antennas we built were the small TTC antennas for GEOS and ISEE-B, Fig. 2a. They were both thin waveguides slotted on both sides and giving toroidal patterns. In the preparations for the ERS-1 SAR satellite, advanced slotted array antenna designs were developed. With this new design capability, the 10m long antennas for ERS-1 and -2, Fig. 6a, were designed and rf tested, as well as the three scatterometer antennas on each satellite. Later, more scatterometer slotted arrays have been delivered, Fig. 6b. Several studies have resulted in novel designs for slotted waveguide arrays: dual and trippel beam antenna, Fig. 6d, compound slot antennas, two types of dual polarised antennas, Fig. 6c. All of these designs have been manufactured and successfully tested.

Mobile communication initially used single-beam antennas, but the increased demands on capacity and link budget required multibeams. An array covering the earth with a number of beams from geostationary orbit were developed in the 70ies and beginning 80ies in the ESA MAM project, Fig. 7a. Short backfire elements gave good performance. However, even smaller beams were required, and small arrays feeding a reflector and using our patch excited cup (PEC) technology were delivered to the Artemis and EMS satellites.

The requirements on passive intermodulation (PIM) were strict on Artemis, but for the ICO project, with high power and many channels, they were extreme. We developed our PEC elements to have no soldering or metal-to-metal connections, and with minimum amounts of dielectrics. More than 3000 S-band elements were delivered to Hughes (now Boeing), Fig. 7b. Similar L-band elements were delivered for Thuraya, and a dual polarised version to the MSV project, Fig. 7c, both array feeds for large unfurlable reflectors. Further developments were and are being made for ESA, including higher power and including diplexers, Fig. 7d.

The atmosphere can be monitored by measuring the time delay when the signal from a GPS satellite to a low-orbit satellite passes through the atmosphere. The GRAS instrument does this, and uses two arrays, one forward and one aft looking. Each array has 18 self-diplexing ring radiators, allowing separate beam forming networks for the 1.2 and 1.5 GHz bands. The structure is gold-plated CFRP, Fig. 8a.

Several microstrip array antennas have been developed in ESA studies, covering active and dual polarised patches. In one study, performed with IDS and EPFL, the dual polarised array consisted of two stretched skins (0.1mm), one with feed network, and one with the radiators, and just vacuum in between, Fig. 8b-c.

Multibeam antennas on satellites are normally made as reflector antennas with multiple feeds. With a single-feed-per-beam concept, four reflector antennas are needed to get sufficient overlap between the beams. Some improvements can be made by increasing the efficiency of the feed, as was done with the hard horn designed by Chalmers and manufactured by RUAG, and also by using dielectric superlayers, as was done in cooperation with TNO in an ESA study. More efficient, but also more complicated is to let each beam use several feeds. In the Multi KaRa study, performed together with Thales, RUAG designed and manufactured a small active feed array for this purpose, Fig. 8d. Ultimately, direct radiating arrays are expected to be used, but the problem is the very large number of elements required. Sparse arrays are therefore now investigated in a study by Chalmers, the Royal Technical University in Stockholm, Ericsson and RUAG.

Multibeam antennas for SAR applications are one-dimensional. An advanced concept with overlapping beams was developed together with Astrium in Friedrichshafen. This concept is still being further developed.

There is a need for continuous multichannel mm-wave radiometry from geostationary orbit. A reflector solution would be too large, therefore RUAG has studied a rotating Y-shaped sparse arrays. It would use active elements and requires an advanced data handling. A small 53 GHz demonstrator has been built and successfully tested, Fig. 8e.

V. POWER HANDLING

Multipaction is a major problem due to the high powers and the vacuum on satellites. The theory and testing are complicated. Our competence has been achieved through several master theses, through a close cooperation with Chalmers, and by participating in ESA/CNES study groups. Testing has been done in various places, also some preliminary at our own facilities.

Corona is another major problem, being more demanding at the critical pressures than multipaction, but only for antennas used during launch. Again, we have cooperated with Chalmers .

Passive intermodulation (PIM) is very problematic for combined Tx/Rx antennas due to the high output powers and the very low level received signal. At Ku-band we avoided metal to metal connections as far as possible and developed PIM-free flanges. Also at S- and L-band, the requirements were extreme. No metal to metal connection in areas with currents, minimized amounts of dielectric materials and non-touching coaxial connections gave very good performance. We also developed our own PIM test facility, quite demanding to build, Fig. 9e.

VI. RF TESTING

In the 70ies we used several outdoor ranges, Fig. 9a, one specially built for test of wide coverage antennas. For the ERS-1 10 m waveguide slotted array, an anechoic chamber with clean room standard and a large planar scanner was built, Fig. 6a. It gave very accurate reults. The same chamber was used for TELE-X and subsequent reflector antennas, Fig. 9b. It then used spherical near-field scanning with the probe moving on a circle, so that the test object only needed to rotate around one axis. This is very useful to avoid the influence of gravitational bending. After the move to the new Saab Ericsson Space buildings, a small indoor test chamber was built, Fig. 9c, and has since been used for most tests. Larger antennas have mainly been tested at the big Saab compact range, Fig. 9d, but also at ESTEC and at TUD in Denmark.

VII. DESIGN METHODS

The design methods have changed significantly during the 40 years covered here. At the beginning, computers were slow and the memory limited. The software used was therefore simplified. This had the advantage that the engineers had to understand the problem well enough to be able to make the correct simplifications. In any case, breadboarding was extensive. The software was essentially made inhouse. In the 80ies, TICRA became a major supplier of reflector software. A major slotted array software package, developed inhouse, was enhanced by several subroutines from Ph D students at Chalmers. From the 90ies, the commercial softwares became more powerful, and are today used in most of the design work. The importance of software lead to the development of a Swedish electromagnetic solver, GEMS, were we participated together with KTH, Saab and Ericsson. The extraordinary development of computers and software during the last 40 years is the most important change for the antenna design work.

Due to the high cost of space equipment, it has to be highly optimized. We must use the most efficient designs. This is best obtained with close cooperation with leading industries and universities, and by keeping close contacts with the research community. Being part of Ericsson gave us insight into defense and telecommunication developments, and this cooperation has continued until this time, although the former LM Ericsson MI division is now three different companies. During the 80ies, we had close cooperation with FOA, Chalmers, Dornier in Friedrichshafen, Aerospatiale in Cannes and ThomsonCSF/Alcatel in Toulouse. From the 90ies, also Hughes in LA, TICRA, TNO, IDS, EPFL, California State University and Lund University can be mentioned as major partners. ESTEC in Noordwijk has of course been of major importance from the beginning.

By visiting and presenting papers at the major conferences, we had a good network in the academic world. When the European ACE (Antenna Centre of Excellence) network of excellence was formed 2004, Saab Ericsson Space was voted as one of the top antenna places in Europe, and we had a strong involvement including the technical coordination of the network. All this gave us connections to the best people for various antenna problems, and trust in our capabilities.

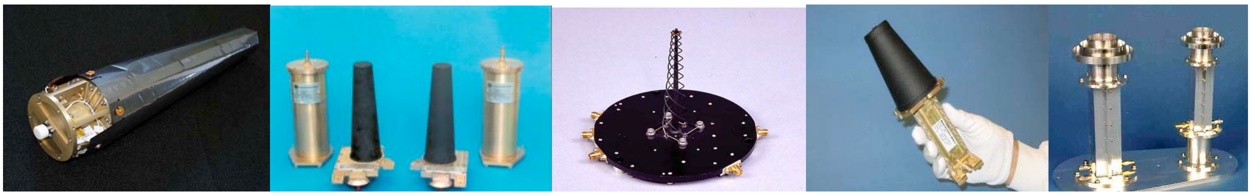

Figure 1. a-d) Quadrifilar helix antennas for L-, S-, C-, and X-band resp, e) Fill-in waveguide radiators

Figure 2. a-c) Toroidal pattern antennas, d-e) Ku-band horns, f) PECs for Sentinel

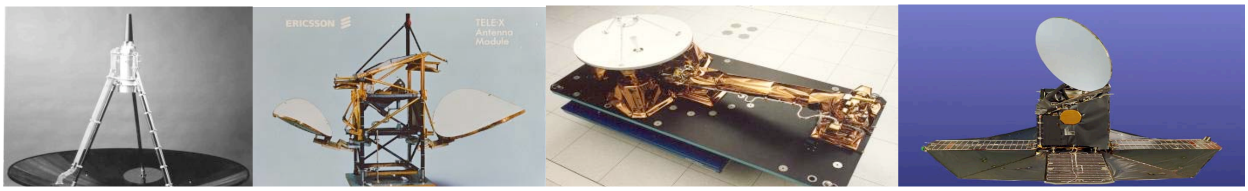

Figure 3. a) ISPM deep space probe antenna, b) TELE-X antenna tower, c) Columbus Ka-band antenna, d) ODIN satellite

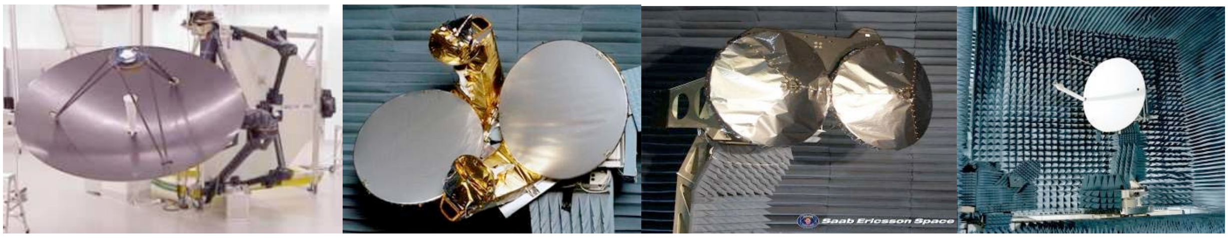

Figure 4. a) Rosetta dicroic antenna, b) AMC23 antenna pair, c) SIRAL interferometer with SLI, d) SAR Lupe SAR antenna

Figure 5. a) Technology demonstrator reflector, b) Large dichroic subreflector, c) Stable dual grid reflector, d) JWST Ka-band antenna

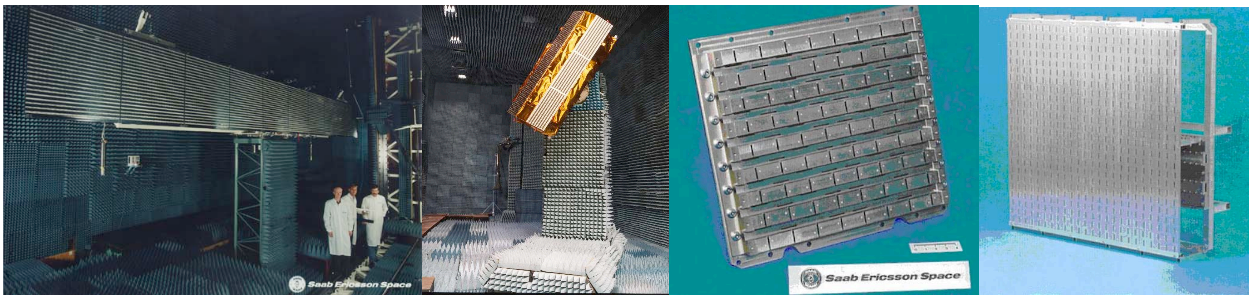

Figure 6. a) ERS-1 slotted waveguide array antenna at planar scanner, b) A-scatt antennas in the test range, c) dual polarised slotted array antenna, d) dual beam slotted array antenna

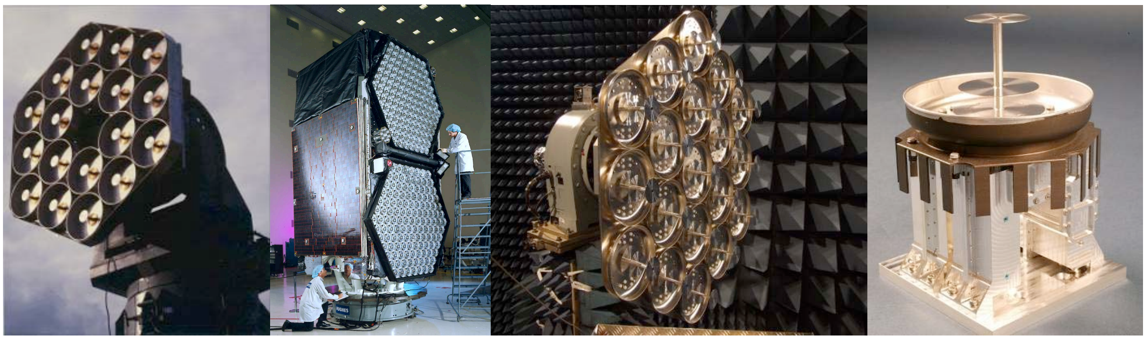

Figure 7. a) MAM array antenna on outdoor test range, b) ICO S-band array, c) MSV dual frequency array, d) S-band PEC with diplexer

Figure 8. a) GRAS antennas, b-c) antenna and feed etched on “drum-skins”, d) Multikara feed array, e) GAS mm-wave radiometer

Figure 9. a) Large outdoor range (closed), b) Large anechoic chamber (closed), c) RUAG small indoor range, d) Saab large compact range, e) PIM test facility

Radar Antenna R&D in Sweden

Lars Josefsson
Lars Microwave, Askim, Sweden
lars.josefsson@ieee.org

Abstract—The development of antenna technology for Swedish radar systems is presented. The period covered is more than 60 years, starting at the end of World War II. The presentation is no doubt **influenced by the author's personal view of the major** achievements in this field, with examples taken mostly from Ericsson projects.

