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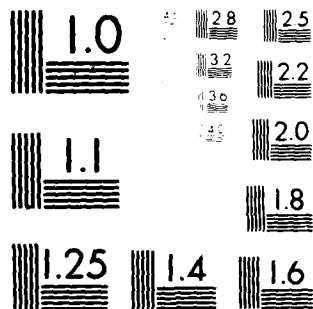
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AREA REPORT - DEVELOPMENTS IN MICROWAVE ANTENNAS
AND APPLICATIONS IN SWEDEN, DENMARK, AND NORWAY

T. C. CHESTON

31 DECEMBER 1980

UNITED STATES OF AMERICA

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AREA REPORT - DEVELOPMENTS IN MICROWAVE ANTENNAS
AND APPLICATIONS IN SWEDEN, DENMARK, AND NORWAY

Sweden, Denmark, and Norway are closely related countries with great similarities in language and customs arising from a long, almost common history of alternating alliances and wars; they form part of the Scandinavian block which further includes Finland and Iceland and all have a close economic as well as cultural relationship. Sweden and Denmark, at least as seen from the outside, seem reasonably similar welfare-type states with much government control. The cost of living in all three of the countries is high (a cup of coffee or a glass of beer can easily cost \$2.50), but that does not mean that the standard of living is correspondingly high—it certainly does not seem to be so in comparison with the US.

Sweden has by far the largest population, 8 million, followed by Denmark with 5 million. Norway, which used to be part of Sweden until it seceded in 1905, has a population of 4 million. Denmark, perhaps as a result of the significant social benefits it provides for its population and the lack of natural resources, is on the verge of a serious financial crisis with interest payments on debts already strangling the economy. Norway, on the other hand, is just beginning to reap the benefits from its rich North Sea oil fields.

Sweden has strong ties of friendship with the US and the UK. Around the turn of the century poor economic conditions in Sweden brought about the emigration of many Swedish people to the US, so that today most Swedes have uncles and cousins over there. Government social reforms are very noticeable in Denmark and Sweden. An extreme example comes from the tale of a professor who heads a department at the Technical University of Denmark, which includes secretarial help and machine shop support staff. In the monthly meetings held by his department, all staff members have an equal voice in selecting a chairman for the year (on at least one occasion it was a machinist) and in deciding what research program to fund and pursue and which to drop. Similar, though less extreme procedures are used in Sweden, and yet, it seems that the system is benign and very good work is being done in those countries.

Sweden has a highly developed industry producing almost everything from vacuum cleaners to cars, submarines, and aircraft. New emphasis has been placed by the government on microwaves, and the Microwave Institute successfully finds industrial applications in ever-increasing numbers, from the sorting of cows to the curing of tires. One may expect new ideas and applications to come from this inventive organization in the future. The group is very ably led by Peter Weissglas, who is also a professor at the Technical University in Stockholm. At the University of Gothenburg, phased-array technology is being developed for relatively small and simple systems and specific applications. In defense electronics, the L.M. Ericsson Telephone Company has a very strong and active antenna group in the Gothenburg facility which cooperates with the university. A government research facility is slowly recuperating from a devastating move to Linköping from Stockholm, during which many of its members were lost. An interesting mm radiometer program is going on there at this time with a comparison of multifrequency responses. In Denmark, the Technical University in Lingby is most active and has a large microwave anechoic chamber available not only for in-house work, but also as a facility that can be hired. Work there includes model and near-field antenna measurements. Another group at Lingby is involved in remote sens-

ing by radiometry and radio echo sounding. Denmark has a significant electronic industry running from hi-fi to test instrumentation; their efforts are not included in this report.

Norway is heavily involved in ocean and oil-related research and development work and relatively little work is being done in the area of microwaves and antennas. The government research laboratory in Kjeller has just finished a project and is about to decide whether to investigate some microwave antenna systems, for example, phased arrays. The main efforts in Norway are found at the Technical University of Trondheim where ship antennas are being developed and where there is a large ionospheric research project (EISCAT) to measure scattering by the auroral zone. More detailed descriptions are given in the following.

