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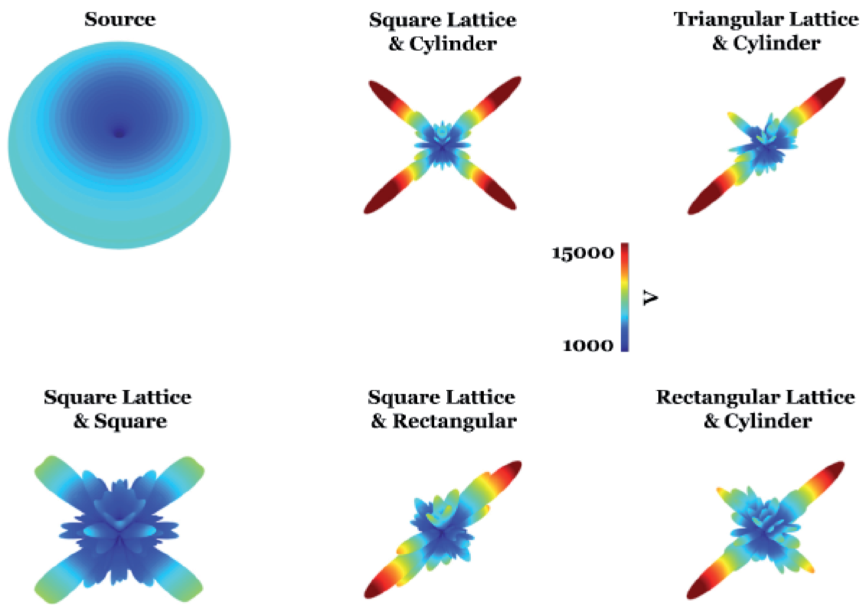

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Contents

Radio Science Bulletin Staff 3
URSI Officers and Secretariat 6
Editor's Comments 8
Metrology of Reflector Antennas: A Historical Review 10
Effect of Mountain Clutter on a VHF (206.5 MHz) Wind Profiler in the Central Himalayas 33
In Memoriam: Siegfried J. Bauer 40
Book Review 42
Et Cetera 44
Solution Box 45
Call for Papers AT-AP-RASC 2022 51
Historical Corner Column 53
Telecommunications Health and Safety 65
Women in Radio Science 69
URSI Commission Triennial Reports Available 75
Maxwell Foundation Newsletter Available 75
President's Address at the XXXIV URSI GASS 76
Report on Second Space Weather Workshop 80
Report on VERSIM 2020 82
URSI Conference Calendar 84
List of URSI Officials 85
Alphabetical Index and Co-ordinates 95
Information for Authors 116
Become An Individual Member of URSI 117

Cover: (top) A "bird's eye" view of the Aries ST RADar (ASTRAD) radar on the roof of the building, showing the fence constructed around the radar to reduce backscatter interference from surrounding terrain. See the paper by S. Bhattacharjee, M. Naja, and S. Ananthakrishnan. (bottom) The electric-field intensity in the far zone obtained for shell structures involving rods. Colors were used to represent field values with respect to observation directions. See the SOLBOX column contribution by Özgür Eriş and Özgür Ergül.

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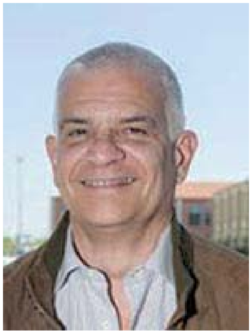

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ASTRID is a VHF (206.5 MHz) radar used for wind profiling. It consists of 12 clusters of 49 elements installed on a rooftop in the Himalayan region of India. When the radar began operation, it became clear that the signals scattered from the surrounding mountains produced such strong interference that the radar couldn't achieve its purpose. The paper by S. Bhattacharjee, M. Naja, and S. Anathakrishnan describes how the source of the problem was identified. The design and construction of a metal wire-grid fence surrounding the rooftop to shield the array from the interference is described, and the successful results of this solution were demonstrated with measurements. This is an example of where simple but clever engineering made the difference in an instrument being operational.

Some of the major factors determining the operating capability of a radio telescope are the shape and surface accuracy of the reflector. J. W. M. Baars has brought us a fascinating history of the metrology of reflector antennas. The paper begins with an explanation of the factors that go into determining the accuracy of a reflector's shape, and common requirements for a particularly accuracy in terms of wavelength. "Classical" reflector metrology is then reviewed, from using theodolites to laser trackers. The development of a variety of geodetic methods is explained, followed by several mechanical methods. The use of photogrammetry is traced from its beginnings until the present day. Finally, the now commonly used technique of radio holography in its several different forms is explained and examined in some detail. This paper is a very nice, comprehensive review of reflector metrology, written in such a manner as to be understandable by someone who is not an expert in the field.

Our Other Contributions

George Trichopoulos has provided us with a very nice review of the book, *Antenna and Sensor Technologies in Modern Medical Applications*, edited by Yahya Rahmat-Samii and Erdem Topsakal. The review was written by Mahta Moghaddam, and the book comes highly recommended.

You will enjoy Tayfun Akgul's Et Cetera column. Be sure to take a look at it.

Giuseppe Pelosi's Historical Corner presents an article by Stefano Selleri that looks at the origins and development of cryptography. I think you'll find this fascinating.

The remarks of the newly elected URSI President, Piergiorgio L. E. Uslenghi, made at the GASS 2021, appear in this issue.

Özgür Ergül's Solution Box column brings a contribution by Özgür Eriş and Özgür Ergül that considers electromagnetic interactions with near-zero-index shells constructed from dielectric rods. The near-zero-index properties result from the dimensions, spacing, and geometry of the rods. Depending on the geometry, quite interesting three-dimensional beams can be formed from the structures. The geometries and wavelengths involved make this a computationally complex problem, and also produce some very interesting results.

Jim Lin's Telecommunications Health and Safety column looks at some interesting instances in which politics may have influenced scientific results or the reporting thereof.

Asta Pellinen Wannberg's Women in Radio Science announces the formation of the first URSI Member Committee Women in Radio Science Chapter, with the chapter in the US National Committee. The officers are introduced, along with a description of several of the chapter's activities. It is hoped that all URSI Member Committees will establish similar chapters.

AT-AP-RASC and the End of the Year

Because of the shortened "triennium" between the GASS 2021 in Rome and the GASS 2023 in Sapporo, the decision was made to combine the two URSI flagship meetings, AT-RASC (Atlantic Radio Science Meeting) and AP-RASC (Asia-Pacific Radio Science Meeting) into a combined AT-AP-RASC, to be held in Gran Canaria May 29 - June 3, 2022. The call for papers for this meeting is in this issue. It will be a hybrid meeting. The paper-submission deadline is **January 15, 2022**. I urge you to submit a paper and plan on attending.

This issue will probably reach you around the end of the year. My very best wishes for most joyous holidays, and a very happy, healthy, safe, and prosperous New Year!

Ross

Metrology of Reflector Antennas: A Historical Review

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Dedicated to the memory of Albert Greve, metrologist extraordinaire

Abstract

The emergence of radio astronomy, space research, and satellite communication after World War II created great activity in the design and construction of reflector antennas of increasing size and precision, compared to the small radar antennas of the war period. With few exceptions, the reflectors consisted of a set of panels, typically a few square meters in size, that were supported on a backup structure. To be an effective reflector, the shape needs to obey the prescribed contour with a precision of about one-twentieth of the shortest operational wavelength. This was achieved with the aid of a continuously improving array of metrology methods, from the original geodetic theodolite-tape to current laser-trackers, digital photogrammetry, and radio holography. We review the historical development by summarizing the different methods and illustrating their applications with examples, mainly from the field of radio astronomy. It is here where the largest and most precise reflectors have been installed, and metrology has been pushed to a level where a reflector of 100 m diameter can be realized with a surface error of about 250 µm, and a 12 m diameter submillimeter telescope with an error of about 10 µm. The reference list is not exhaustive: it covers major papers of a general nature and detailed descriptions of the examples presented in the text. Table 1 provides a list of the acronyms used in the paper.