I. THE START

Already in 1939 radar experiments were under way in Sweden. During the war Ericsson developed radar equipment ("echo radio") for the Swedish Navy (with moderate success). After the war radar units were bought from France, Great Britain, Germany and other countries. Later Ericsson got contracts for license production of search and fire control radars for the Swedish Army. Ericsson was also involved in licence production of radar systems for the Swedish Lansen aircraft (J 32B), based on designs by CSF in France[1,2].

II. THE J 35 DRAGON FIGHTER AIRCRAFT

The first J 35A version was equipped with a radar from CSF (Compagnie Generale de Telegraphie sans Fil) in France, designated PS-02. The first all-Swedish airborne radar PS-03/A was developed by Ericsson for versions J35 B and D, cf. Fig. 1. This antenna had a parabolic reflector front fed by a rotating circular waveguide feed (conical scan). The antenna platform had 3 axes for steering and stabilizing the antenna beam.

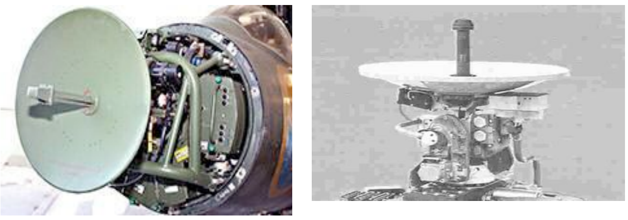

Figure 1. (left) The PS-02 radar, (right) the PS-03/A antenna.

As the military threat changed from targets at high altitudes to low flying aircraft the radar had difficulties detecting targets against the strong ground echoes which entered in the antenna wide angle sidelobes. A new antenna, Fig. 2, was needed in the more advanced radar PS-01/A for the J 35 F version. With the Cassegrain antenna the wide angle sidelobes were drastically reduced compared to the previous antenna in PS-03/A. The radiation performance is excellent over more than 10 % bandwidth. The antenna is compact and has a low weight.

From the middle of the 1960s, different sized twist Cassegrain antennas were developed, from 43 cm diameter to 140 cm diameter. They were used in anti-aircraft fire control systems as well as in airborne radar systems.

Fig. 2. The PS-01/A Cassegrain antenna.

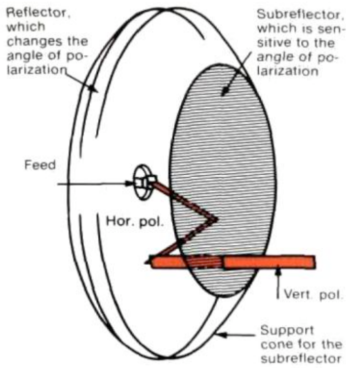

Fig. 3. The principle for the polarization twisting.

III. MORE ABOUT TWIST CASSEGRAIN ANTENNAS

The principle for the twist Cassegrain antenna was patented in 1952 by C. A. Cochrane at Elliott Brothers in Great Britain. As seen in Fig. 3 the antenna has a polarization sensitive, relatively large subreflector and a polarization twisting main reflector. The feed is a small forward radiating horn causing minimum blocking of the aperture.

The (parabolic) main reflector consists of a wire grid layer spaced one quarter of a wavelength in front of a solid metal reflector. The wires in the grid layer are oriented 45 degrees relative to the vertical direction, while the subreflector wires are horizontal. Thus, the field reflected from the subreflector (with horizontal wires) can be decomposed into two components: one parallel to the main reflector grid and one perpendicular to the grid. Both components are reflected in the main reflector but with 180 degrees phase difference. When combined the total field has been rotated 90 degrees and hence changed to vertical polarization, passing unobstructed through the subreflector grid.

This is the basic operation of the twisting mechanism, some variations exist. In the basic configuration the function is good over 10-15 % bandwidth. More bandwidth can be obtained with multiple grids [3].

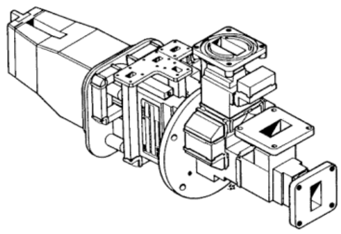

Figure. 4. The monopulse feed for a twist Cassegrain antenna covering both X- and Ka bands.

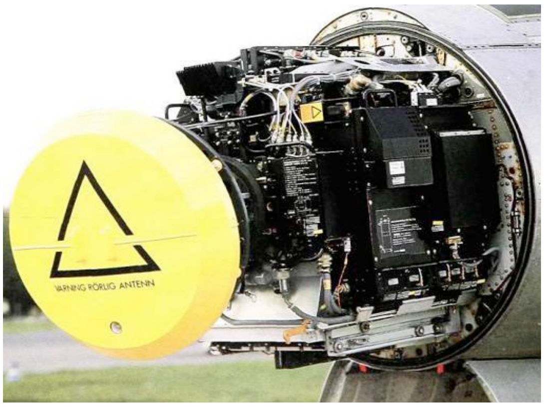

Figure 5. The PS-46/A doppler radar in the JA 37 Viggen aircraft.

A twist Cassegrain antenna was also chosen for the Swedish fighter JA 37 Viggen, Fig. 5. High mechanical stability and low sidelobes were critical for this Doppler radar, PS-46/A. The illumination function of the dual mode monopulse feed was optimized with excellent results in both sum and difference channels. As shown in the Fig. there are also two dipoles feeding the reflector (for the IFF function) and a small waveguide horn antenna.

A flat plate waveguide slotted array antenna could have been seen as an alternative to the Cassegrain antenna in PS-46/A. However, in terms of bandwidth and radiation pattern performance the optimized Cassegrain antenna was the better choice. (There are even thin absorbing sheets inserted in the conical sections in order to eliminate the feed spillover in the wide angle region.)

Fig. 6 shows the search and track antennas of the Skyguard anti-aircraft defence system developed for Contraves. Note the IFF dipole array integrated with the search antenna. The tracking antenna is a monopulse 1 m diameter twist Cassegrain antenna.

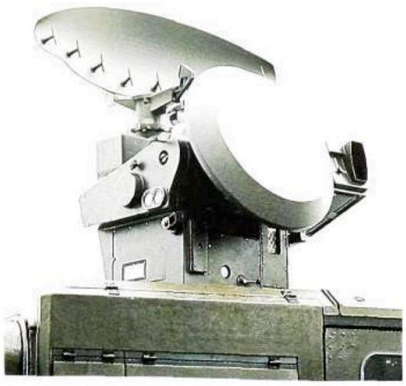

Figure 6. Search and track antennas for the Skyguard system.

IV. Phased Array R&D in the 1970's

A. *The ESA project*

In 1968 Ericsson and Chalmers (the latter with support from Ericsson) embarked on a joint four year R&D program in the field of phased array antennas: ESA = Electronically Scanned Antennas. The results of this effort included several doctor degrees at CTH, an experimental X-band ESA with search and track capability (up to 4 simultaneous targets), lots of microwave hardware, and of course very valuable knowledge for both parties [4].

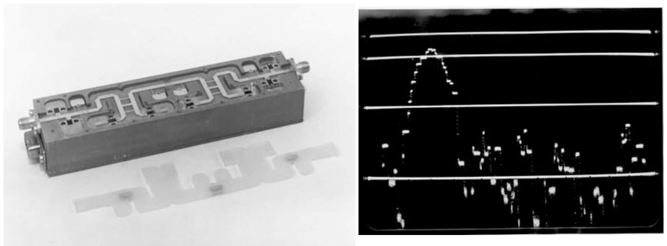

Figure 7. ESA project, (left) X-band 4 bit diode phase shifter, (right) dynamic scanned antenna pattern.

B. *Multilayer stripline array antenna*

Another early array project in the 1970's was the development of a monopulse flat plate array antenna with independent sum and difference antenna patterns [5]. The application in mind was a missile seeker antenna. The optimum sum and difference aperture excitations were realized with a multilayer stripline design, Fig. 8.

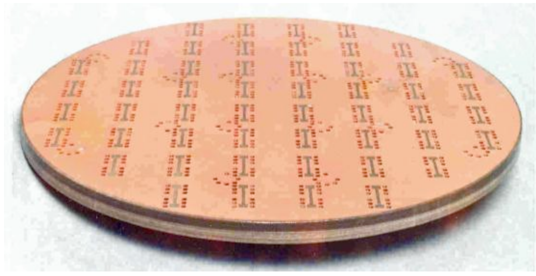

Figure 8. The three-layer monopulse stripline array antenna.

C. *CESAM - An experimental broadband phased array antenna*

This study demonstrated the capability of beam steering ± 60 degrees over 40 % bandwidth (7-11 GHz) with circular polarization [6]. Compared to conventional broad beam antennas the design demonstrated a high PG product as required in electronic warfare applications.

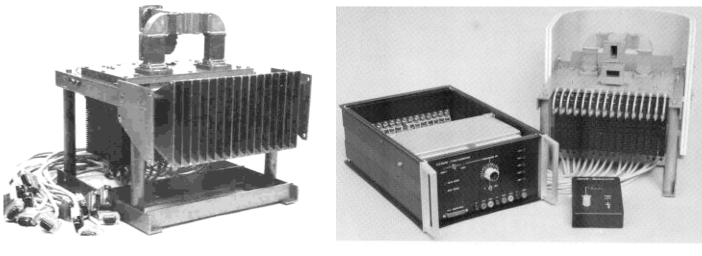

Figure 9. (left):The CESAM phased array with ferrite phase shifters, (right): with steering unit and wire grid polarizer mounted.

V. HARD

In the 1980's a mobile short range 3D air defence search radar was introduced. It was named HARD for Helicopter and Airplane Radio Detection, Fig. 10.

Figure 10. (left The rotating radar unit. (right) Waveguide array with radome removed.

The HARD antenna is phased scanned in elevation. Each horizontal row of waveguide slots is connected to a solid state transmit/receive module. In order to minimize the beam squint over the frequency band the waveguides are fed in the center with different slot spacings in the two halves [7]. The waveguide array in Fig. 10 is made in metallized CFRP.

It is obvious that the antenna function in the HARD radar is not realized by an antenna separate from the rest of the radar, but is rather integrated into the system, Fig. 11. This is typical at this time in many advanced radar applications.