SWEDEN

The Institute of Microwave Technology (IM)

This is one of Europe's outstanding microwave centers (ESN 34-10:472 [1980]). It is government-owned and sponsored through the Swedish Board of Technical Development (SBTD). It was founded in 1968 to find industrial applications of microwaves and conduct basic research in associated areas, e.g., semiconductor electronics, diode lasers, and optical fibers for communications. The institute in all its aspects, technical as well as administrative, carries the hallmark of its managing director, Dr. Peter Weissglas, who is also a member of the board. It is a place full of new ideas and well worth watching for future developments. The institute has premises in the Royal Institute of Technology (RIT) where Weissglas has a chair as a professor of electrical engineering. IM is growing very fast. It had an annual budget of Swedish Kr 13 million in 1979, and projects an increase to Swedish Kr 20 million, and 80 people for 1981. Half of its income comes from appropriations of SBTD. The other half is from diverse contracts from industry or government or from the sale or assignment of patents. Figure 1 gives the organization chart.

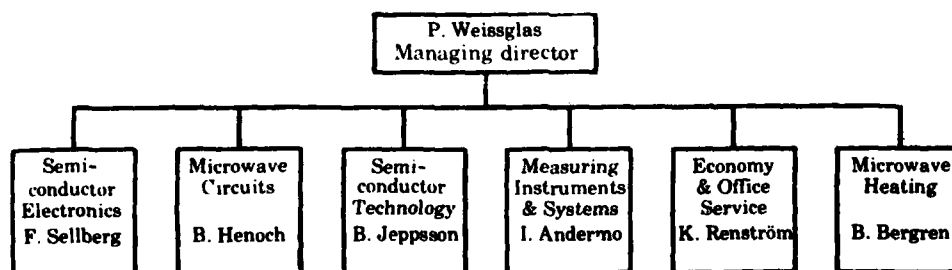


Fig. 1. Institute of Microwave Technology

The semiconductor technology group covers the field of semiconductors as well as optical fibers and diode lasers. In the measurement group, most interesting schemes have been perfected concerning the measurement of velocity. To determine the velocity of a ship, for example (speed-log), two simple high-frequency sonars are used to examine the return pulse from the water at some fixed range (depth) below. The returns are modulated by the changing inhomogeneities

in the water as the ship travels. The two sonars are in close proximity (one to two inches), are of similar design, and are aligned with the direction of motion. The returns are correlated to find the time delay which is the time taken to travel the distance between the two sonars, and hence the speed is derived. The advantage of the method is that the velocity is measured relative to water away from the ship, thus avoiding errors due to turbulence. The sonar sensors can be replaced by optical, infrared, or other sensors to measure, for example, the velocity of a ribbon of steel in a hot-rolling steel mill.

The major projects of MI include:

Measurements: velocity measurements (ship's log [SAL-ACCOR Log, commercially available from Jugner Marin AB, Fack S17120 Solna, Sweden], flow of paper or ribbon of steel or cloth or yarn, velocity of train over rails); level measurements (level meters for filling shoots).

Electronic Identification, Localization, and Sorting: traffic control of buses, shunting of railroad stock, identification and billing of vehicles crossing into toll roads, tunnels or bridges (e.g., Lincoln Tunnel), storage and placement of containers, identification and sorting of cattle.

Industrial Microwave Heating: sealing containers, gluing book spines, retreading tires, sterilizing food.

Microwave Circuits: TV-satellite receivers, FET solid-state radar transmitters.

Semiconductors: FET development, solar cells, quartz fiber technology, diode lasers.

Royal Institute of Technology (RIT), Stockholm

As previously noted, Dr. Peter Weissglas is Professor of Electrical Engineering at RIT as well as managing director of MI, and most of the microwave projects are carried out at MI.

At RIT there is some research underway on the medical applications of microwaves. Microwaves are used experimentally in cancer therapy where they permit the discriminatory heating of the center of tumors, since the outer parts are better cooled by the flow of blood. In a different project, a very early start has been made to look at multifrequency holographic imaging which may eventually lead to industrial use of automated control, location, and placement of parts, for example, the automatic handling of automobile parts. Dr. Enander, professor of electromagnetic theory at RIT, is developing a microwave-radar-type system for finding avalanche victims.

FOA (Försvarets Forskningsanstalt)

FOA is the National Defence Research Institute. The Electronics Department was recently moved to the outskirts of Linköping, some 2.5 hours from Stockholm by train (except for the acoustics division that is still in Stockholm). It has well-conceived and spacious modern buildings in the vicinity of the university. The move was not welcome by the staff; many left, without suitable replacements being found. Government salaries are claimed to be lower than those in industry, adding one further hurdle. At this time, emphasis is given to creating an excellent facility that would be an attraction in itself. The department has most suitable quarters and is superbly equipped with instruments, but it will require some time before it regains its momentum. The organization is by divisions, which are subdivided into sections.