1. Introduction

When Grote Reber [1] designed his 10 m diameter parabolic reflector in 1936, his plan was to observe the sky at the highest possible frequency. He believed that the radiation from the region around the center of the Galaxy, discovered in 1932 by Karl-Guthe Jansky [2], would be of thermal origin, and hence would increase in intensity with increasing frequency. He thus started his observations at 10 cm wavelength, the shortest wavelength

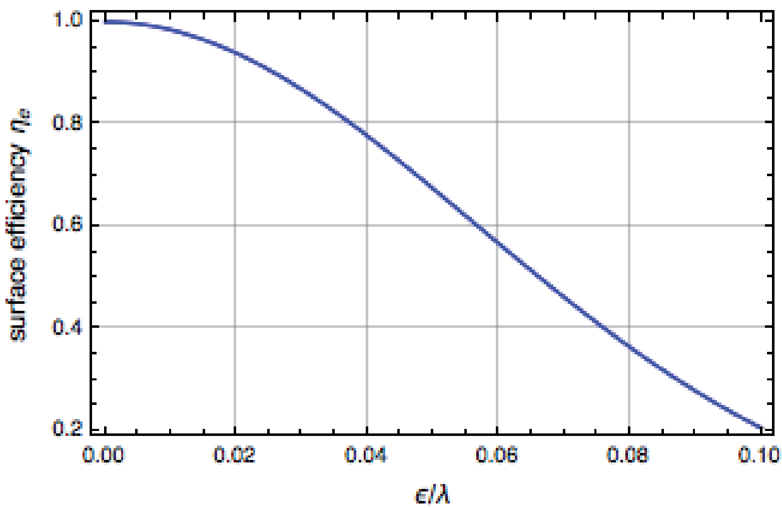


Figure 1. The "Ruze" curve shows the "surface scattering efficiency," η_S, as a function of the surface rms error, ε, normalized to the wavelength, λ.

where electronic components were available at the time. How precisely should his reflector have represented a paraboloid? He applied the criterion due to Rayleigh and used in optics that the maximum deviation of the mirror should be less than one-quarter of a wavelength (positive or negative, thus half a wavelength peak-to-valley). If we assume these errors to be randomly distributed with a Gaussian distribution, the rms error would have to be less than about one-tenth of the wavelength. In 1952, John Ruze [3] published his "tolerance theory" of random errors in the reflector profile. We there found that an error of $\lambda/10$ rms leads to a loss of efficiency of 80%. Most users found this an unsatisfactory situation. A value of $\lambda/16$ is often considered the limit, where the efficiency is decreased to about one-half (Figure 1).

Eventually, Reber observed at about a 2 m wavelength, and his reflector could be considered perfect. However, if one wants to observe at the submillimeter wavelength of 0.35 mm, a surface rms error of $\lambda/16$ means a surface precision of 22 μm! This is close to the specification of 25 μm for the 12-m antennas of ALMA, the Atacama Large Millimeter Array in northern Chile [4]. To achieve such performance not only requires fabrication capabilities of high quality, but also measuring methods to demonstrate both the manufacturing precision and the setting of the reflector panels to the required precision on the telescope's structure. This involves metrology methods and instruments with an accuracy of better than 10 μm "in the field."

Most large reflector antennas have a surface composed of a number of surface panels, placed in concentric rings of trapezoidal panels on a supporting backup structure (BUS) by means of adjustable screws that we shall call adjusters. The overall precision of the reflector surface is the superposition of the following components of errors:

i) The manufacturing precision of the individual panels, indicated by ε_p ;

ii) The gravitational deformation of the panels and the supporting backup structure, ε_b ;

iii) The deformations caused by temperature differences in the structure and by wind forces, ε_T ;

iv) The accuracy of the adjustment of the panels by the chosen method of surface metrology, ε_a

It is reasonable to consider these error contributions to be independent from each other. The overall root-mean-squared (rms) reflector error, ε_R , can then be written as

$$\varepsilon_R = \sqrt{\left(\varepsilon_p^2 + \varepsilon_b^2 + \varepsilon_T^2 + \varepsilon_a^2\right)} \,. \tag{1}$$

Considering that the desired overall surface error should be less than about five percent of the shortest wavelength, and assigning equal contributions to the four aspects above, we see that the desired measuring and setting accuracy must be of the order of two to three percent of the shortest wavelength. For a 25 m telescope operating at 10 cm wavelength, the measuring accuracy should be about 2 mm. For a 12 m submillimeter telescope operating at 0.3 mm, we would need 6 μm measuring accuracy, i.e., a half-millionth of the reflector's diameter. This is a formidable requirement, in particular if it has to be fulfilled in the field. There are several routes along which the problem has been attacked, and the purpose of this paper is to present a historical review of the methods and instruments that have been developed and applied over the lifetime of radio astronomy, about 75 years. The presentation will be descriptive and illustrated by selected examples with references to the original papers. Estler et al. presented an exhaustive general review of large-scale metrology with 133 references, not limited to reflector antennas, in 2002 [5].

Apart from the measurement and setting of reflector surfaces, other aspects of the construction and operation of large and accurate – and hence short-wavelength – reflector antennas can be discussed under the general designation of metrology. An obvious example is the pointing and tracking precision under operational conditions. Temperature variations and wind influence cause deformations in the structure, which lead to pointing errors that cannot be sensed by the encoders. In order to correct for these in real time, one has to install a sensor system with accompanying algorithms that determines the structural deformation, and provides correcting data to the pointing control system. Such active systems are known as Flexible Body Compensation (FBC) [6]. They include the use of Finite Element Analysis (FEA) in correcting deformation due to gravity and measured temperature differences in the structure, along with sensors for directly measuring structural deformations that lead to pointing errors. These aspects warrant a separate paper.

2. Classical Reflector Metrology: From Theodolite to Laser Tracker

There are very few radio telescopes with a continuous reflector, fabricated in one piece. A major example was the NRAO 36-ft mm-telescope, machined in the mid-sixties in one piece on a large lathe to an accuracy of about 100 μm. That was a factor of two worse than specified. Moreover, after assembly on Kitt Peak, it soon became clear that there were serious thermal problems. However, readjusting the surface was impossible. Eventually, the reflector was replaced in 1983 by a traditional paneled reflector of 12 m diameter [7]. The usual way to form the reflector is to divide the surface into a number of concentric rings, and to place individual surface panels, typically of one to two square meters in size on a backup structure through adjusters. This assures the possibility of adjustment of the composite surface to a desired contour. The panels are fabricated to a certain specification and their accuracy is checked in the shop before delivery. Sometimes, the

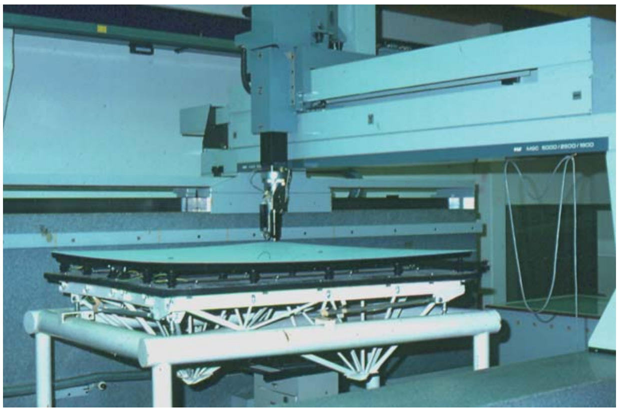


Figure 2. The support frame with two panels of the Millimeter Radio Telescope's surface in coordinate measuring machines. The measurement accuracy was <5 µm, and the average panel surface error was 27 µm.

machine with which the panel surface has been shaped is also used to measure the resulting surface, which involves the danger of overlooking systematic errors in the fabrication process. Modern, large coordinate measuring machines (CMM) allow the measurement of panels of several square meters to an accuracy of a few micrometers. This can be done for the measurement of single panels, or during the assembly of a number of small tiles on an intermediate support subframe [8]. An example is shown in Figure 2, where two panels of the IRAM 30-m mm-radio-telescope (MRT) were measured and adjusted on a joint subframe in a large coordinate measuring machine in 1979 [9]. A similar layout was used on the Large Millimeter Telescope (LMT) in Mexico with subframes of about 10 m^2 , each carrying eight panels. There, the original setting was done on a coordinate measuring machine in the shop. A check and fine adjustment just before mounting on the telescope was performed with a laser tracker [10].