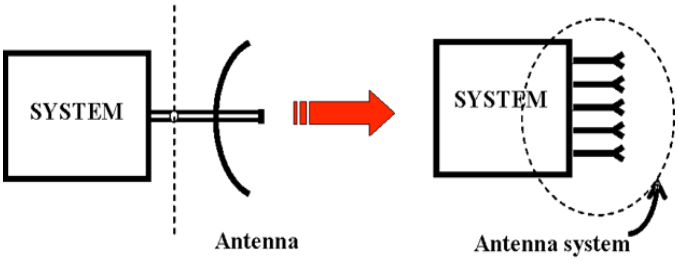

Figure 11. The paradigm shift: the antenna is integrated in the overall system.

VI. GIRAFFE AMB

The Giraffe search radar had in its first versions a rotating reflector antenna. The more advanced recent units have multiple beams phased steered in elevation while still rotating in azimuth.

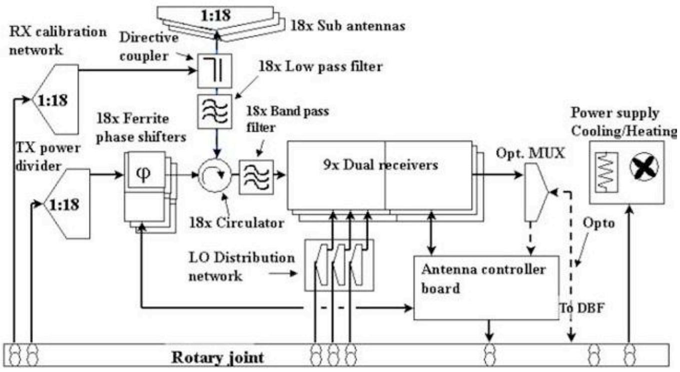

Figure 12. The Giraffe AMB *antenna* (!).

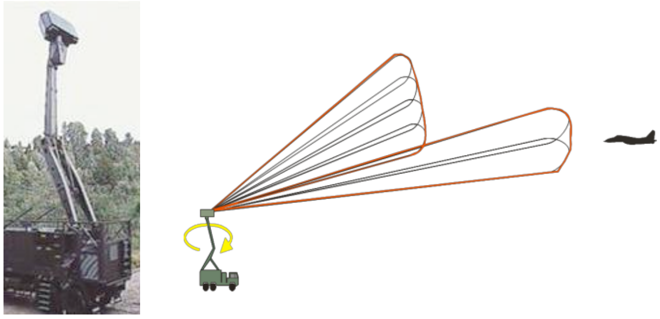

Figure 13. (left) Giraffe AMB, (right) flexible search patterns.

As seen in Fig. 12 the Giraffe AMB (Agile Multi Beam) has two separate beam forming systems. The received signals for each row in the aperture are digitized and sent to a digital beamforming unit in the main radar cabinet. The transmitted signals are phased steered by ferrite phase shifters.

VII. ERIEYE – THE SWEDISH AIRBORNE EARLY WARNING SYSTEM

Ground based long range radars installed in masts have limited coverage due to the curvature of the earth. Furthermore, they are vulnerable and have limited, if any mobility. The advantage of airborne solutions is apparent and several studies had been undertaken in this area since the 1960's.

The system finally arrived at was an S-band active phased array antenna mounted on a small turboprop aircraft, Figs. 14-16.

Figure 14. The ERIEYE radar mounted on a Saab 340 turboprop aircraft.

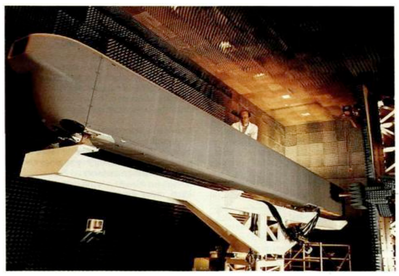

Fig. 15. The ERIEYE phased array during near field testing in an anechoic chamber.

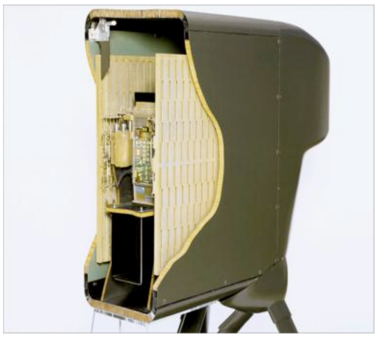

Fig. 16. Cross section of the ERIEYE dorsal unit.

The dorsal unit has two 8 meter long slotted waveguide arrays, one on each side, Fig. 16. There are about 200 solid state transmit/receive modules. The unit is air-cooled. To compensate for temperature variations a built-in calibration system is used. Very low sidelobes in azimuth are achieved by a Taylor weighting on receive.

Following successful tests of a functional model 6 AEW systems were ordered by the Swedish FMV in 1993. Today the system is operational in many countries.

VIII. THE ARTHUR PHASED ARRAY ANTENNA

ARTHUR stands for Artillery Hunting Radar. By electronic steering of the beam both in azimuth and elevation it can detect projectiles before impact and calculate the launch site with high accuracy. Phase shifters are used for azimuth steering of the beam and in elevation the beam is steered by frequency variation.

In ARTHUR, as well as in HARD and ERIEYE, slotted ridge waveguides are used in order to achieve a large scan sector. In ARTHUR the vertical aperture waveguides are more than 2 m long which means that the longitudinal slot radiators are displaced very little from the waveguide center line. The manufacturing tolerances are therefore stringent. The detailed design was based on high accuracy slot measurements combined with theoretical slot models [8].

Fig. 17. The ARTHUR phased array antenna.

IX. AESA – ACTIVE ELECTRONICALLY SCANNED ANTENNA

For the next generation multi-role airborne radars studies were intensified in the 1990's. In 1996 a testbed with about 100 active transmit/receive elements had been developed [9], Fig. 18.

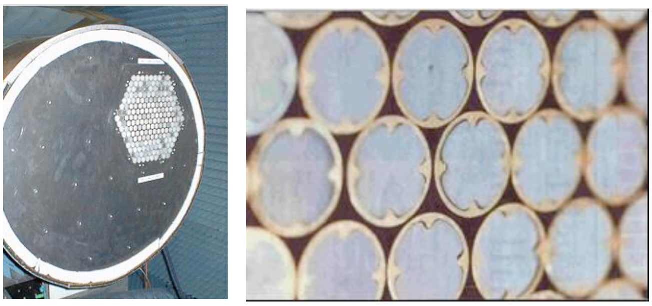

Figure 18. (left) AESA testbed, (right) dual polarized dielectric loaded radiating elements.

The development of a full-scale operational AESA system is a major undertaking. For the continued work foreign partners have been sought in order to share the development costs. A joint Swedish–Italian program called M-AESA has started, aiming at technologies with multifunctional capabilities [10]. One recent Ericsson contribution in this field is the Generic AESA Demonstrator program – GENA. An S-band hardware test bed is shown in Fig.19.

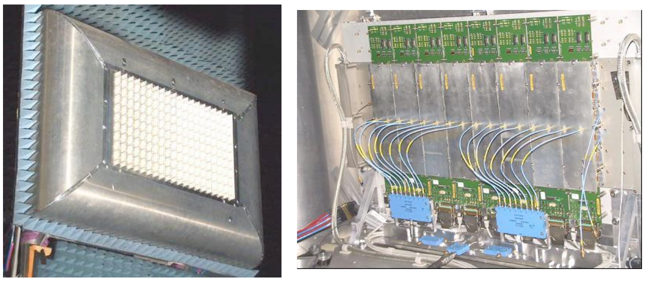

Figure 19. The Gena S–band demonstrator with 96 active elements, out of total 200. Front and rear views.

With international collaboration Saab is now able to offer AESA solutions in future JAS Gripen aircraft, Fig. 20. It could be of some interest to compare this approach with a proposed AESA from 1981, Fig. 21.

Figure 20. AESA radar for Gripen (Saab AB).

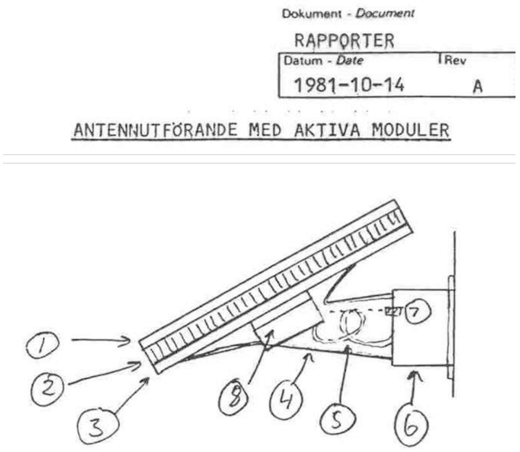

Figure 21. A 1981 proposal. The numbers indicate:

1. Radiating elements
2. TR modules
3. Power divider
4. Composite structure
5. Signal cable
6. Turntable (roll)
7. Optical channel
8. Power unit

X. THE FUTURE

Radar antennas that conform to the shape of an aircraft or other vehicle, *conformal antennas*, might seem as the ultimate future solution. However, it will require advances in areas such as: electromagnetic modelling, system design, building technology, and signal processing. Research on conformal antennas in Sweden started some 30 years ago and many interesting results have been reported [11, 12], Fig. 22.

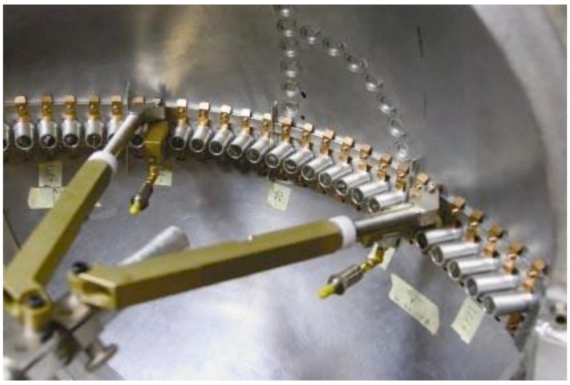

Figure 22. Measurements on a convex array (inside).

XI. REMARKS.

Ericsson's main business has traditionally been telecommunication. The radar unit in Mölndal, initially devoted to airborne radar, provided the basis for an expansion into other applications. As a result we have seen the growth of ground based and naval radar systems. Antennas and systems were also developed for weather radar and satellites, and soon microwave relay links became an important area [14]. The technical spinoff between these activities has contributed greatly to the proficiency and knowhow of the Ericsson Antenna Department, and to the results obtained.

From the start KFF, later FMV (The Swedish Defence Material Administration), took active part also in the technical development of radar systems, incl. antennas, especially during the first 10-20 years of the Swedish radar history. Another important contributor has been FOI (Swedish Defence Research Agency). Collaboration between Ericsson and other companies as well as several technical universities should also be remembered.

REFERENCES

[1] J. Meurling and R Jeans, The Ericsson Chronicle, Informationsförlaget, Stockholm, 2000, pp. 251-257.

[2] J. Gribbe, ed., "Early airborne radar", TRITA/HST 2008/13, History of Science and Technology, KTH, Stockholm.

[3] L. Josefsson, "Cassegrain radar antennas with broadband and multiband performance", Proc. IEEE Natl. Radar Conf., March 12-13 1986, pp. 115-119.

[4] L. Josefsson, "Radiation performance of an experimental phased array", Proc. Europ. Microw. Conf. Aug. 23-28 1971, pp. B2/2:1-4.

[5] L. Josefsson, L. Moeschlin, and V. Sohtell, "A monopulse flat plate antenna for missile seeker", Proc. Mil. Electr. Defence Expo, Wiesbaden Sept. 1977.

[6] L. Josefsson, " Designing a broadband phased array antenna suitable for use in ECM systems", Defense Electronics, Feb. 1980, pp. 85-88.

[7] E. R. Karlsson, "Waveguide element for an electrically controlled radar antenna", U S Pat. 4788552 (1988).

[8] A. Derneryd and T. Lorentzon, "Design of a phase/frequency scanned array antenna with non-resonant slotted ridge waveguide elements", Proc. IEEE AP-S Symp. 1991, pp. 1728-1731.

[9] L. Josefsson, L. Erhage, and C. Vaktnäs, "An AESA development model for next generation fighter aircraft radar", Proc. IEEE Int. Symp. Phased array systems and technology, Boston 15-18 Oct. 1996. pp. 454-457.

[10] A. Wennberg, "Se, snacka och stör med samma antenn", Elektroniktidningen, 13 Dec. 2012.