The antenna work is done in Division 340, Waves and Circuits, headed by Gunner Svennerus. Active antenna work is done in a section headed by Bertil Peterson.

Phased-array work was formerly carried out by Dr. Steyskahl, who left recently to join the RADC. The work, which is pretty much in abeyance now, included ferrite and diode phase shifter developments. In one version, the array was active and used FET X-band amplifiers that were developed by the MI, and latching phase shifters that used a meander line on a ferrite substrate. There was a transmitter-receiving circulator, a switch, and an isolator, and the final power output was 1 Watt CW. Ferrite materials are actually being made at FOA for their own use.

The Passive Circuit Section is headed by J. Loren. The work, described by A. Bergquist of the research staff, includes production of materials (ceramics and ferrites); transmission lines (strip lines and fin lines of various forms, some presently being used for mm waves); components and circuits (phase shifters, terminations, filters, multiplexers, circulators); and measurements (properties, reflection coefficients, measurements of dielectric and magnetic constants, absorption). Some developed components had in the past been adopted by industry and resulted in a profit to FOA.

The Antenna Measuring Facility Section, described and shown by N. Gustavsson, has a fair-sized anechoic chamber lined with absorber from the Rantec Corporation (CA). It is fully instrumented for radar target measurements, monostatic or bistatic, and is sensitive enough to detect a plastic fishing line. A very large anechoic chamber is being readied for completion with instrumentation by late 1981. It will be 14 m wide, 35 m long, and 12 m high. This is approximately 6 times bigger in volume than the very large chamber in Lyngby, Denmark (see below) but still smaller than the chamber at NRL. Fully-screened installation will be carried out by Emerson and Cuming. The facility is planned to be used to measure antenna patterns, both near and far field, and to obtain radar cross sections from models. Both phase and amplitude will be available for recording.

An outdoor antenna facility is available, superbly instrumented, with a mast, a rail system, antennas that can be raised (4 m) or lowered, or tilted back. At a distance of 20 km is a further instrumented measuring range, for 1 to 3 m diameter antennas, covering frequencies of 1 to 35 GHz. Multistatic radar reflectivity measurements can be taken at that facility, which has a 100 m radius circular railroad track. At this time, antenna measurements are available more as a service to industry than for their own development, because of the shortage of people at FOA.

The Missile Guidance and Sensor System Division (370) under G. Rosenquist, is mainly involved in both theoretical and experimental studies of guidance systems. There is an interesting mm wave project under A. Sume with plans for experimental 34, 60, and 94 GHz radar-radiometer comparison studies with variable polarization. Cassegrain antennas giving about 1° beam widths will be used. The study is being conducted in cooperation with the Radar Reconnaissance and Combat Control Division (360) under S. Jonsson and will include environmental and air, ground, and sea target characteristics. The use of pseudo colors for interpretation of displays will also be studied.

Chalmers University of Technology, Gothenburg

Professor E. Folke Bolinder, director of the Department of Network Theory in the School of Electrical Engineering, has a prime interest in phased-array antennas. Many different versions are being developed (ESN 34-10:470 [1980]), together with required components, i.e., phase shifters, switches, and strip line power dividers. Research is mostly supported by government or industrial

grants. Projects are briefly described below.

CHALMANT (CHALmers L-band Maritime ANTenna) is an L-band array intended for a ship-board communication-via-satellite system. There are two phased-array antenna panels on the same trainable pedestal, pointing to two different directions. Suitable cabling and diode switches select one of the two panels, and electronically adjustable phase shifters control the beam pointing direction up to $\pm 35^\circ$. Each panel has a square matrix of 8×8 radiating elements which are cavity-backed circular slots with selectable left or right hand circular polarization. About 20 dB of broadside gain has been achieved. The system has been successfully tested at sea. CHALME (CHALmers and L.M. Ericsson) is a 9-element X-band phased array with phase shifters and power dividing networks developed in a cooperative effort with the L.M. Ericsson Telephone Company. CHALPHAS (CHALmers PHased Array System) is an X-band 64-element system using dumbbell slots as radiating elements. The system was difficult to build and assemble. The phase shifters use ferrite meander lines. At this time work is in progress on a conformal array at L-band with 16 printed circuit radiators, each with a phase shifter, all on a nominal 1-meter diameter cylinder.