The reflector surface normally will thus consist of a large number of panels, each with its own small-scale manufacturing error and possibly intermediate-scale deformation due to gravity and temperature, placed through adjusters on the backup structure (BUS) with a certain adjustment error. The backup structure itself will deform under the influence of gravity, wind, and temperature, leading to relatively large-scale errors. A metrology system is needed to determine the correct setting of the adjusters. Often, the actual adjuster setting also considers *a priori* knowledge about the intrinsic deformation of the panels – for instance, warp – by applying small offsets. In the following sections, we review the "geodetic" and "mechanical" methods that have been applied for the measurement of panel setting and reflector surface precision.

2.1 Classical Geodetic Methods: Measuring Distance and Angle

The classical method is to measure angle and distance to a point on the surface from a point on the reflector axis, often the vertex, with theodolite and measuring tape. The tape is either laid along the surface or stretched between two points. In the latter case, a correction for the sag of the tape must be made. The angle measurement is sensitive to variations in the refraction along the path, which can be significant on large reflectors. Greve performed the original setting of the Effelsberg 100-m telescope with this method, and achieved an uncertainty of < 1 mm in the final calculated rms surface error [11]. Using the same method, he set the original surface of the 30-m millimeter telescope on Pico Veleta to 150 µm [12]. These are among the best-ever values reached with this method, and they involved very careful and cautious measuring and attention to outside influences, such as temperature and humidity. The tape measurement can be avoided by measuring two angles from positions on the axis a known distance apart (Figure 3). This introduces twice the refraction variations in the sight line, while the error in tape measurement translates only for a small part into a vertical setting error for reasonably flat reflectors. This measurement will thus be slightly less accurate. An advantage is that it can more readily be used on a reflector pointing outside the zenith. This scheme was applied in 1966 with an alignment telescope positioned along the reflector axis and a set of pentaprisms stacked along this axis and pointing at the concentric rings of targets on a 30 m communication ground station, and achieved a precision of 0.5 mm [13]. At the Parkes radio telescope in Australia, a rapid and automatic method was developed whereby targets reflected in a mirror set at known angles were photographed. Measurements could be made at the operating elevation angle with the goal of removing structural deformations due to gravity, wind and temperature variations. The achieved accuracy was about 1 mm rms [14],

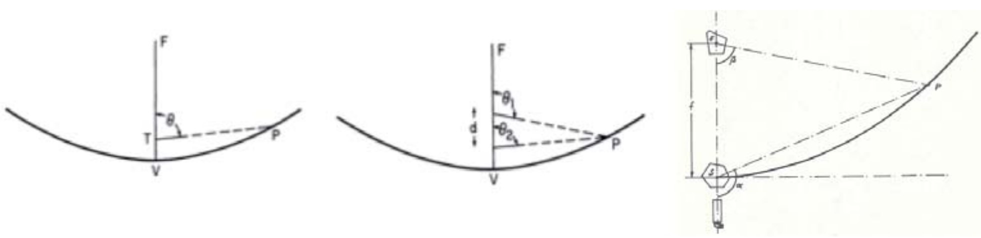


Figure 3. The "classical" methods with theodolite (θ) and tape (TP) (left); "two-angle" with known d (center); using two pentaprisms (right).

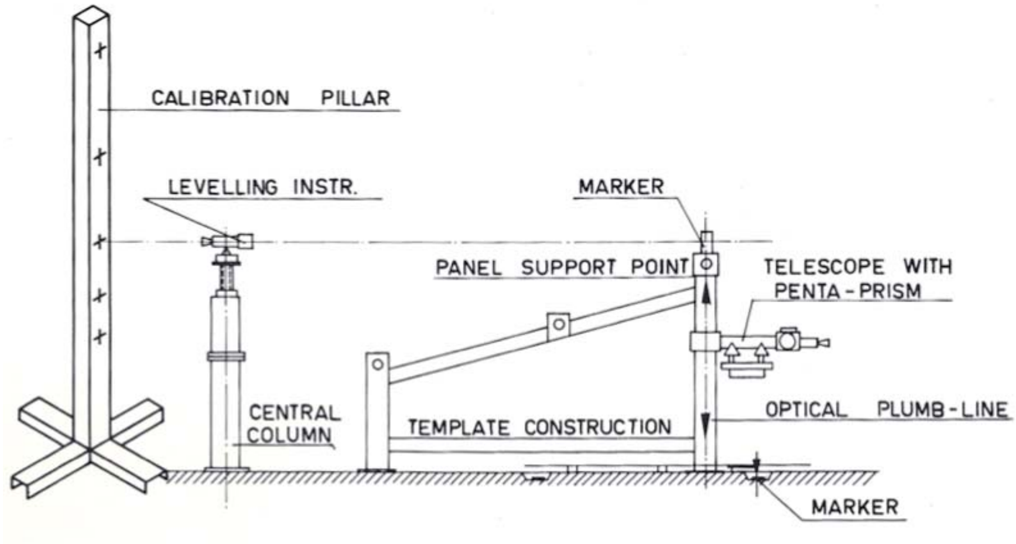


Figure 4. The measuring system used during assembly of the Westerbork Synthesis Radio Telescope dishes. The setting of the template points for the support of the reflector surface panels was done with respect to the calibration pillar and markers on the floor.

An alternative geodetic method applies an automatic level instrument, as, for instance, in the assembly of the reflectors of the Westerbork Synthesis Radio Telescope (WSRT) in the Netherlands. The surface panels and backup structure of the 14 dishes of this array were assembled in a template that was placed in a temperature-controlled assembly hall (Figure 4). The template provided support pins for the panels at precise height and radial coordinates. These were set radially by an optical plumb line, a telescope with attached pentaprism, to markers on the floor, and in height by an automatic level instrument in comparison to a calibration pillar with markers. After the panels were connected to form the reflector surface, but before they were attached to the backup support structure, the surface was measured with the level at several hundreds of points, and adjustments were made by shimming where needed. The accuracy of the method was about 0.1 mm: the reflectors showed a final rms of 1.5 mm, a factor of three better than the original specification [15]. Radiometric measurements at several wavelengths confirmed the overall reflector precision.

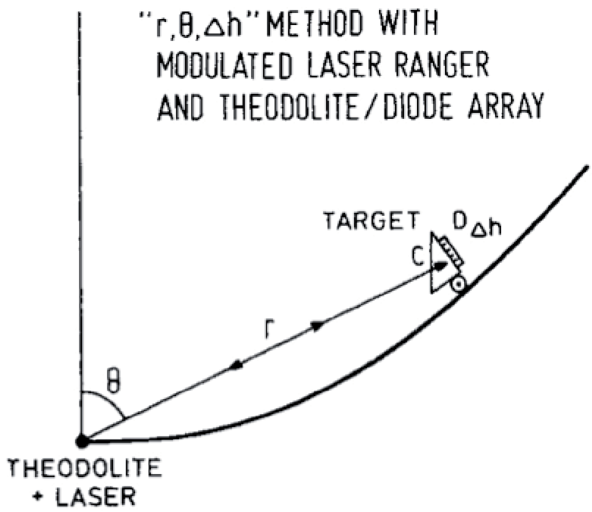


Figure 5. The principle of the laser ranging and height measurement of the reflector of the MPIfR/IRAM 30-m millimeter telescope.