[11] V. Sohtell, Microwave antennas on cylindrical structures, Ph. D. thesis, Chalmers University of Technology, Sept 1987.

[12] L. Josefsson and P. Persson, Conformal Array Antenna Theory and Design, IEEE/Wiley 2006.

[13] O. Dahlsjö, "Antenna research and development at Ericsson", IEEE Ant. Prop. Mag., April 1992, pp. 7-17.

The Story of Allgon: HF, VHF, Cellular and Microwave Antennas During Allmost 60 Years

Claes Beckman
Center for Wireless Systems, Wireless@KTH
KTH Royal Institute of Technology
164 40 Kista, Sweden
E-mail: claesb@kth.se

Bo Karlsson
CellMax Technologies AB
Gullfossgatan 3A
164 40 Kista Sweden
E-mail: bossebkas@gmail.com

***Abstract*— Allgon, "The Antenna Specialist", was a leading international design house and manufacturer of antennas for almost 60 years. The company was started in Stockholm in 1947 under the name of "Antennspecialisten", by the Swedish engineer Torbjörn Cramner and his wife Veronica. In 1951 the company moved to Åkersberga north of Stockholm where its main facilities where located until the late 90's. During its life time the company designed and produced antennas for HF, VHF, Cellular and Microwave frequency bands, and for military, emergency, private and cellular radio systems. The company was in 2004 acquired by the US based company Powerwave but still today many of its original antenna designs are in production and many thousands of its base station antennas for mobile networks are still deployed all around the World**

Index Terms*— Allgon HF, VHF, Cellular, Microwaves Antennas

I. HISTORIC OVERVIEW

The story of Allgon begins in 1947 when the Swedish antenna engineer Torbjörn Cramner and his Hungarian born wife Veronica, founds the company "Antennspecialisten" at Idungatan in the center of Stockholm [1]. The product portfolio is focused on antennas for "private radio" (citizen bands) and FM radio antennas for cars. In 1951 the company moved to Åkersberga, a small city some 50 km North of Stockholm where its main facilities where located until the late 90's.

In the late 1960s, the Cramner couple decided to go separate ways which led to a split of the company. Torbjörn continued one part including HF antennas etc. and also continuing the brand name Allgon. Veronica named her part Carant (short for "car antenna") which also reflected the company's product portfolio

Carant was very succesfull in its field and in the year 2000, acquired by Smarteq, a company then focusing on hands free products. At the same time, Smarteq also acquired the car antenna and application division of Allgon, which actually led to that two parts of Allgon that had been separated for some 30 years, finally came together again. Today Smarteq develops a number of antennas for vehicles, some of them produced in Hungary by a company named Carant! The final remains after the Hungarian antenna entrepreneur Veronica Cramner

In 1974 Allgon went bankrupt. The main reason for this economical failure was the enormous effort put into the development of HF log–periodic antennas (see Fig. 3) used for diplomatic communications at a time when there were no communication satellites available. These antennas, with a length of over 25m and a weight sometimes exceeding several tons, were produced in Norberg, in the county of Västmanland, some 200km from Åkersberga where they were designed. The development and production of these grandiose HF antennas was a big economical gamble for the company which eventually caused its bankruptcy. However, several of these magnificent antennas are still in use today and can be found even on the internet [2]

The company was then instead aquired by Hjalmar and Jonas Kämpe and renamed Allgon Antenna AB (Allgon AB). The company under its new leadership maintained the car and CB radio antenna products but during the 1970's they also initiated a new product area: antennas for the Swedish defense.

During the "cold war" the Swedish defense industry grew strong with Bofors, Saab, Philips, Ericsson and many small national sub-contractors all benefitting from Sweden's policy of staying neutral and hence needing to build its defense using mainly domestic equipment suppliers. Allgon then developed antenna products for all military branches: Navy, Army (see Fig. 4) and Air force.

In 1980 the NMT 450MHz analog mobile phone system was introduced in the Nordic countries. At the beginning Allgon lacked base station products for this system but did produce car mounted antennas for the terminals. Soon a system version for the 900MHz band was introduced and then Allgon was prepared with product for both base stations as well as handhelds.

In 1989 the company was listed on the Stockholm stock exchange and in the wake of the exponential growth in the cellular industry, the company grew enormously during the 1990's. The company was during this period divided into 3 separate business areas with focus on: 1) antennas and near antenna products for mobile systems, 2) terminals and 3) cars. Its main facility was still in Åkersberga but for the system products division, design and production had moved to the Stockholm suburb Täby. Also, a repeater design group was set up in Solna and microwave link development was set up in Gothenburg.

On the base station antenna side, the main developments during the mid 90's were to include dual polarizations for diversity (which dramatically reduced the size of base station antenna installations, Fig. 5), and dual bands for combined operations of the two 2G bands (the GSM 1800 band become available after 1997). Later the dual band antenna products were extended to also include several GSM and 3G bands for networks all around the World

On the terminal side the antenna development was also rapid during the 90's. With the introduction of the pocket size mobile phone there was also a need for smaller, but still well-functioning terminal antennas. Allgon solved this issue by inventing the extractable terminal antenna which combined an extractable quarter wave antenna with a helix at its bottom. At the end of the millennium Allgon produced around 100 million terminal antennas per year.

At the beginning of the third millennium, Allgon was probably the world's second or third largest antenna company. It had a market cap exceeding three billion Swedish krona but since the Kämpe family had sold off their share in the late 90-ties, it became an easy victim for bankers with greater interests in mergers and acquisitions than antennas

In 2002 the terminal antenna division was sold off to US based company Centurion. The remaining part of Allgon was first merged together with LGP Telecom before it in 2004 was sold to the US based RF sub-supplier Powerwave. In 2005, one year after the acquisition, the brand name Allgon was gone and most of Allgon's former employees had left the company.

The story of Allgon could as well have ended here. But it didn't! Today the Kämpe family runs a new antenna business: CellMax. The company designs high gain base station antennas for 3G and 4G networks, and produces them at Allgon's former subcontractor, Gelab (Gäddede Elektronik AB), in the north of Sweden. The car and vehicular antennas are continued within Smarteq. The repeater part is still active within DeltaNode

Allgon was throughout its life time a world leading design house for antennas. But it was also an environment filled with entrepreneurial spirit. The Allgon spirt continues to live on and so do also many thousands of its products, e.g. the base station antennas for mobile networks that are still deployed and in full use all around the World!

Figure 1. The Allgon logotype, illustrating the flexibleantenna mount

II. HF, VHF, CELLULAR AND MICROWAVE ANTENNAS

Below follows illustrations of some of Allgon's more memorable antenna designs

A. Car mounted FM antennas

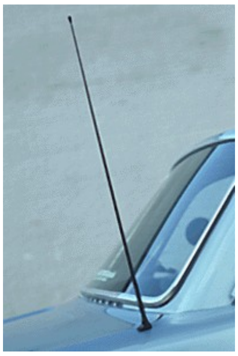

Figure 2. Allgon Car mounted whip antennas for FM radio. The brand name Allgopn originally comes from the nam of a car antenna mount that coiuld be pointed at all angles: "all-gon".

B. The Allgon Log Periodic Dipole Antenna

Figure 3. An Allgon LPD16 antenna during its dismounting in Switserland. The Allgon LPD 16 K was a steerable log-periodic antenna for communication over medium and long distances in the HF range. It was designed for transmitters up to 250kW per carrier and 100% AM modulation over the entire frequency range 6-30MHz. The boom was tillable allowing for beam shaping to optimize the communication.

C. HF military broadband antennas

Figure 4. The reflection free directional broadband antenna RFD707. The reflection free directional broadband antenna RFD707, was a lightweight HF antenna for military field operations. Similar products are still in use by armies all over the world today. Since it was a thin wire antenna, it was internally at Allgon referred to as the "Hallén- antenna" (referring to the great Swedish antenna professor [3]).

D. Cellular base station antennas

Figure 5. Base station antennas for GSM: a) in a space diversity configuration b) using polarization diversity which dramatically reduced the space and windload for the same performance

E. Terminal antennas

Figure 6. The evolution of Allgon's terminal antenna designs: a) is a extractable λ/4 wave antenna with a bottom helix, b) is a short helix and c) is an inbuildt PIFA (Planar Inverted F Antenna), not seen.

ACKNOWLEDGMENT

This paper is dedicated to all the fantastic people that contributed with their skills and personalities to the creation of one of history's greatest antenna companies. In particular we would like to mention: Torbjörn and Veronica Cramner, Hjalmar and Jonas Kämpe, Erland Cassel and Ulf Saldell,

REFERENCES

[1] Österåkers hembygds- och fornminnesförening. http://milstolpen.org/agaria.html

[2] http://ref.awr.org/ForSale/Allgon.htm

[3] Carl-Henrik Walde, and Gunnar Petersson, "Erik Hallén and His Integral Equation, Swedish Defence Activities, the ANTENN Conferences, Stealth Craft Smyge.". Swedish Antenna Veterans' Day at EuCAP 2013, Thursday 11th April 2013

The Industrial Story of the Hat-Fed Reflector Antenna for Global Microwave-Link Market

The 25 Years From Invention Via Comhat to Mass Production in Arkivator

Tomas Östling
Arkivator AB
Gothenburg, Sweden
tomas.ostling@arkivator.com

***Abstract*—This paper tells the history and development of the hat-fed reflector antenna from invention to a large industrial business. Today Arkivator is among the largest reflector antenna manufactures for microwave point to point links in the world, - with a capacity to produce over 200 000 antennas per year.**

***Index Terms*—hat antenna, reflector antenna**

I. The Invention

Professor Per-Simon Kildals invented the hat antenna back in 1986 [1]. Then, he had already worked with designing primary feeds for reflectors (he invented the dipole-disk feed with ring [2] in 1984 that was in production in a Norwegian company for 10 years). He had then also become interested in characterizing feeds for improved aperture efficiency of the reflector. This resulted in definitions of sub-efficiencies [3] that later were extensively used when designing hat feeds.

The hat feed is actually a result of a theoretical formulation of the radiation from the line feeds of the radio telescope in Arecibo in 1986 [4]. This work was done as a preparation for designing a new Gregorian subreflector system for the famous radio telescope, which was finally built and tested and reported in 1994 [5]. From the theoretical formulation of the line feeds he realized that one of the elements in the line feed could be used as a self-supported backwards-radiating waveguide feed for a ring-focus paraboloid, if he used a corrugated “hat” at the end of the open waveguide. The basic idea of using corrugations came because he during the same years worked with corrugated horn feeds, and he generalized and extended the corrugated surface to a concept of soft and hard surfaces [6], now regarded as the first metamaterials concept. He studied also the use of corrugations to improve radiation along the outer side of the waveguide [7]. In the end the first hat feed was published only with circular corrugations in the hat (not along the outer side of the waveguide), and this is how it looks also today. The first published feed had very narrow bandwidth [8], and couldn’t be used at all, but time-consuming experimental adjustments of the geometry gave after some years, good radiation pattern together with low x-polar performance and return loss. The first antennas were used in a military radio link [9] and was later also developed for satellite-TV reception, but these applications were not successful in the market.

Figure 1. 0.3m and 0.6m antennas

In the beginning of the 90s Ericsson got interested in the invention and investigated it on a Master project [10]. The development of computers and numerical methods had then come so far that the tuning now could be done by EM-simulations, which is much more efficient. During the next years several improvements and developments were done and patent-protected [11], such as definition of ring-shaped phase centers [12], studies of scattering from screw heads [13], and developments of special versions of it, see the PhD thesis of Jian Yang [14].

II. Start-up Company

The story of COMHAT (COMmunication by HAT antenna technology) started at a Swedish antenna conference held in Gothenburg 1997 (Antenn-97). Entrepreneur Bengt Gustavsson, that recently had been selling reflector antennas from Precision Antennas to the Nordic market, was looking for new businesses. Professor Per-Simon Kildal had worked with Ericsson and they had decided to use the hat antenna in the new

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generation Point-to-Point reflector antennas for Mini-Link® microwave radio. It gave the idea to start a company around the invention a proof-of-concept. The business idea was to market, develop and manufacture hat antennas to the global microwave backhaul/radio link industry. At this time the backhaul business included European companies such as Alcatel, Ericsson, Nokia, Sagem, Siemens; North Americans such as Stratex, Harris and Japanese NEC. In Sweden, especially in Gothenburg area, there was also a couple of smaller microwave companies/start-ups. Also among the prospected customer were the national telecom companies and new mobile telephone companies. The potential market growth was in the foreseen rising demand for mobile telephone and the launch of new 3G networks.