L.M. Ericsson MI Division, Military Electronics, Mölndal

The L.M. Ericsson Telephone Company employs some 80,000 people and is Sweden's largest manufacturer of electronics as well as the largest producer of defense electronics with its MI Division in Mölndal, near Gothenburg, where it employs some 2,000 people. Many different types of radar systems are produced there. It has the responsibility for equipping the new "Viggen" multipurpose aircraft for attack, reconnaissance, and interception. It produces the Giraffe (a mobile search pulse Doppler radar on a Swedish equivalent of a cherry picker); the Sky-guard (ground based fire control system); Peder (surveillance and tracking radar development in cooperation with UK's Marconi Radar Systems Ltd); MTI improvement kits (adaptable to other radars); laser range finders; and other equipment.

The MI Division is divided into marketing, engineering, and production. The Antenna Group is one of 5 groups in the engineering department. It has an excellent team with a total of 32 people working under the direction of Olaf Dahlsjö. Many different types of antennas are being developed, some for production and others only for preliminary research. There is much cooperation between the Antenna Group and Bolinder at Chalmers.

A flat plate experimental antenna for missile application has been developed at X-band, giving low side lobes in both sum and difference monopulse patterns. The antenna is about 5.5 wavelengths in diameter and only 7 mm thick. The aperture is divided into 16 sectors with a total of 52 strip line radiators. The plate consists of a multilayer strip line and combining networks, cleverly chosen to separately optimize the monopulse sum and difference patterns. Some assembly problems are still to be overcome. A broadband (40%) X-band phased array was developed for ECM. Electronic steering up to $\pm 60^\circ$ is in the E plane only and is achieved with Sedco Systems, Inc. (US) phase shifters. There are 16 radiating elements; they are H plane horns, adjacent in the E plane with a spacing of 0.3λ at the lowest frequency, and with a strip line corporate feed. Circular polarization is obtained with a wire grid in front of the aperture. On contract with the European Space Agency (ESA), an L-band, multibeam antenna aperture was developed to demonstrate feasibility for use with a satellite global communication system. A hexagonal aperture is formed by 18 short back-fire radiators. The antenna was tested with 18 power amplifiers supplied by Mullard Ltd (UK) and a beam-forming matrix built by Marconi Space Defence Systems Ltd (UK).

The repertory of production antennas includes a set of relatively thin X-band Cassegrainian twist reflectors 15 to 27 inches in diameter and giving sum and difference patterns with first side lobes about -30 dB and then dropping off rapidly.

DENMARK

The Electromagnetic Institute of the Technical University of Denmark (TUD)

The Technical University of Denmark, located in Lyngby, is the main technical training center in Denmark and accommodates some 3,000 students. The Electromagnetic Institute (ESN 35-1:12 [1981]) is part of the Electrical Engineering Department and has a staff of over 60 including some 15 PhD students and 11 professors or associate professors. Professors have freedom of choice of research work, at which they spend about 40% of their time, but to spend funds they do require approval from a committee on which all staff members, regardless of work assignments, have an equal voice. In principle, this even applies to funds obtained from outside for specific research jobs. In spite of this, the system seems to operate and a high standard of research is maintained.

A very large anechoic chamber is being administered by Dr. Jørgen Appel-Hansen, who is an associate professor. The inside dimensions of the chamber are about 9m x 12m x 10m, which is large by any standards, and lined with Emerson and Cuming absorber. The chamber has very low reflectivity, and can be used down to perhaps 20 MHz. It is well equipped with recorders, high-precision turntable, gimbal platforms, etc., and can be run by and interact with computers; especially, some of the more tedious measurements can be programmed.

The chamber is used for many different types of measurements but of particular interest to Appel-Hansen's group are various forms of near-field measurements of antennas, leading to accurate far-field predictions. Predictions of antenna gain have been shown to be extremely accurate. In one case the field was measured at 1.5, 2.5, and 5.0 m from the antenna giving a predicted far-field gain of respectively 36.85, 36.88, and 36.85 dB. The anechoic chamber is offered on a service basis with or without help by professional staff to perform measurements. The chamber itself rents (at the time of this writing) at a little less than \$50 per hour and has been used by organizations from all over the world, including some from behind the iron curtain.

There are a number of research programs for the improvement of near field measurements. Other research projects include a search for the best effective-phase center of a radiator or aperture (Torkeld Hansen); propagation of EM waves over vegetation (Ernest Krogager); and near-field studies with the aim of finding an antenna which gives a very plain field and a compact (close) range (Jørgen Hald).