2.2 Advanced Geodetic Instrumentation

In the nineteen seventies, new distance and angle measurement instruments were developed that were based on lasers. Early versions of an instrument based on the principle of "laser-ranging" were presented by Payne [16] at NRAO in 1973, and by Greve and Harth [17] at the Max-Planck-Institut für Radioastronomie (MPIfR) in 1984. The MPIfR instrument was developed for the adjustment of the 30-m Millimeter Radio Telescope (MRT). The principle is shown in Figure 5. To avoid atmospheric fluctuations, the light was sent through a closed duct that could be moved over the surface. At the end the target, a retro-reflector returned the light to the theodolite for the measurement of the distance, r, while a diode array measured the variation in height of the surface, Δh, with respect to the theoretical value set by the angle θ. It showed a measuring accuracy of about 50 µm rms, and was used during the initial setting of the surface of the Millimeter Radio Telescope in 1982. The instrument did not come into routine use because of problems with the laser attachment to the theodolite, which would have required significant changes to the layout. Hewlett Packard introduced the laser-interferometer, which enabled the measurement of changes in the distance to a target at distances of the order of ten meters with an accuracy of one in a million. This instrument was used in the metrology

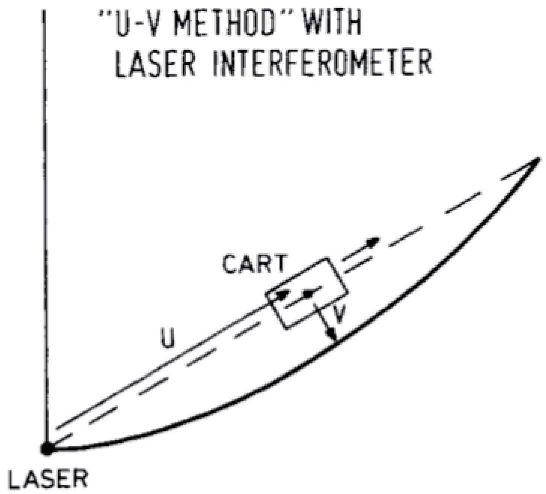


Figure 6. The principle of the laser-interferometer measurement of the UK/NL James Clerk Maxwell Telescope's 15-m submillimeter-telescope.

system proposal for the James Clerk Maxwell Telescope, a 15-m submillimeter telescope on Hawaii (Figure 6). A cart with a retro-reflector was pulled along a beam from center to reflector edge, and continuously measured the changes in the coordinates, *u* (radius), and *v* (depth), from which the coordinates of the surface can be derived [18]. Tests in the laboratory indicated a measuring accuracy of ~20 µm rms over ~10 m distance. Deployment on the telescope showed some weakness in the mechanical system and an unexpected sensitivity to vibrations. Routine use was also not realized. It seems fair to note that the principles and experimental realizations of both these instruments were original, and showed the feasibility to achieve the stated use. However, the instruments were obviously not engineered and fabricated to the level where field operation could be assured. Originating in physics/electronics research laboratories, they lacked the detailed engineering that industrial engineers could have provided. Both groups decided to abandon their methods and switch to applications of radio holography, to be described below, which by the early 1980s had caught the interest of radio astronomers.

Leica and Automated Precision Inc, (API) introduced the commercial laser-ranger integrated in a theodolite for a simultaneous measurement of both angle and distance to a target. Such an instrument is also called a *total station* or a *laser tracker*. The target contains a retro-reflector for the range measurement that is based on a phase measurement of a modulated laser beam. Current commercial laser trackers are routinely used for the measurement and setting of reflectors. The typical accuracy is 1 arcsecond in angle and $(10 + 5/\mathrm{m})$ µm in distance. The measurement is analyzed in real time, and allows the immediate adjustment of panel position. A great advantage of the laser tracker is that it will automatically follow (track) the target while it is moved over the reflector's surface, and data can be obtained at any position. Figure 7 shows the layout of the Leica Laser Tracker, and a picture of the instrument. A similar instrument, manufactured by Faro, was applied for the initial setting of the "European" AEM antennas of ALMA, whereby a surface accuracy of 35 µm rms was achieved on the reflectors of 12 m diameter. The measuring accuracy was estimated to be ~25 µm.

A further development was the Laser Scanner, also called Laser Radar, that operates without the need of targets. This enables the scanning of the reflector at varying elevation angles even during operation of the telescope. A Leica terrestrial Laser Scanner was used for a deformation study of the Effelsberg 100-m telescope in 2013. The elevation-dependent focal length could be

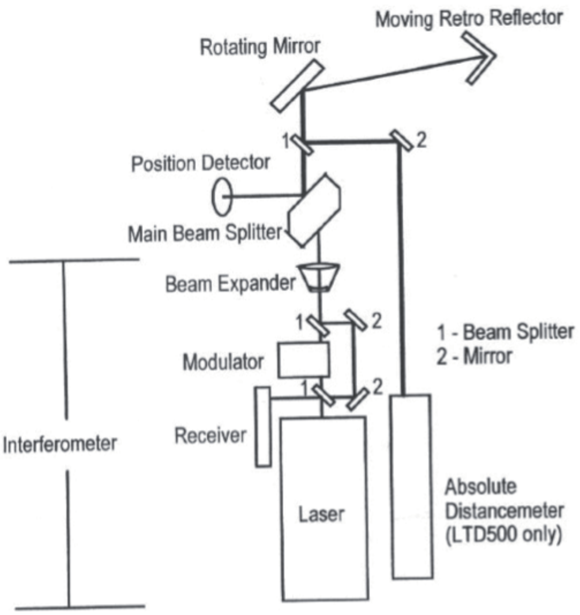


Figure 7a. The functional layout of the Leica Laser Tracker.

Figure 7b. A photo of the Leica Model 403 Laser Tracker.

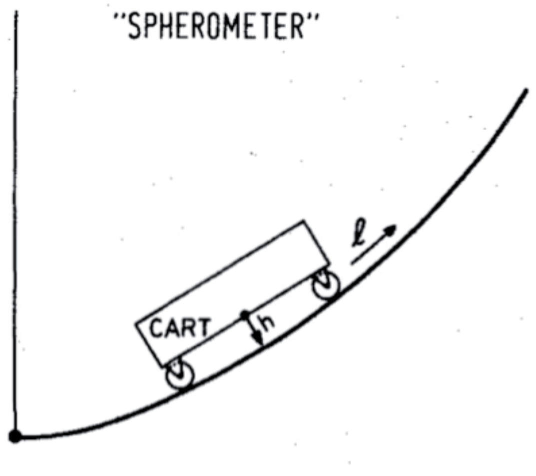


Figure 8. The "spherometer" cart developed for the NRAO 36 ft millimeter telescope.

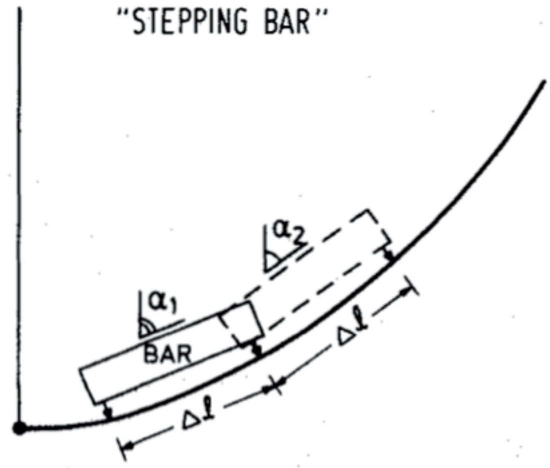


Figure 9. The "stepping bar" method applied at the NRAO 140 ft radio telescope.

monitored with an accuracy of better than 0.1 mm, while the standard deviation of the distance measurement over 50 m was about 1.3 mm [19]. The Laser Scanner/Radar appears particularly suited for large telescopes with remotely controlled adjusters of the surface panels. When sufficiently accurate scans of the surface can be obtained in quasi-real-time, the online correction of time-variable deformation, due to wind or temperature variations, becomes feasible. This is being planned for both the 64-m diameter Sardinia Radio Telescope (SRT) and the 100-m Green Bank Telescope (GBT). First tests on the Green Bank Telescope with LASSI (Laser Antenna Surface Scanning Instrument) based on the Leica ScanStation P40 led to a full design effort starting in 2020 [20]. First tests showed that deformations of about 55 μm can be determined in about five minutes if the wind speed is less than 4 m/s. The goal is to operate the system during daytime when the thermally induced deformations are most critical. A system for real-time surface correction, using six Digital Photogrammetric Units and three long-range Laser Trackers, is under development by Automated Precision Inc. for the 500-m Arecibo-type fixed reflector FAST (Five-hundred-meter Aperture Spherical Telescope) in China. The goal is to measure the absolute position of 1000 reflector panels to an accuracy of 2 mm within one minute of time [21].

2.3 Alternative "Mechanical" Methods

In the context of this historical review, we briefly mention a few original methods of surface metrology that were developed for a particular telescope or application. They have not penetrated into the arsenal of ubiquitous use.