The name of the company was decided during a road trip to presumable suppliers. Professor Kildal wanted the name to describe the technique, the hat antenna, and Gustavsson combined it with communication = ComHat.

A period started to write a business plan, to find investors and some small scale design activity in Gustavssons home. In 1999, the first investment was established and a new office and personal were hired. In spring 2000, the first contract was celebrated; 100pcs 1.2m antennas to Gothenburg company Viking Microwave. The pace rises in the company, both electrical and mechanical design was made for 4 sizes; 0.2, 0.3, 0.6 and 1.2m antennas. The market activities were also intensified with a number of road shows, to European Microwave Week and CeBit several times. New customers came: A2B, Transtema, TimeSpaceRadio, SAF Tehnika, Sagem, Netro.

III. Antenna Industry

In May 2002 an important step was taken for Comhat: It merged with subcontractor manufacture Provexa. Provexa was producing reflector antennas for Ericsson's MiniLink® and suddenly Comhat had the no1 radio link manufacture among its customers. One of Provexas owners was Anders Hultmark, an entrepreneur and industrialist that has been involved since then and still owns the company. The match between the two companies was obvious, Comhat had the R&D and a product, Provexa had a large production capacity. Soon the whole company was situated in Ödsmål, north of Gothenburg. The R&D activities were focused on expanding the product portfolio, more frequencies were added and new customer adapted interfaces were designed.

IV. Microwave Company

In 2004 was Lyscom incorporated in the business. Lyscom was a hardware manufacture for the microwave industry. It had successfully introduced tuning-free E-plane microwave filter to the radio link market. Among the customers were Allgon Microwave and Ericsson. 2005 was the antenna and microwave business separated from the surface treatment business that, meanwhile, also had grown bigger. Comhat and Provexa were now two separate companies again. Comhat was concentrating in providing filter, couplers, antennas and measurement systems to customers all over the world. The slogan was "Comhat – Connecting Radios". New customers were Allgon Microwave for the antennas, SR Telecom and Ceragon. A very successful Master thesis was made during this time. Master student Martin Denstedt managed to increase the bandwidth almost by a factor 3 to more than 30% by numerical optimization of the geometry of the feed itself [15]. He was awarded the Swedish "Lilla Polhemspriset" for the best Master thesis in Sweden that year.

V. Arkivator Telecom

In 2007 Arkivator acquired Comhat. One of the reasons was the need of consolidation in the microwave filter business. A lager volume in the filter business, gave Arkivator possibility to meet customers' requirement in cost reduction. Now the antenna and filter products were a part of a bigger company, giving access to a large and efficient production facility. Very soon the manufacturing was moved to the main factory in Falköping. A demand for a new size of antennas was growing among the customers, 0.9m antennas. Arkivator decided to develop a new antenna where the cost of the product should have the main focus from the start of the project. Because of the great performance of the antenna, to a moderate cost, the 0.9m antenna has been well received by the customers. Shortly afterwards Arkivator also developed E-band antennas in the sizes 0.2, 0.3 and 0.6m. The interest for these antennas is growing bigger but Arkivator is still waiting for the volumes to develop in the same way it has done for the lower frequency bands. Maybe 2013 is the year when E-band will go from talk to walk.

A. Next Generation Hat Antennas

The story of the hat antenna shows how long time it can take from invention to industry. For the hat feed it took 15 years. Today, after being producing the hat antenna for about 12 years, Arkivator has started to sell and manufacture the next generation hat antennas. The antenna program is going through a complete re-design. The reason is that the whole telecom industry has experience a tremendous change. The map has change, new customers have come and several have left, some new competitors have entered the scene but more have disappeared. Fig. 2 shows not only the success of the hat antenna, but also the need of a next generation antenna. Arkivator took the lesson learned from the 0.9m antenna and

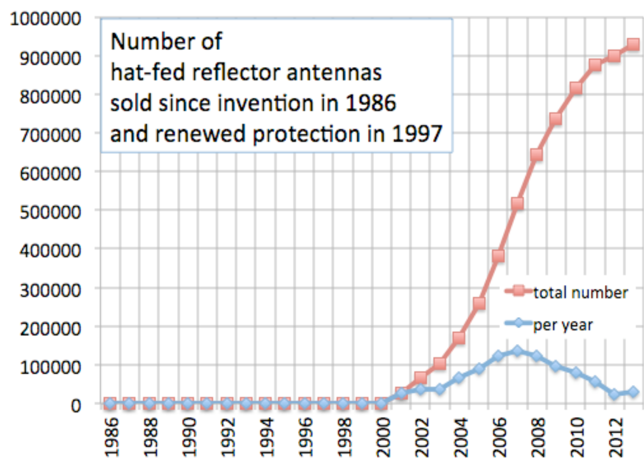


Figure 2. Total number of sold hat antennas

Figure 3. Next generation 0.6m antenna

added some more new ideas. The result is an antenna with much better performance at a lower cost. The design has gone through computer optimization in electrical and mechanical way achieving better efficiency, optimized radiation pattern, lower return loss, lower weight etc. The first size to be launched was the 0.6m with the 1.2m shortly afterwards. The 0.3m will be released in a year. Arkivator foreseen great success on the market.

Acknowledgment

During the whole time, from start-up to today's antenna industry in Arkivator, we have had the best relation with Professor Per-Simon Kildal, Assistant Professor Jian Yang and the rest of the team at the Antenna Group at Chalmers. Their support and help has been very valuable.

References

[1] Per-Simon Kildal, "Reflector with self-supported feed", original hat antenna patent from 1986 granted in several countries.

[2] P-S. Kildal and S.A. Skyttemyr, "Dipole-disk antenna with beamforming ring", IEEE Trans. Antennas Propagat., Vol. AP-30, No. 4, July 1982, pp. 529-534.

[3] P. S. Kildal, "Factorization of the feed efficiency of paraboloids and Cassegrain antennas," IEEE Transactions on Antennas and Propagation, vol. AP-33, pp. 903-8, 1985.

[4] P. S. Kildal, "Study of element patterns and excitations of the line feeds of the spherical reflector antenna in Arecibo," IEEE Transactions on Antennas and Propagation, vol. AP-34, pp. 197-207, 1986.

[5] P.-S. Kildal, L. Baker, and T. Hagfors, "The Arecibo upgrading: Electrical design and expected performance of the dual-reflector feed system", Proceedings of the IEEE, vol. 82, 5, pp. 714-724., 1994.

[6] P. S. Kildal, "Definition of artificially soft and hard surfaces for electromagnetic waves," Electronics Letters, vol. 24, pp. 168-70, 1988.

[7] T. Ulversoy and P. S. Kildal, "Radiation from slots in artificially soft and hard cylinders," IEEE Transactions on Antennas and Propagation, vol. 37, pp. 1628-32, 1989.

[8] P. S. Kildal, "The hat feed: a dual-mode rear-radiating waveguide antenna having low cross polarization," IEEE Transactions on Antennas and Propagation, vol. AP-35, pp. 1010-16, 1987.

[9] P. S. Kildal and T. Jensen, "Efficient small reflector with hat feed," in Sixth International Conference on Antennas and Propagation (ICAP 89) (Conf. Publ. No.301), 4-7 April 1989, London, UK, 1989, pp. 154-7.

[10] J. Hansen, A. A. Kishk, P. S. Kildal, and O. Dahlsjo, "High performance reflector hat antenna with very low sidelobes for radio-link applications," in IEEE Antennas and Propagation Society International Symposium. 1995 Digest, 18-23 June 1995, New York, NY, USA, 1995, pp. 893-6.

[11] Per-Simon Kildal, "Reflector antenna with improved gain and low reflection coefficient at the waveguide input", patent on improvements of hat antenna from 1997, granted in several countries.

[12] Jian Yang, P-S Kildal, "Calculation of ring-shaped phase centers of feeds for ring-focus paraboloids", IEEE Transactions on Antennas and Propagation, Vol. 48, No. 4, pp. 524-528, April 2000.

[13] Jian Yang, Per-Simon Kildal, "Scattering by screw heads in reflecting surfaces and their effect on the sidelobes of reflector antennas", Microwave and Optical Technology Letters, Vol. 38, No. 3, pp. 213-217, 5 August 2003.

[14] Jian Yang, "Moment method analysis of antennas on cylindrical structures by using G2DMULT and design of hat fed reflector antennas", PhD thesis from Chalmers University of Technology, October 2001.

[15] M. Denstedt, T. Ostling, Y. Jian, and P. S. Kildal, "Tripling bandwidth of hat feed by genetic algorithm optimization," in 2007 IEEE Antennas and Propagation Society International Symposium, 9-15 June 2007, Piscataway, NJ, USA, 2008, pp. 2197-200.

A Short History of Reverberation Chambers for Over-the-Air Measurements: The Story of Bluetest From Crazy Idea to Commercial Success

Charlie Orlenius
Bluetest AB
Gothenburg, Sweden
charlie.orlenius@bluetest.se

***Abstract*—The breakthrough of mobile phone communications in the late 1990's led to the invention and development of reverberation chambers for Over-the-Air measurements of wireless devices at Bluetest and Chalmers University of Technology. This paper gives a short description of the most important events over the course of 13 years in the development from early idea to worldwide acceptance and commercial success. The history given here will focus on the scientific achievements over the years, with some mentions of the commercial development.**

***Index Terms*—reverberation chamber; over-the-air; MIMO; antenna measurements; Bluetest**

I. THE IDEA

The idea was simple, yet revolutionary: *build a small and compact antenna measurement instrument based on a reverberation chamber, preferably small enough to be placed on the antenna designer's own desk.* Figure 1 shows a visual of the idea created by the inventor Professor Per-Simon Kildal.

During 1990's, digital cellular communication became established and common for everyone to use. The market for mobile phones literally exploded during this time and this lead to a new challenge for antenna engineers. As a small, handheld unit the mobile phone and its antenna needed another design approach than what was common practice within design of traditional antennas, such as radar antennas or point-to-point microwave links. Not only were the mobile phone antennas supposed to be as small as possible, but they needed to be designed in short time and could only cost a dime. This put new demands on methods for characterizing the performance of these small antennas.

So, the idea to use reverberation chambers for measurements of small antennas and mobile phones were essentially an answer to the industry's demand for faster, simpler, and less costly measurement solutions.

Reverberation chambers, or mode-stirred chambers as they are sometimes called, were not a new invention in the late 1990's when this story begins. In fact, they were well known within the area of Electromagnetic Compatibility (EMC) testing as an efficient and cost-effective alternative for producing high field strengths and for the possibility of radiating the test object from all different angles of arrivals in a simple way [1]. Actually the first patent application for a reverberation chamber was filed in the US in the 1940's for the application of acoustic testing. The long-time use of reverberation chambers for other applications meant that a solid scientific base already existed when the reverberation chamber technology was developed for mobile phone antenna measurements by the researchers at Chalmers and Bluetest. Example of an important background paper frequently used by the research group during this period was [2].

Figure 1. Early sketch of the idea of creating a reverberation chamber based antenna measurement instrument to help the mobile phone antenna designer in its challenge to design smaller antennas in shorter time.

While the idea of using a reverberation chamber for such an application turned out to be revolutionary, it was in itself based on a deeper insight of what is important when characterizing the performance of electrically small antennas: for an antenna with arbitrary low gain radiation pattern, and with signals arriving at arbitrary, time-varying angles, there is no more important parameter than the total radiation efficiency for determining whether an antenna will work in a real situation or not.