Remote sensing research, under Prof. P. Gudmandsen, includes radiometric studies with 3 radiometers, 5, 17, and 34 GHz respectively. The system, described by N. Skou, has been used to obtain sea ice signatures in the Greenland area in work supported by the NSF, Washington, and the Ministry of Greenland. The results were used to compile ice data. It has been found possible to differentiate between new and old ice. In other remote airborne investigations of Greenland's ice and in other areas, the thickness of the ice was measured with 60 MHz and 300 MHz radars. Twenty meter accuracy was claimed up to 3,000-m depths. In a US-Danish cooperative effort, holes were drilled to examine the ice and to recover some of the histories locked in at the time that it was formed. The group has also

participated in another Greenland ice multisensor measurement experiment (optical, infrared, microwave), "SURSAT," as part of a Canadian project.

Still other investigations in Greenland use a real aperture side-looking radar mounted on an Otter aircraft for mapping. Gudmandsen describes much of the remote sensing work in "Electromagnetic Studies of Ice and Snow" published as proceedings of a seminar, "Remote Sensing Applications in Agriculture and Hydrology," ISPRA Establishment (Varese, Italy) 1980.

NORWAY

ELAB-Norwegian Institute of Technology (NTH)

The Electronics Research Laboratory (ELAB) is part of SINTEF, the non-profit Engineering Research Foundation at Trondheim's technical university, the Norwegian Institute of Technology (NTH). The staff of NTH and the appropriate laboratories and offices are often shared by SINTEF, so that to an outsider, it is not always very clear where the demarkation line is. ELAB is associated with the Department of Electrical Engineering at NTH and has a staff of 120 people. (SINTEF has a staff of 800.) The effect of this seemingly complicated arrangement is to make the high technical competence that is found at the university available to meet pressing needs of the government and industry. It is a noteworthy arrangement. Funds for ELAB come in about equal parts from industry, government institutions (e.g., the post office), and the Royal Norwegian Council for Scientific and Industrial Research (NTNF).

NTH is variously referred to in English as the Technical University of Trondheim, and the Norwegian Institute of Technology. It is the only university in Norway that offers technical subjects. There is much emphasis on the ocean, underwater acoustics, fishing, and offshore technology at this time, and only relatively little research in antennas and related microwave devices.

Prof. O.H. Longva described some of the past work on antennas which included 100/300 MHz log-periodic antenna arrays for an aircraft landing system and an L-band 48-element cavity-backed phased array with two faces for use with a maritime satellite communications system, similar to CHALMANT. At this time work is in progress on variously shaped printed patch-antennas to be used as single elements and as arrays. The major interest at the present time is on designing HF ship-antennas in the 1 to 15 MHz range. This is done with scaled copper models of the ship and is carried out as a regular service for new ship design. (With one existing system the study suggested changes resulting in a 6 dB improvement which was actually realized with the system when built.) Other work includes the design of radomes for Norwegian manufacturers (A/S Selco and Norcem).

Prof. Tor Hagard at NTH is director of the EISCAT (European Incoherent Scatter Association) Program (ESN 35-1:14 [1981]). This program calls for the installation of a UHF and VHF transmit/receive system at Tromsø for aurora borealis observations. At UHF, 933.5 MHz, the antenna is a mechanically fully steerable parabolic dish, 32.5 m in diameter, supplied by the Toronto Iron Works in Canada. Additional receivers, giving bistatic scattering information including Doppler, will be at Kiruna in Sweden and Sodankylä in Finland. Russia wants to participate and has offered to supply a third receiving site in Murmansk. Considerable problems have been encountered in the development of the high-power transmitter which is being purchased from the US and is 2 years behind schedule at this time. When in operation, 48 hours operation per week is planned with analysis being carried

out at Tromsø. The VHF antenna operates at 224 MHz and consists of an offset cylindrical parabolic reflector with a circularly polarized feed that was developed at NTH. The reflector is 40m x 120m and is mechanically steerable in the N-S plane on an axis parallel to the cylinder axis. The feed is a linear array of crossed dipoles above a ground plane. The two sets of dipoles are balanced with impedance matching rods. An effective antenna efficiency of about 70% was obtained. Two transmitters are available, one for each polarization. The antenna can be split into four adjacent parts, each 35 m long and each part can be pointed independently. The antenna has been built and tested with low power.

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