2.3.1 The Spherometer

A measurement of local curvature and distance can be made with a spherometer, typically consisting of a cart with an encoder on the wheels to measure the track, l, along radials on which a depth sensor measures the local depth, h (Figure 8). A twice-repeated integration delivers the profile of the reflector. Payne et al. [22] made experiments and demonstrated the feasibility of this method, achieving an rms accuracy of ~40 μm on the NRAO 36-ft mm-telescope.

2.3.2 The Stepping Bar

An alternative is the stepping bar of length Δl with an inclinometer, stepped along a radius and measuring distance and angle, α, step-by-step (Figure 9). Again, after integration of the data, the profile can be derived. Tests by Findlay and Ralston on the NRAO 140-ft telescope indicated that an accuracy of 40 μm could be reached on a proposed 25 millimeter telescope [23].

2.3.3 The Owens Valley Radio Observatory Method

A unique and sophisticated setup for measuring, accurately shaping, and fabricating highly accurate reflectors was developed by Robert Leighton at Caltech in the mid-seventies [24]. The goal was to develop an economical method to deliver a millimeter telescope for the Owens Valley Radio Observatory (OVRO) with a diameter of about 10 m, with good performance at 1 mm wavelength. The plan was to produce some four or five of these to establish a mm-wavelength array. Eventually, the fifth antenna, with a surface error of about 25 μm, was placed on Mauna Kea, Hawaii, as the Caltech Submillimeter Observatory (CSO). The method employs the geometric characteristic of a parabola and is shown in Figure 10. The ray of the HP laser-interferometer (LI) is deflected through 90° by the pentaprism, P, located on the slave cart, SC, that runs on the horizontal directrix template, T_D. It then hits mirror, M, on the cart, C, that moves along the parabolic template, T_C. The ray now travels to the focus, F, of the

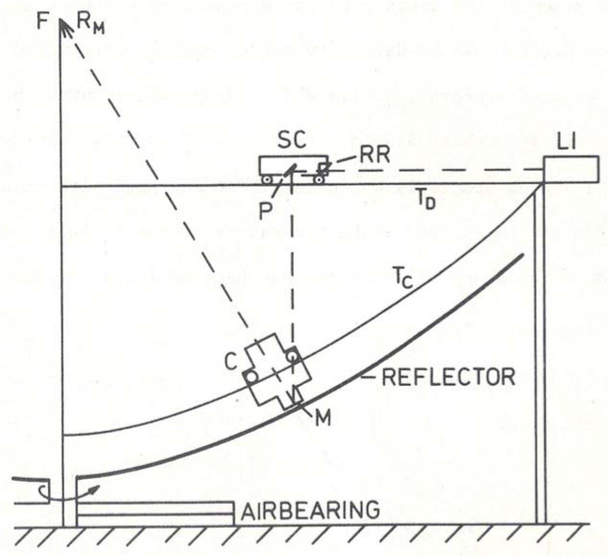


Figure 10. A sketch of the laser interferometer system devised by Leighton for the Caltech millimeter array.

parabola, where it is sent back on its path by the retro-reflector, R_M , via M to P on the slave cart. The path PMF must be constant for any position of M on a parabola. The returning ray is reflected to LI by the retro-reflector RR on SC. The template T_C is adjusted until the interferometer indicates a null: M hence lies on the parabola. With T_C accurately established, mirror M is replaced by a cutting head that brings the top layer of the aluminum honeycomb of the reflector into the parabolic shape. During the cutting, the entire reflector rotates about its axis, supported on an existing air bearing, used for the grinding of the Palomar 5 m optical mirror. After attaching the thin aluminum top sheet, the reflector is measured and small-scale fine cutting is applied to increase the precision. A detailed description was given by Woody et al. [25].

Most methods mentioned up to now require moving people and targets over the surface, and hence are essentially limited to measuring in the zenith position of the telescope. In operation, the antenna will occupy an intermediate elevation angle for most of the time, and it is highly preferable to set the surface to the best accuracy at such an elevation angle. We are thus interested in a non-contacting method to determine the reflector profile at an arbitrary elevation angle. We have mentioned above the Laser-Scanner that may enable correction for time-dependent structural deformation. We now direct our attention to an alternative method of quickly collecting sufficient data for the determination of the detailed shape of a reflector.

3. Photogrammetry

The three-dimensional shape of an object can be derived from the analysis of a number of photos taken by one or more cameras at a number of predefined positions. This process is called photogrammetry. In order to measure the detailed shape of the reflector, a sufficient number of targets are attached to the surface that are photographed under different angles by the camera(s). A small number of targets define the reference plane. From the photographic positions of the remaining targets, their three-dimensional position with respect to the reference plane can be derived. Comparing the data with the theoretical numbers for the perfect paraboloid delivers the “error distribution” of the actual reflector surface. In the case where the reflector is composed of individually adjustable panels, the measured deviations can be (partially) removed by adjusting the heights of the panels.

The first application of photogrammetry on a radio telescope occurred in late 1962, when John Findlay at NRAO in Green Bank arranged for the company D. Brown

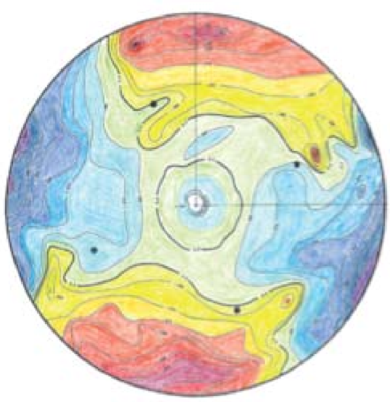


Figure 11a. A photogrammetric measurement of the 85-ft radio telescope at NRAO from a helicopter in 1962. This shows the map in the horizon-looking position: it shows a strong systematic astigmatic deformation. The contour interval is 1.5 mm; the rms deviations are about 3 (left) mm and 6 mm (right) (after Findlay [26]).

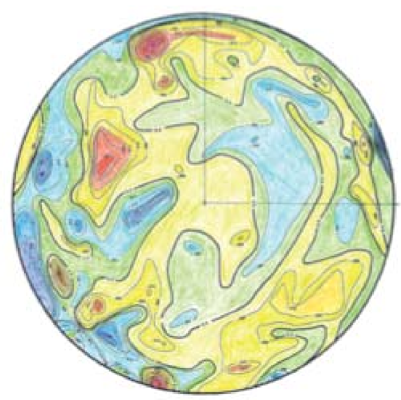


Figure 11b. This map in zenith position indicates a more random distribution of deviations. The contour interval is 1.5 mm; the rms deviations are about 3 (left) mm and 6 mm (right) (after Findlay [26]).

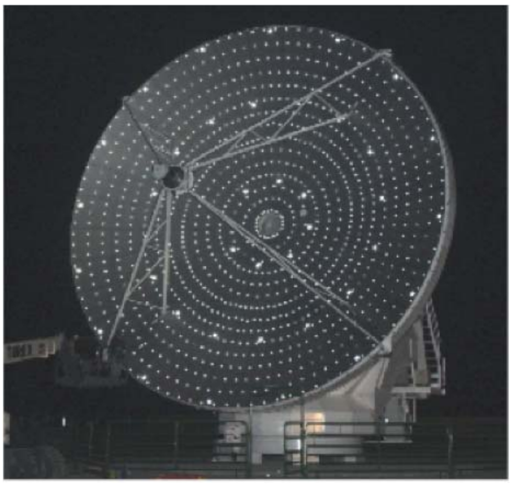


Figure 12a. Photogrammetry on an ALMA prototype antenna: a picture of the reflector with targets. The bright targets are calibration targets, while the lighter targets are the measurement grid.

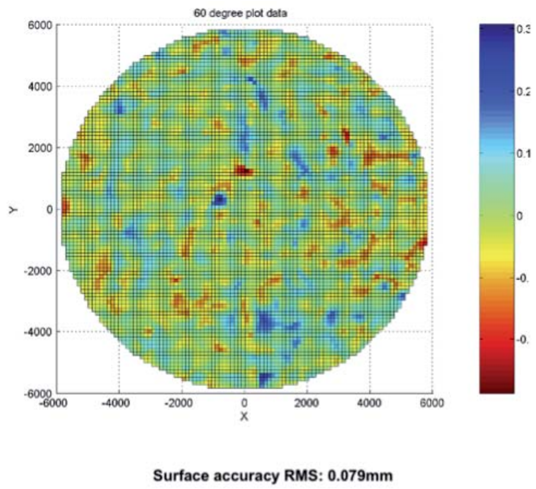


Figure 12b. Photogrammetry on an ALMA prototype antenna: a map of the surface deviations.