II. Exploring the Idea

The company Bluetest was founded in autumn of 2000 as a way to create possibilities to research the idea of reverberation chambers for antenna measurements. This was in reaction to the difficulties of getting adequate funding to explore the idea to its potential within the academic world. The idea was even considered crazy by some members of the academic society at the time. However, the solution turned out to work well; a tight relationship between Chalmers and Bluetest was established and is active still today, although not as integrated as in the initial development work. In fact, Bluetest was in the beginning renting space at the university, and much laboratory equipment was shared among the two parties.

The tight cooperation between Bluetest and Chalmers has led to many co-authored articles and conference papers. Naturally, though, Bluetest has been focusing on the industrial development of the technology, whereas Chalmers has focused on investigating the academic aspects, leading to several Master, licentiate, and PhD theses related to reverberation chambers over the years.

One should also note that there have been other collaborating parties during the years, especially within the Swedish antenna research environment. Examples of these are SP Technical Research Institute of Sweden, FOI Swedish Defence Research Agency, Intenna Technologies, Ericsson AB, and Sony Ericsson Mobile Communications.

Another driver of the development of OTA measurements for mobile phones was the Swedish organization TCO (previously known for their successful quality certification of computer screens) which at the time had the aim of introducing a quality marking for mobile phones. Since no standardized measurement method existed for the measurement of radiated power from mobile phones, TCO commissioned Chalmers University and the newly formed company Bluetest to investigate and produce a solid measurement procedure [3]. The relationship with TCO also meant that the reverberation chamber measurement method caught the eye of the public, which was demonstrated by several newspaper articles during the early years of the new century.

III. Improving Basic Functionality

The big challenge during the first years of developing the reverberation chamber technology for testing of wireless devices was to improve the measurement accuracy down to a standard deviation of 0.5 dB, which was the figure demanded by the industry.

Size of the chamber was an important parameter, and as shown in figure 1 the vision included chambers so small that they could be placed on a desk. At least one such prototype chamber was actually produced, as can be seen in figure 2 (even though the chamber on the photo is placed on the floor). The shown chamber was specifically made for measurements of antennas for Bluetooth units, something that was a new and hot topic in the first few years of the new century. Here is also the origin of the name Bluetest to be found; testing of Bluetooth antennas was a natural market for the new company.

Figure 2. Early prototype chamber for Bluetooth measurements showcased at the IEEE International Symposium on Antennas and Propagation in Boston, MA, USA, 2001.

The standard size of the first chambers were however larger, in fact the smallest dimension of the chamber, 80 cm, was determined by the size of the somewhat narrow door to the first lab room used by the research group. This turned out to be an advantage, since the first Bluetest chambers were possible to deliver fully mounted from factory to any lab, regardless of lab door size.

Nevertheless, the relatively small Bluetest chambers (in comparison to traditional EMC reverberation chambers, or almost any type of anechoic chamber) meant a real challenge in terms of meeting the required measurement accuracy. To overcome the challenge, several significant improvements of the reverberation chamber technology were discovered by the Chalmers-Bluetest researchers. This includes the characteristic mechanical stirrers placed along chamber walls, the turntable facilitating the so called platform stirring [4], as well as the three orthogonally placed fixed measurements antennas making it possible to use so called polarization stirring [5] to avoid polarization imbalance of the created statistical field environment. With these improvements the small reverberation chamber was fully capable of measuring relevant parameters such as radiation efficiency, impedance mismatch, Total Radiated Power (TRP), and Total Isotropic Sensitivity (TIS).

IV. A NEW ERA: MULTIPORT ANTENNAS

The big breakthrough of reverberation chambers came however when the concept of multiport antennas was introduced in mobile handsets during the first years after 2000. First implementations of multiport antennas in mobile phones were used for antenna diversity applications with the intent to mitigate fading effects. Since the diversity technology in handsets was new, there was initially some confusion of how to characterize diversity antennas properly.

An early description of which parameters were important for diversity antennas came from the cooperation between Chalmers and Samsung Electronics in 2002 [6], where the concept of effective diversity gain was first introduced; an important step in order to validate both the radiation efficiency and correlation of diversity antenna configuration. The ideas were subsequently refined and the measurement process in reverberation chamber described [7-9]. Also, diversity measurements for active devices were demonstrated as early as 2004 [10].

Since the reverberation chamber inherently supports a multipath fading environment, it is very straightforward to measure diversity antennas, since they can operate in a way which is similar to their intended operation in real life. This was a big reason for the success of reverberation chambers for testing of small antennas, since one could easily switch between active and passive measurements, or between single- and multiport antennas, and in short time access the relevant parameter for the tested antenna.

Later on, the multiport antenna concept was developed to the more advanced Multiple-Input-Multiple-Output (MIMO), and here was yet another advantage for the reverberation chamber: MIMO measurements were a straightforward development from the diversity measurements mentioned above. Passive MIMO measurements were shown in 2004 [7], whereas MIMO measurements with active devices were impossible because there were no instruments with the capability available. However, some initial measurements were demonstrated with WLAN devices [11], and in connection to this the concept of connected reverberation chambers were introduced [12].

V. CHANNEL EMULATION

With the improvements mentioned above, the reverberation had become a serious alternative for antenna designers all over the world, with Bluetest's patented measurement system sold to the European, Asian, and American (North and South) continents.

Further improvements to both the reverberation chamber hardware itself and the measurement procedures were however to be uncovered over the coming years. For instance was the mode stirrer configuration in the Bluetest reverberation chambers refined with modified mechanical stirrers and improved positioning of the fixed measurement antennas behind a shielding plate. With these improvements a measurement accuracy of 0.2 dB (standard deviation) over most of the chambers usable bandwidth was shown [13]. The basic understanding of measurement accuracy was also improved by this work, exemplified by the developed measurement uncertainty model which can predict accuracy from parameters such as the line-of-sight contribution inside the chamber [14].

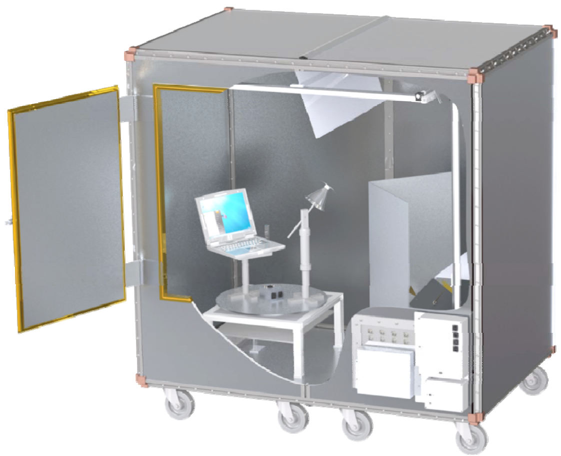


Figure 3. Picture of modern Bluetest reverberation chamber for testing of wireless devices. Cavity dimensions are 1.2m x 1.7m x 1.8m.

With the introduction of the fourth generation mobile communication systems the concept of MIMO in handsets gained a significant interest, which led to a high demand from industry to quickly come up with measurement methods to characterize active MIMO units. The reverberation chamber was fortunately well prepared for this, and Bluetest was able to deliver the first functional measurement system for LTE devices with active MIMO in December 2009, which coincided with the first LTE (4G) networks opening to the public.

Since the first delivery of an active MIMO testing system for LTE in 2009, the Bluetest reverberation test systems have dominated the market for this type of testing. Figure 4 shows the number of delivered Bluetest systems with active MIMO option installed per each year from 2009, where the increase is forecasted to continue over the next few years.

An important shift in how to deal with characterization of wireless units came with the introduction of 4G and MIMO. In order to more closely emulate real-world conditions and relate the measurement metrics to end-user performance, the industry shifted towards using data bit throughput as measurement metric instead of previously used component parameters such as antenna radiation efficiency or receiver sensitivity. This shift in characterization parameters also led to more focus on emulating real-world scenarios directly in the measurement setup. For the anechoic chamber, the solution presented was to add probes in a circular ring surrounding the test object in order to create a multipath signal environment with certain statistical properties in a small area at the center of the circle. In the reverberation chamber the solution was simpler. With the multipath signal environment supported naturally by the chamber, it is straightforward to add any number of signals required for the MIMO configuration. An advantage of the reverberation chamber in this case was the natural 3D environment, which meant the user did not have to reduce the scope to 2D-only measurement as in the anechoic chamber.

With the increased focus on emulation of channel characteristics, there was a need to investigate the actual real-time properties of the channel created in a reverberation chamber, for instance the tuning of channel properties by loading the chamber or the concept of pre-fading the signal with a channel emulator instrument prior to feeding it to the reverberation chamber. Some of this was outlined in the presentation of the connected chamber concept [12], and was further analyzed in several publications, for instance in terms of delay spread [15], Doppler spectrum [16], and frequency diversity [17].

Although highly demanded by the industry, the task of agreeing on a standard for active MIMO measurements turned out to be both difficult and time-consuming, and is not yet finalized at the writing of this paper. Two organizations are working in parallel on this topic, worldwide 3GPP and North American CTIA, and both target first versions of their standards during 2013. The reverberation chamber is considered for both of these standards.

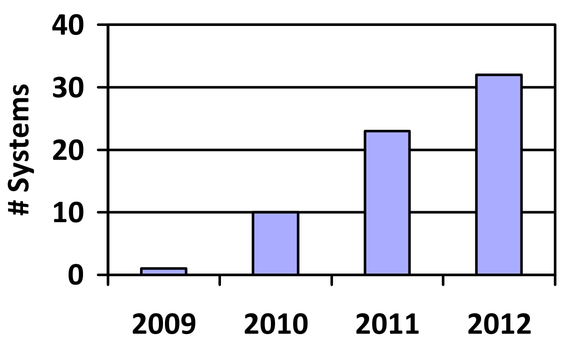


Figure 4. Number of installed Bluetest measurement systems with active MIMO option over the period of 2009-2012.

The reverberation chamber is starting to find its way into various measurement standards, which is natural not the least due to the high market acceptance that have increased over the last decade. Sales of Bluetest measurement systems have seen an exponential increase over the time period, and the number of installed systems is found in the three digit range. For testing of mobile phones with single antenna parameters such as TRP and TRS the 3GPP organization allows for the use of reverberation chambers [18].

VI. Future

With current available capabilities, the reverberation is a well established and natural choice for designers of wireless devices all over the world. With an expected explosion of the number of wireless devices to come over the next decade, the importance of and need for reverberation chambers are not believed to diminish, but rather the opposite. The reverberation chamber will continue to be an attractive alternative due to its small footprint, relatively low price, accurate and quick measurements, and its simplicity in handling.

Although one may think the reverberation chamber has reached its potential in terms of capability of various measurement procedures, this is not case. There are a few areas where we probably will see new developments over the next decade. Besides further developments of existing measurements methods, such as deeper knowledge of channel emulation in the reverberation chamber, the largest increase of reverberation chambers will probably be in new areas where the wireless technology is now being used more frequently. One such example is the vehicular industry; another is the area of machine-to-machine (M2M) communication. Another breakthrough development that is already being discussed within the research community is the possibility of assessing the antenna radiation pattern from a reverberation chamber measurement.

Nevertheless, the reverberation chamber technology has reached a certain stage of maturity, demonstrated for instance by a few published book chapters [19,20], and invited review article [21] describing the technology.

The development of reverberation chamber for measurements of wireless devices cannot be seen as anything else as a success, and it is interesting in hindsight to see how it all started with a simple, yet revolutionary, idea and then it went on to become a dominating technology for this specific type of testing.

All in all, the next decade for reverberation chamber research has the promise of being just as exciting as the previous one.

Acknowledgment

In addition to thanking all the various persons who have been involved in the events described here, a special thanks go to Professor Per-Simon Kildal, Chalmers University of Technology, for the help in gathering information for the recollection given in this paper.

References

[1] M. Bäckström, O. Lunden, and P.-S. Kildal, "Reverberation chambers for EMC susceptibility and emission analyses," *Review of Radio Science 1999-2000,* pp. 492-452, 2003.

[2] D. A. Hill, M. T. Ma, A. R. Ondrejka, B. F. Riddle, M. L. Crawford, and R. T. Johnk, "Aperture excitation of electrically large, lossy cavities," *Electromagnetic Compatibility, IEEE Transactions on,* vol. 36, pp. 169-178, 1994.