Associates of Florida to perform a photogrammetric survey of the 300-ft and 85-ft telescopes. About 300 targets were attached to the reflector surface of the 300-ft telescope. A special camera with an ultra-flat glass plate was mounted on a helicopter, and three photographs were taken at strategically chosen angles with respect to the reflector's axis at a distance of about 600 m. Data were obtained with the telescope pointed at 0°, 30°, and 51° zenith distance, respectively. Similar measurements were obtained of the 85-ft telescope in zenith and horizon positions. These results are shown in Figure 11. The rms measurement accuracy was estimated to be 4 mm on the 300-ft and 1.5 mm on the 85-ft telescope [26]. This was acceptable at the time, but clearly insufficient for the next generation of radio telescopes for short cm-wavelengths that require a surface precision of 1 mm or less.

In the two decades after the measurements of the NRAO telescopes, photogrammetry was barely used for the setting of radio telescopes reflectors, but the technology of the cameras and measurement machines along with software was steadily improved, notably by the Brown Company. By 1984, the company name had become Geodetic Services Inc. (GSI), and a new highly improved system, based on a microprocessor-controlled large film (23 cm × 23 cm) camera had been developed and marketed [27]. This system was used in 2000-2001 at the 300 m diameter spherical antenna of the Arecibo Observatory, after its second major upgrade, which was completed in 1997. Six cameras, mounted on the cable support towers of the antenna, were used to photograph the enormous area of the reflector. A total of 48 images were obtained to determine the positions of the 40,000 targets of 7 cm diameter that were attached to the surface. An rms value of 0.3 mm in each coordinate of the target was achieved, corresponding to an accuracy of 1 part in 1 million [28].

The emergence of digital cameras and advanced data-analysis methods has significantly widened the capabilities and areas of application of photogrammetry. Recently, there has been a growing use of the method for the measurement of large and highly accurate radio telescopes. The method is quick and relatively simple in its execution; it is non-contacting and hence applicable at varying antenna elevation angles. It thus is quite convenient in the early stages of antenna commissioning to remove the errors incurred in the initial setting of the surface panels. Being able to measure the reflector at several elevation angles provides data on the gravitational deflections in the structure, and enables a quantitative check on the quality of the structural finite-element model. For large telescopes, such as the Large Millimeter Telescope and the Green Bank Telescope, that rely on real-time adjustment of the reflector panels' positions to offset gravitational deflections, this is particularly advantageous.

In the early years of the twenty-first century, photogrammetry was used to characterize the two ALMA prototype 12-m antennas at the site of the VLA in New Mexico. Figure 12 shows one of the ALMA antennas with the calibration targets as bright spots and the measurement array of weaker dots. A result with an rms error of 79 μm is shown on the right side. The photographs were taken with a digital camera from a cherry picker that was moved through a number of positions at more than 5 m distance from the nearest edge of the reflector, to obtain between 100 and 150 images in a time of about 15 minutes. In the example here, the measured rms error of consecutive setting iterations converged from 400 to 70 micrometers in seven iterations. By making photos at several elevation angles between 5° and 90°, accurate data could be derived for the change in focal length and the stability of the focus with varying temperatures [29].

Table 1. Acronyms

AEM	Alcatel-European Industrial Engineering-MT Mechatronics
ALMA	Atacama Large Millimeter Array (Chile)
API	Automated Precision Inc.
BUS	BackUp Structure
CMM	Coordinate Measuring Machine
COMSAT	Communications Satellite Corporation
CSO	Caltech Submillimeter Observatory
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
ESA	European Space Agency
ESO	European Southern Observatory
FAST	Five-hundred-meter Aperture Spherical Tele scope (China)
FBC	Flexible Body Compensation/Control
FCRAO	Five College Radio Astronomy Observatory
FEA	Finite-Element Analysis
FEM	Finite-Element Model
FT	Fourier transformation
GBT	Green Bank Telescope
HHT	Heinrich Hertz Telescope
HPBW	Half-power beamwidth
INAOE	Instituto Nacional de Astrofísica Óptica y Electrónica (Mexico)
IRAM	Institute for Radio Astronomy at Millimeter-waves
ITALSAT	Italian (Ka-Band) Satellite
JCMT	James Clerk Maxwell Telescope
JPL	Jet Propulsion Laboratory
LES	Lincoln-laboratory Experimental Satellite
LMT	Large Millimeter Telescope (Mexico)
MIT	Massachusetts Institute of Technology
MPIfR	Max-Planck-Institut für Radioastronomie
NAIC	National Astronomy and Ionosphere Center
NASA	National Aeronautics and Space Administra tion
NRAO	National Radio Astronomy Observatory
OOF	Out-Of-Focus
OVRO	Owens Valley Radio Observatory
SKA	Square Kilometre Array
VLA	Very Large Array
WSRT	Westerbork Synthesis Radio Telescope

Later photogrammetry measurements by Hills and Schwab [30] indicated from repeated measurements an rms error of a measurement of the reflector of between 20 μm and 30 μm. This was about equal to the surface specification (25 μm, goal 20 μm). At this requirement level, photogrammetry is thus not yet a viable method for final panel adjustment. However, it offers a relatively easy and fast solution for initial measurement and setting. Interestingly, the accuracy was sufficient to show a systematic spherical aberration in the surface of both the "European" and "American" prototype antennas. Coincident with this finding, an error in the holography software was identified by Robert Lucas that causes such an aberration (see below). Indeed, the antennas had previously been set with the erroneous holography package, thereby introducing the systematic error.

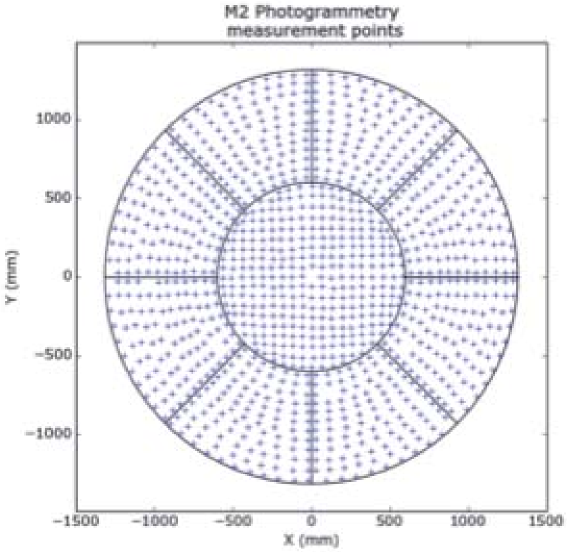


Figure 13a. Potogrammetry on the Large Millimeter Telescope subreflector, showing the sampling grid.

Figure 13b. The measurement setup for potogrammetry on the Large Millimeter Telescope subreflector. The camera (upper left) was moved to measure several hundred positions in three dimensions. Calibration bars are visible in the lower-left corner.

The Large Millimeter Telescope subreflector (diameter 2.5 m) was measured in the shop with both a laser tracker and photogrammetry [31]. The measured rms deviation of the hyperbolic surface was about 27 μm with the laser tracker and 24 μm with photogrammetry. Difference surface maps indicated a residual measurement rms error of 15 μm - 20 μm for the laser tracker and 10 μm - 12 μm for photogrammetry at these short distances in a laboratory environment. While this was a very good result, the stable laboratory environment in which the measurements were taken undoubtedly helped it. A measurement of an exposed telescope will suffer from environmental effects, such as wind, temperature, and humidity.

Photogrammetry has recently returned on the scene for the measurement of large telescopes, notably the 50-m

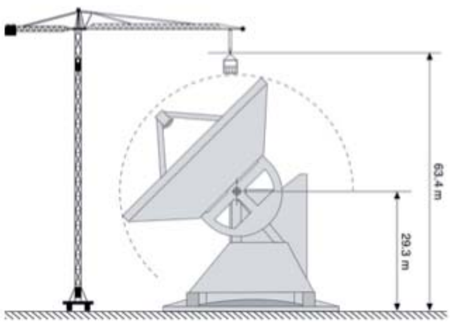


Figure 14a. The setup for photogrammetry of the Large Millimeter Telescope reflector. The crane carries the camera (upper left).

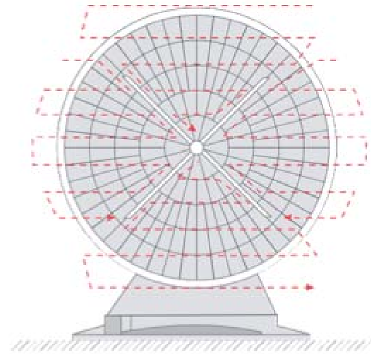


Figure 14b. The measurement pattern for photogrammetry of the Large Millimeter Telescope reflector.

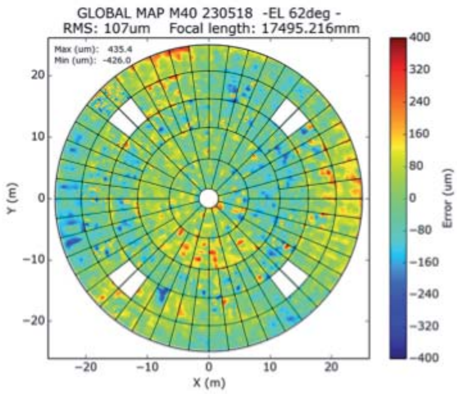


Figure 14c. The map of surface deviations indicates an overall rms of 107 µm for the Large Millimeter Telescope.

Figure 14d. A photo of the Large Millimeter Telescope.

Large Millimeter Telescope (LMT) in Mexico and the 64-m Sardinia Radio Telescope (SRT). Both telescopes employ a paneled surface supported on remotely controlled adjusters. A first use of these is the correction of elevation-dependent gravitational deformations on the basis of Finite-Element Model (FEM) predictions. Eventually, real-time thermal- and wind-induced deformations might be corrected with the adjusters. Next to the Large Millimeter Telescope on its 4600 m high site is a 60 m tall tower crane that enables the relatively easy execution of photogrammetric reflector surface measurements (Figure 14). From repeated measurements under stable weather conditions, an rms measurement error of about 70 µm has been derived [32]. After applying the surface corrections with the remotely controlled adjusters, the overall reflector showed an rms error of about 100 µm. There appears to be room for improvement, in particular with a more accurate radio-holography surface measurement, to be discussed below.

The capability of photogrammetry to measure and monitor structural deformation in a telescope is well illustrated in the study by Subrahmanyan of the 22-m diameter Cassegrain antenna of the Australia Telescope Compact Array [33]. Not only the large-scale deformation of the main reflector surface but also displacements of the subreflector and its quadripod support structure were measured at a number of antenna elevation angles. The relative positions of the targets on the structure could be measured with an accuracy of about 1:500,000, while the absolute position was determined to 1:60,000. Displacements of the subreflector of about 0.1 mm could be reliably determined. At the SRT on Sardinia, Italy, photogrammetry has been extensively used during on-site construction, erection, and alignment. A detailed comparison was made between Finite-Element Models and photogrammetric results [34]. Photogrammetry of the reflector suggested measuring errors ranging between 30 µm and 90 µm rms. This probably reflects the time-varying atmospheric situation between measurements. There are plans to use real-time photogrammetry for on-line deformation correction through the panel adjusters. The contractor, COMSAT, used photogrammetry for the demonstration of the surface specification during the delivery procedures of the Green Bank Telescope (GBT) in June 2000.

Table 2 contains both the measurement accuracy and the actual reflector accuracy (rms). The *measurement accuracy* is often estimated by taking the difference of two or more consecutive measurements. In other words, it

Table 2. Photogrammetry of Radio Telescopes

Institute	Location	Telescope	Diam. (m)	Accuracy (μm)		Data	Year	Ref.
				Measurement	Surface			
NRAO	Green Bank	85-ft	26	1500	3000	Plate	1962	26
NAIC	Arecibo	Sphere	300	500	5000	Film	2001	28
ALMA	New Mexico	Vertex	12	20	30	Digital	2005	30
CSIRO	Australia	ATCA	22	50	200	Digital	2004	33
INAF	Sardinia	SRT	64	–	<300	Digital	2015	34
INAOE	Mexico	LMT	50	50	150	Digital	2018	32

shows the *repeatability* of the measurement setup. Clearly, for a reliable determination of the reflector accuracy, the measurement accuracy must be significantly smaller than the actual reflector deviations. From the literature, it is not always clear whether the quoted accuracy is the repeatability or the overall reflector error. In any case, it is preferable to perform an independent check on the significance of the result. A convenient way is the measurement of the aperture efficiency at a few high frequencies to derive the reflector rms error [3].

Clearly, the capabilities of photogrammetry have increased enormously since 1980. The technique can now usefully be applied to radio telescopes of the highest precision. These very accurate telescopes, operating at millimeter wavelengths, were designed and built since the early seventies. Part of the design challenge was the development of methods and equipment for the final measurement and adjustment of the reflector surface with an accuracy well below 100 μm. As we have seen, the "classical" methods were not capable of achieving this, and photogrammetry is not yet competitive in view of the requirements. A natural approach was to search for a measuring method that is close to the "normal" use of the telescope, e.g., using cosmic radio sources and radio-astronomy equipment (receivers). Such a solution was eventually found. It goes by the name of "radio holography." It is currently the most accurate and widely used technique for the measurement of radio-telescope reflectors. We summarize the development of radio holography in the next section.

4. Radio Holography

In the classic text, *Microwave Antenna Theory and Design*, published in 1949 in the MIT Radiation Lab Series, the author, S. Silver, discusses the Fourier transform (FT) relationship between the field distribution in amplitude and phase over the aperture of the antenna and the far-field radiation pattern, also in amplitude and phase. The relation is reversible, and hence the aperture-field distribution can be recovered if one has a complete knowledge of the radiation field, both in amplitude and phase. Silver then notes: *"in practice, the radiation pattern is only known in power and the aperture distribution cannot be determined uniquely."* In 1966, Roger Jennison wrote a pocket book, *An Introduction to Radio Astronomy* [35]. In an appendix, he pointed to the same Fourier transform relationship and mentioned: *"this relation may be reversed to give the field in the aperture plane in terms of the directivity pattern (in amplitude and phase)."* Remarkably, although interferometry was extensively discussed in his book, he did not mention the use of an interferometer to record both the amplitude and phase of the radiation pattern.

The January 1966 issue of the *IEEE Transactions on Antennas and Propagation* contains a paper entitled "Measurement of the Complete Far-Field Pattern of Large Antenna by Radio-Star Sources" by P. G. Smith of the Research Triangle Institute in Durham, NC, USA [36]. In this paper, the complete theory of using an interferometer – the additional antenna delivering the needed reference signal – for the measurement of the radiation pattern of an antenna is presented. This paper went unnoticed by the radio-astronomy community, although the present author referred to it in two papers, also in the *IEEE Transactions*, in 1972 and 1973. The 1972 paper [37] presented an interferometric measurement of the Dwingeloo Telescope antenna pattern at 21 cm wavelength. In a private comment on that paper, Barry Clark of NRAO, Socorro, suggested to the author to use the phase information from the pattern measurement to derive the shape of the reflector. Unfortunately, we had not recorded the absolute phase during those measurements, and we missed the chance to be the first to demonstrate the feasibility of *radio holography*. Around this time, Clark made the same suggestion to John Findlay, who was leading the design studies for a 65 m diameter Millimeter Telescope [38]. Two 1971 papers by Bates and Napier extensively treated the theory and experimental confirmation of the *holographic approach to radiation pattern measurements* [39, 40]. These appear to have escaped the attention of radio astronomers, probably because the aspects of measuring the reflector shape were not explicitly mentioned in this work. In the early seventies, Jack Welch, who was at the time working with S. Silver at Berkeley, mentioned the method to his PhD student Richard Hills, but it did not result in an experiment on the Hat Creek Interferometer. Upon his return to Cambridge, UK, in 1974, Hills suggested the method to Martin Ryle. Scott and Ryle used the 5-kilometer synthesis telescope in Cambridge, UK, to measure the pattern of

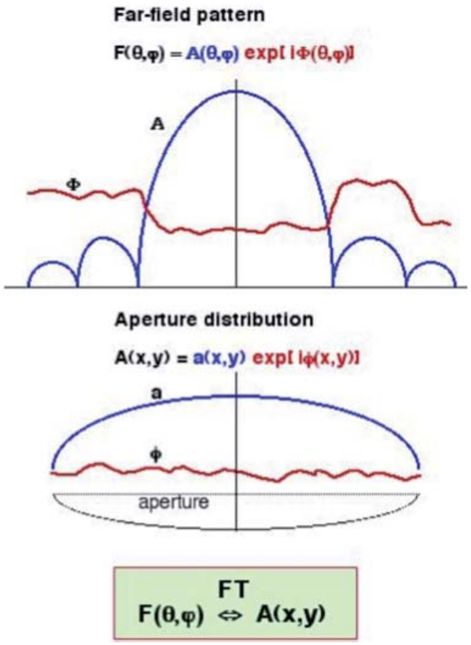


Figure 15a. The principle of deriving the aperture distribution through Fourier transformation of the far-field radiation pattern.