[3] P.-S. Kildal and C. Carlsson, "TCP of 20 Mobile Phones Measured in Reverberation Chamber: Procedure, Results, Uncertainty and Validation", available from Bluetest AB, www.bluetest.se, Feb. 2002.

[4] K. Rosengren, P-S. Kildal, C. Carlsson, J. Carlsson, "Characterization of antennas for mobile and wireless terminals in reverberation chambers: Improved accuracy by platform stirring", *Microwave and Optical Technology Letters*, Vol. 30, No 20, pp.391-397, Sep. 2001.

[5] P.-S. Kildal, C. Carlsson, "Detection of a polarization imbalance in reverberation chambers and how to remove it by polarization stirring when measuring antenna efficiencies", *Microwave and Optical Technology Letters*, Vol. 34, No. 2, pp 145-149, July 20, 2002.

[6] P. S. Kildal, K. Rosengren, B. Joonho, and L. Juhyung, "Definition of effective diversity gain and how to measure it in a reverberation chamber," *Microwave and Optical Technology Letters,* vol. 34, pp. 56-9, 2002.

[7] P. S. Kildal and K. Rosengren, "Correlation and capacity of MIMO systems and mutual coupling, radiation efficiency, and diversity gain of their antennas: simulations and measurements in a reverberation chamber," *IEEE Communications Magazine,* vol. 42, pp. 104-12, 2004.

[8] P. S. Kildal and K. Rosengren, "Electromagnetic analysis of effective and apparent diversity gain of two parallel dipoles,"*IEEE Antennas and Wireless Propagation Letters,* vol. 2, pp. 9-13, 2003.

[9] K. Rosengren and P. S. Kildal, "Radiation efficiency, correlation, diversity gain and capacity of a six-monopole antenna array for a MIMO system: theory, simulation and measurement in reverberation chamber," *IEE Proceedings-Microwaves, Antennas and Propagation,* vol. 152, pp. 7-16, 2005. (See also errata in vol. 153, p. 400, 2006.)

[10] R. Bourhis, C. Orlenius, G. Nilsson, S. Jinstrand and P.-S. Kildal, "Measurements of realized diversity gain of active DECT phones and base-stations in a reverberation chamber", IEEE AP-S International Symposium, Monterey, CA, 2004.

[11] Olano, N., C. Orlenius, K. Ishimiya, and Z. Ying. 2008. "WLAN MIMO throughput test in reverberation chamber", IEEE AP-S International Symposium, San Diego, CA, 2008.

[12] C. Orlenius and M. Andersson, "Repeatable performance measurements of MIMO systems in connected reverberation chambers with controlled keyhole effect", *Radioengineering*, Vol. 18, No. 4, Dec. 2009.

[13] C. Lötbäck Patané, M. Franzén, C. Orlenius, "Analysis and Improvement of Reverberation Chamber Method for Characterization of Small and Terminal Antennas", European Conference on Antennas and Propagation (EuCAP), Rome, Italy, 2011.

[14] P.-S. Kildal, X. Chen, C. Orlenius, M. Franzén, C. Lötbäck Patané, "Characterization of Reverberation Chambers for OTA Measurements of Wireless Devices: Physical Formulations of Channel Matrix and New Uncertainty Formula", IEEE Transactions on Antennas and Propagation, Vol. 60, No. 8, pp. 3875-3891, Aug. 2012.

[15] X. Chen, P. S. Kildal, C. Orlenius, and J. Carlsson, "Channel sounding of loaded reverberation chamber for over-the-air testing of wireless devices: coherence bandwidth versus average mode bandwidth and delay spread," *IEEE Antennas and Wireless Propagation Letters,* vol. 8, pp. 678-81, 2009.

[16] K. Karlsson, X. Chen, P.-S. Kildal, J. Carlsson, "Doppler spread in reverberation chamber predicted from measurements during stationary step-wise stirring", Antennas and Wireless Propagation Letters, Vol. 9, pp. 497 - 500, 2010.

[17] P. S. Kildal, A. Hussain, X. Chen, C. Orlenius, A. Skarbratt, J. Asberg, T. Svensson, and T. Eriksson, "Threshold Receiver Model for Throughput of Wireless Devices With MIMO and Frequency Diversity Measured in Reverberation Chamber," *IEEE Antennas and Wireless Propagation Letters,* vol. 10, pp. 1201-1204, 2011.

[18] 3GPP TS 34.114 v11.3.0, "User Equipment (UE) / Mobile Station (MS) Over The Air (OTA) antenna performance; Conformance testing", Dec. 2012.

[19] P.-S. Kildal, C. Orlenius, "Multipath Techniques for Handset/Terminal Antennas", chapter in book by J. Volakis (Ed.), Antenna Engineering Handbook, McGraw-Hill, June 2007.

[20] M. Andersson, A. Wolfgang, C. Orlenius, J. Carlsson, "Measuring Performance of 3GPP LTE Terminals and Small Base Stations in Reverberation Chambers", Chapter 12 of "Long Term Evolution: 3GPP LTE Radio and Cellular Technology", CRC Press, 2009.

[21] P.-S. Kildal, C. Orlenius, J. Carlsson, "OTA Testing in Multipath of Antennas and Wireless Devices with MIMO and OFDM", Proceedings of the IEEE, Vol. 100, No. 7, pp. 2145-2157, July 2012.

Personal Recollections and Interviews Covering Swedish Antenna History: Hallén and His Integral Equation, Defence Activities, the ANTENN Conferences, Stealth Craft Smyge.

Carl-Henrik Walde[1], Gunnar Petersson[2]

[1] Chief engineer emeritus, SNRV/NRS, Täby, Sweden, info@walde.se

[2] Associate professor emeritus, KTH, Stockholm, Sweden, gunpet@kth.se

Abstract **– This document has two parts, the first written by Petersson on professor Erik Hallén and the second by Walde with some personal notes on Hallén and an overview of the antenna activities of the Swedish total defence.**

Index Terms – Erik Hallén, radio history, antennas

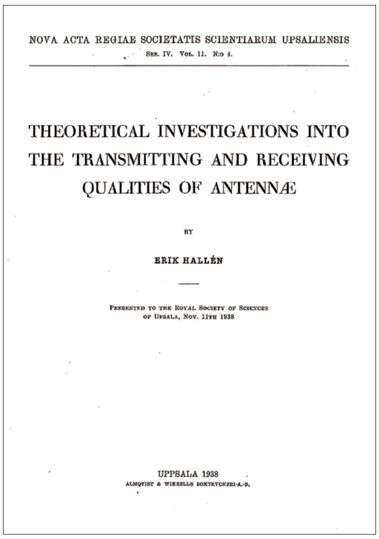
I. Professor Erik Hallén

The first author of this paper has been asked to mention Erik Hallén, an internationally wellknown antenna theorist, and include an overview of his work. My coauthor, who worked closely with professor Hallén and is familiar with his theories, has been kind to submit the following, based on a chapter in a recent book commerating the 100th anniversary of the Nobel Prize in Physics awarded to Guglielmo Marconi and professor Ferdinand Braun in 1909 [1].

Erik Gustaf Hallén was born September 16 1899 and achieved his *Degree of Master of Science in Engineering* at Chalmers Technical University in Gothenburg 1921, after which he studied at the University of Uppsala, Sweden. He achieved his PhD diploma in 1930. His thesis (in German) was called *Über die elektrischen Schwingungen in drahtförmigen Leitern.*

During his time in Uppsala, he worked with professor Carl Wilhelm Oséen, who influenced him in establishing a solid theoretical base in research and experiment. At the university he studied coils with thin threads at high frequencies for which the current varies along the wire. His theoretical results were accompanied by numerical calculations, a great intellectual challenge considering the state of computers at that time. After his PhD, Hallén continued studying problems concerning oscillations and waves.

In 1945 Hallén was appointed professor in Electromagnetic theory at the Royal Institute of Technology in Stockholm, Sweden. Hallén's main interest now became antenna theory, in which area he is internationally famous, especially for the distribution of current on a straight metal rod antenna. This is world-wide known as *Hallén's integral equation***.**


NOVA ACTA REGIAE SOCIETATIS SCIENTIARUM UPSALIENSIS

SER. IV. VOL. 11. N:O 4.

THEORETICAL INVESTIGATIONS INTO THE TRANSMITTING AND RECEIVING QUALITIES OF ANTENNÆ

BY

ERIK HALLÉN

PRESENTED TO THE ROYAL SOCIETY OF SCIENCES OF UPSALA, NOV. 11TH 1938

UPPSALA 1938

ALMQVIST & WIKSELLS BOKTRYCKERI-A.-B.

Figure 1. First page of Erik Gustaf Hallén fundamental paper on the theory of wire antennas.

Another area that became of great importance at that time was *reflection-free antennas***.** A metal rod antenna has resonance when the length of it is half a wave-length. It means that such an antenna is strongly dependent on frequency. Hallén realised that if it was possible to decrease the outgoing wave on the antenna to almost zero at the end points, there would be no reflections and no standing wave. At first, his idea was to cover an insulating rod by a thin resistive layer with a spiral shape. The wave which left the gap of the antenna should decrease along the rod in order to be zero at the end of the rod. A disadvantage is that there is a loss of energy and that the efficiency will be small.

He very soon started with another idea, where the energy decrease was achieved by introducing capacitors along a metal rod. The antenna was equipped with a number of insulating slabs with increasing thickness. The antenna would radiate a small portion of power at every discontinuity and thus the outgoing wave along the rod decreased and the power was negligable at the end of the rod. This construction showed to be successful and an antenna with a broad bandwith was obtained. A so designed antenna, the length of which was one metre, worked properly for frequencies over 400 MHz.

Although a pure theorist he was very keen on testing his theoretical results with experiments. To measure amplitude and phase of the current along the antenna one of his students, Erland Cassel, constructed a modified cathod ray tube, the purpose of which was to minimize the influence of the measuring device on the actual current distribution. This was the first time an actual measurement of the phase of the antenna current was performed.

As professor he also gave undergraduate and advanced courses at Royal Institute of Technology, (Kungliga Tekniska högskolan, KTH). He spent much time his first year at KTH writing three volumes of lecture notes, which was the base of his course book *Electromagnetic Theory*. This book was very didactical and became fundamental for the education in theoretical electrical engineering even at other universities. The subject was taught in a very specific way, as it discussed the electricity of matter in a very formal and concentrated way, essential for engineering. The book is not only a course book but also an excellent reference source. Hallén also received the *Cedergren Medal*, an award given every five years to a teacher who had been producing outstanding literature in a technical field. His book was translated into English and used as course book at many foreign universities. Along with his research in Sweden Hallén spent many periods as a guest professor at Harvard University, Mass, and at CalTech in California.

Another book published during the fifties, based on lectures that Hallén gave at the University of Uppsala in the thirties, is *Forced Oscillations, Operator Calculus.* As in all other books, Hallén showed his ability to express the problems of Theoretical Physics in a practically useful way. He adopted ideas of Oliver Heaviside and gave those ideas a stringent mathematical form, which was missing in the original paper by Heaviside. The successors at the chair in Electromagnetic Theory has adopted his ideas, and antenna theory and wave propagation have been further developed and is still an important research area at KTH.

Hallén gave excellent lectures to undergraduate students as well as to graduates. His lectures were accompanied with demonstrations of basic phenomena and were together with his course literature indeed appreciated by the students. His courses gave a good methodological base for understanding and solving theoretical problems of different kinds for future engineers outside the university world.

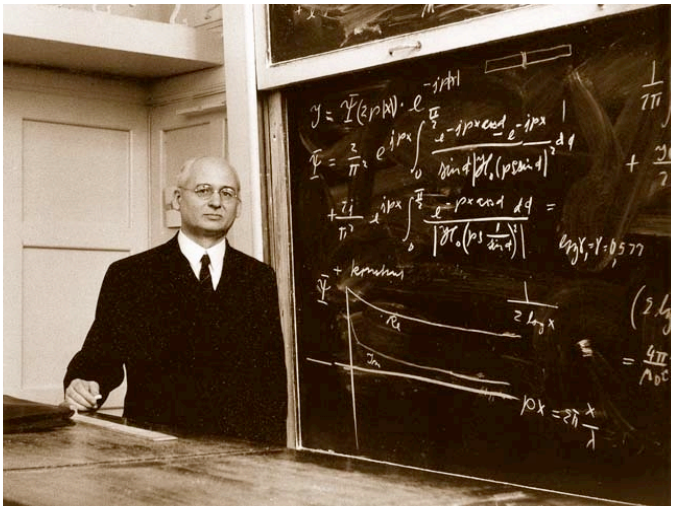


Figure 2. Erik Hallén in front of a blackboard. (Unknown photograper)

In 1955 he married Lila Richardsson, a University librarian from United States. In private Erik Hallèn was a jovial and entertaining personality with many cultural interests. He was an inspiring person and many of his disciples have successfully contributed to Swedish industrial innovation, especially in antenna theory and practice. His name is still known to students at the Royal Institute of Technology, Stockholm. Erik Hallén died 75 years old in February 1975.

After these words by my coauthor, the author would like to give some personal comments about the legendary professor Erik Hallén.

The author is a long time fellow and secretary of SNRV, the Swedish National Committee of URSI (Union Radio-Scientifique Internationale), in Sweden working under the auspices of KVA, the Royal Academy of Sciences. Long before my term there, Hallén was an active fellow of that committee often taking part in the URSI General Assemblies.

Figure 3. Antenna experts John Kraus W8JK and Erik Hallén at the 12th URSI General Assembly in Boulder, USA, in 1957. (Photo courtesy of Kraus estate)

In the 1950's, I was one of the few students of *Teknisk Fysik* (Engineering Physics) in Sweden, at that time available only at KTH, the Royal Institute of Technology in Stockholm. We were taught Hallén's *Teoretisk Elektroteknik* (Electromagnetic theory). He was a radiant teacher, his book was good and we understood what he said or at least believed that. However, he was as feared as was his final oral examination.

My senior friend Gunnar Brodin, who studied Electrical Engineering at KTH, was asked by his class to approach professor Hallén telling him that the students thought that he was too demanding. Brodin got the blunt reply “I think not.” and then “By the way, what is your name?”. It may be a consolation for the late Brodin that he became a professor at his alma mater and rector there, finally raising to Excellency and Marshal of the Realm, i.e. royal court CEO.

As the number of students increased, Hallén was forced to change his oral examination to a written, but a very unusual one. I was one of those taking part in the premiere. Sitting at our desks, professor Hallén greeted us by saying “You have got five hours to solve eight problems correctly, although I might accept a few miscalculations. If you cannot address all eight, I suggest you now leave and do something else”.

Anyhow, all stayed on and after about three hours Hallén reentered, loudly saying: “Those who are ready may approach and I will check your solutions”. For most of us, these words came as a shock, but not for two of my brilliant classmates, Karl Johan Åström and then Torsten Bohlin. For the latter, Hallén grumbled a bit ending with: “You must not spell Poisson with a lower case P”. Of course, they passed with honours and later became control theory professors at Lund University and KTH respectively, Åström being awarded the IEEE Medal of Honor in 1993. I passed, too, without honours.

II. Early swedish defence activities

In 1899 the Royal Swedish Navy became interested in wireless communication and in 1901-1903 radio equipment were installed in a few ships and land stations. Ten years later the merchant mariners joined, soon followed by the army.

In the first half of the century Swedish radio research was negligible and we used antennas readily available or described in the literature. We had to rely on the industry, mainly in Germany where the Swedish engineer Ragnar Rendahl was responsible for the AEG-Telefunken radio laboratory. In 1908 the Swedish Navy succeeded in recruiting him to the Navy as its principal radio engineer. Mechanically minded, he also designed a wellknown antenna mast with zigzag shape.

In the 1920s, the ”multiple tuned antenna”, designed by Ernst F W Alexanderson, was installed at Grimeton Radio SAQ as was two long directional antennas, designed by Harold H Beverage, at the receiving station Kungsbacka Radio SAK.

The author joined the navy in the 1950's and one of his first jobs was to procure a broadband vertical antenna for 100-160 MHz, the frequency band for short-haul communications within the Royal Swedish Navy. Allgon Antennspecialisten made an antenna based on a patent by its managing director Torbjörn Cramner. It had the form of a thick cylinder with thick counterpoise rods, the radiating elements made of copper nets, rigidity reinforced by plastics. The prototype is in the navy historical collections, the series units are still in use.

Based on Hallén's theory, an army wire antenna för 30-80 MHz was made by Allgon and widely deployed. The design had ”frankfurters” as discrete elements. If correctly slung up into a tree, it worked and had some directivity; if not the performance was poor.

III. The antenna meetings

A well-known way of research, development and series manufacture of military equipment and systems is called *The Swedish Model*. It is based on close cooperation between defence staffs, defence procurement offices, universities, research institutes, industry with consultants and telecom operators, and – very important – the users. The overall aim is high quality, moderately priced equipment and systems. Hierarchical support is strong; hierarchical interference is minimal as is undue bureaucracy.

In that spirit and to bring industry and users together, the army people invited to the first *Antenna Meeting* in May 1974 at FOA, the National Defence Research Institute. About 20 participants gave their views on existing antennas, described measurement facilities, indicated research plans and suggested joint projects; future work was agreed.

Present at that meeting were Lars Höök and the late Curt Norell; they became the driving force. The general meetings took place about once a year with varying venues:

1974	in Stockholm
1976	in Kristianstad and the nearby testing facility at Ripa
1977	in Köping
1977	in Kristianstad and Ripa
1978	in Stockholm at the Navy board and FOA Sandkullen
1979	in Linköping and the FOA testing facilities
1980	in Varberg and at SAQ, Grimeton Radio station
1981	in Karlskrona
1982	in Arboga

In addition to these, there were colloquia and working groups; some of them internal i. e. without the presence of industry.

In 1982 FMV, the Defence Materiel Administration, re-organised and established a joint electronics directorate FMV:ELEKTRO with six technologically oriented divisions, FMV:Radio with the author as chief engineer and manager.

ELEKTRO was an ideal organisation with good directorate leadership, smooth bureaucracy, all necessary administrative support in the directorate, and extremely wide delegation to the lower echelons. Coordination of interfaces and projects increased; earlier confrontation between the defence services decreased.

The meetings continued under the new command with Arboga for VHF antennas in 1982 and for HF antennas in 1983. In 1985, the *Antenn 85* general meeting, also in Arboga, gathered almost 200 registered participants.

At that meeting ”P”, Per-Erik Ljung at FOA, delivered an almost shocking talk on radar targets on ships and what to do to minimize them, in essence meaning that our ships were poorly designed.

The author had invited two FMV naval architects to the event. During ”P”:s talk, commander (E) Lars Salomonsson, later raising to rear admiral, became more and more upset. In the end he said to ”P”: ”Now I want you to go with me to the Karlskrona naval base. There you will see why we can't design in a different way.”

In Karlskrona ”P” was pushed into the naval yard drawing office. According to normally reliable sources Salomonsson returned some hours later expecting rough talk, but found the gentlemen sitting at a table, sketching. They said: ”We are designing a new ship”, i. e. what became HMS Smyge, our first stealth ship. Navy people from all over the world went to Karlskrona to have a look. USS Zumwalt, due for delivery in 2014, has features resembling those of Smyge, but with a formidable price tag.

Figure 4. Senior antenna specialists Per-Erik Ljung (left) and Erland Cassel at A*ntenn 94*. Ljung passed away in 2012, Cassel in early 2013 during the final preparation of our EuCAP manuscript. (Photo FFV)

Figure 5. *Antenn 85*. Walde on the podium, Höök standing, Norell sitting in the front row. (Photo FFV)

Figure 6. *Antenn 85.* Many antenna enthusiasts in the Arboga cinema, FOA antenna chief engineer Göran Svennérus in second row, left. (Photo FFV)

The conferences were now run triennially and from *Antenn 88* at Strömstad they were organised as scientific events with call for papers and proceedings. The international attendance increased and quite soon we had to switch the conference language to English. We kept the practical issues, exhibitions, study tours and social activities in this series:

Figure 7. HMS Smyge; “smyga“ = “sneak”. (Photographer unknown)

Antenn 85	in Arboga
Antenn 88	in Strömstad
Antenn 91	at Fårö
Antenn 94	in Eskilstuna
Antenn 97	in Gothenburg
Antenn 00	in Lund
Antenn 03	in Kalmar
Antenn 06	in Linköping
Antenn 12	in Solna, in the Radio and Microwave Days
Antenn 14	in Gothenburg, embedded (cf. 2012)

Antenn 09 did not materialise as FMV no longer would act as sponsor. Also, Internet had taken over much of the information transfer and meetings were no longer the main way of exchanging information.

In the end, SNRV took the responsibility to revive the antenna conferences. To keep up the number of participants SNRV decided to merge with similar events of the SNRV Radio and Microwave Days. By that, we hope to keep these meetings – they are very important for networking.

The oral presentation of this paper will give an overview of industry and testing facilities as well as a number of antenna projects that were successful and a few that were not.

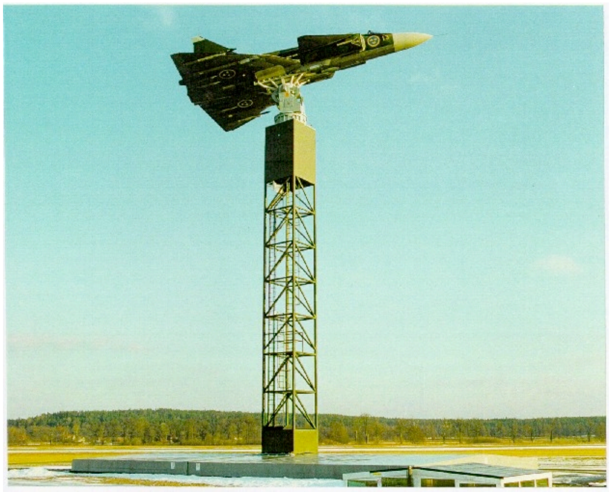


Figure 8. AMPA, a test bed at Arboga, sponsored by FMV. (Photo Sturebild, Reinhold Carlsson)

Acknowledgments

Many thanks are due to the EuCAP organisation for including a historically oriented session.

The authors want to thank Lars Ladell and Lars Höök for spending generous time when being interviewed.

Posthumously, we want to thank Erland Cassel for an early telephone conversation.

Dedication

The authors have dedicated this paper to Erland's memory.

Figure 9. Erland Cassel, who became one of our most prominent antenna designers, in a typical pose. (Photo Anders Bjurström)

References

[1] K. Grandin, P. Mazzinghi, N. Olander, G. Pelosi (Eds.), "Wireless World". Royal Swedish Academy of Sciences and Firenze University Press, Italy, 2012 (ISBN 978-91-7190-178-1).

[2] SNRV website www.snrv.se

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I EuCAP 2013, den sjunde europeiska konferensen för antenner och vågutbredning som ägde rum i Göteborg i april 2013, ingick en historisk del under temat svensk antennhistoria. Eftersom en stor del av de nio presentationerna rörde försvarsmaktens projekt har vi fått löfte att publicera dessa i ett FHT-dokument tillsammans med en sammanfattande artikel som Carl-Henrik Walde har skrivit för IEEE Magazine on Antennas and Propagation. Alla artiklarna är på engelska.

I flera föredrag poängterades det värde som FMVs antennmöten haft för landets antennutveckling. Här ser vi några bilder från ANTENN 85 i Arboga där ”P”, laborator Per-Erik Ljung på FOA, stod för ett revolutionerande föredrag som ledde till framtagandet av försöksfartyget Smyge.

Carl-Henrik Walde på podiet, Lars Höök stående och Curt Norell sittande på första bänk (FFV).

FOAs antennexpert Göran Svennérus sittande längst till vänster på andra bänk (FFV).

Två antennprofiler vid ANTENN 94 Per-Erik Ljung och Erland Cassel (FFV).

HMS Smyge (okänd fotograf).

Försvarets Historiska Telesamlingar

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