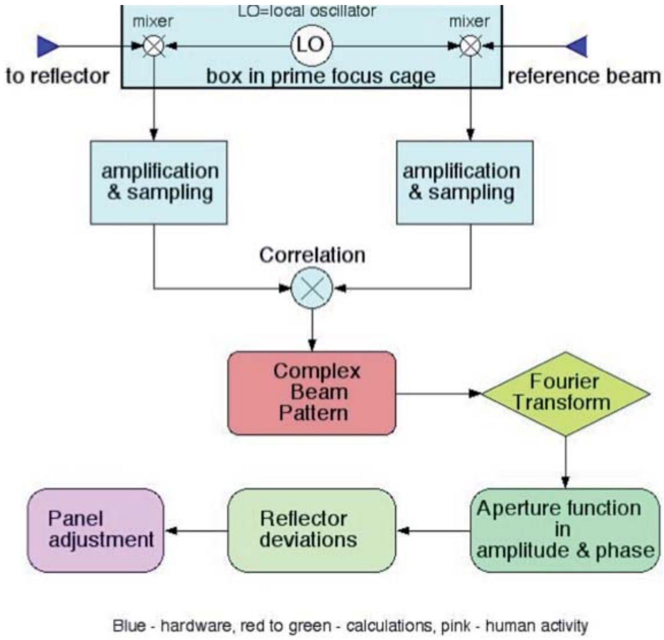


Figure 15b. A block diagram of the components of a holography system.

four of the eight antennas of the array, in both amplitude and phase, while using the other four array elements as reference sources. It demonstrated the practical feasibility of the method, and was published in 1977 [42]. Already in 1976, Bennett and colleagues at the University of Sheffield, UK, had published a ground-braking paper entitled "Microwave Holographic Metrology of Large Reflector Antennas" [41]. This paper did arouse the interest of radio astronomers, and builders of radio telescopes and ground stations for deep space and satellite communication. A few years later, the Sheffield group added to their theoretical work a measurement of the UK Chilbolton 25-m antenna using the beacon at about 11 GHz on the ESA "Orbiting Test Satellite" (OTS). Although the principle obviously occurred to others, it was the papers by Bennett et al. and Scott-Ryle that inspired a growing activity in the radio-telescope and space-exploration communities towards the application of radio holography for the measurement and setting of the reflectors.

The term r*adio holography* is generally used for any method to *measure the phase distribution of the reflector aperture field and to identify deviations from the expected function with local distortions from the prescribed profile shape of the reflector.* The information is obtained by Fourier transformation of the measured *radiation pattern both in amplitude and phase* by observing a radio source of high intensity at great distance. The method has been widely used to measure radio telescopes since the mid-1980s. Over the years, the method has been thoroughly analyzed and several variations have been introduced. In particular, the high requirement on surface precision of (sub)millimeter telescopes has inspired detailed work in this field, especially in the control of systematic instrumental phase effects in practical situations where the signal source must be located at close range from the antenna under test. Measuring accuracies of better than 10 μm have been achieved for telescopes of 10 m - 30 m diameter.

The principle of holography is illustrated in Figure 15 on the left, and the basic block diagram is shown on the right. The antenna under test and a separate antenna that projects a steady reference beam receive radiation from a distant source. The test antenna is scanned in two coordinates over the source, and its output signal is correlated with the constant reference signal. The output of the correlator is the complex beam pattern of the test antenna with both amplitude and phase information over the angular region over which the pattern was sampled. Applying a Fourier transformation (FT) to this data delivers the distribution of the reflected field in the aperture of the antenna, both in amplitude and phase. For a point source in the far-field of the antenna and a perfectly parabolic reflector, the phase function of the aperture distribution will be a constant. Any deviation of the reflector from the ideal shape will project a phase change in the aperture field that we measure and identify with the reflector's imperfection. The spatial resolution of the aperture function is determined by the angular size of the measured beam pattern. Invoking the Nyquist criterion, a pattern measurement over an angle of n half-power beamwidths (HPBW) will yield a spatial resolution over the aperture of D/n, where D is the diameter of the antenna's aperture. There are a number of variations on this theme in the actual execution of a measurement.

4.1 Full-Phase Holography

The best method, which we call *full-phase holography*, is to use a separate antenna to provide the phase reference and to measure the pattern in full interferometric mode, i.e., in amplitude and phase. This is quite laborious, as one needs a phase-stable system with a separate antenna that must be sufficiently large to provide the needed signal-to-noise ratio. If one operates an interferometric array with a number of elements, life becomes quite easy, because all equipment, including the correlator and Fourier-transform software, is routinely available. Moreover the reference antenna is as big as the antenna under test and will deliver a very strong reference signal.

4.2 Near-Field Holography

If one is willing or forced to leave the far-field range offered by cosmic sources and satellite beacons, one can use an earthbound transmitter at a finite distance in the *near field* (Fresnel range) of the antenna. The straightforward Fourier transform cannot be applied before several corrections are made to the measured phase distribution to account for the geometrical effects of the finite distance to the source. These have, over time, been worked out. Currently, it is possible to make accurate surface maps with the aid of transmitters at only several hundreds of meters distance from antennas of 10 m - 20 m diameter at wavelengths of the order of one millimeter. In most cases, the full-phase mode is used, although in principle the phase-retrieval method is possible and has actually been applied.

4.3 Phase-Retrieval Holography

In this *phase-retrieval* method, introduced by Morris in 1985 [43], no reference signal is needed. The phase distribution over the aperture is estimated from the measurement of at least two power beam maps, obtained with different feed positions along the beam axis near the focus, through a laborious optimization algorithm. The method is often called *out-of-focus (OOF)* holography. In principle, this opens the way to use the available radio-astronomy receiver. However, the required SNR is an order of magnitude higher than in the full phase case. This will rarely be achievable with a cosmic source, but a strong satellite signal can offer the solution for which one often needs a special receiver because of the fixed frequencies of satellite beacons.

In the following sections, we review these alternative methods somewhat more closely and illustrate their characteristics with measurements on a number of radio telescopes.

4.4 Full-Phase Holography in the Far Field

Around 1980, the well-known water-vapor maser at 22 GHz in the Orion Nebula exhibited a giant outburst, with a flux density of about one million Jansky. For some time, the group at Max-Planck-Institut für Radioastronomie in Bonn, working on design and construction of the 30-m millimeter radio telescope (MRT), had been considering radio holography for the measurement and setting of the reflector surface panels. With the appearance of the Orion Maser it was determined that a sufficient signal-to-noise ratio would be available (assuming that the source would remain sufficiently strong over the time until the measurements would be done, a few years later), and a system for holography at 22 GHz was designed and built. It was decided to use full-phase holography. This implied that a reference antenna would need to be placed near or on the antenna under test. A very convenient arrangement is a receiver package with both receivers placed "back-to-back" behind the primary focus, with one feed in the focus illuminating the reflector, and the reference channel looking out to the source along the telescope's axis. The reference antenna is often just a broad-beam horn. Because of its wide antenna pattern, the signal remains almost constant despite the scanning of the antenna over the source during the measurement, and the small changes in its amplitude and phase can be accounted for in the data analysis. On the Millimeter Radio Telescope, a 2 m diameter reference reflector was mounted in the prime focus box, looking outward along the axis of the main reflector. This system achieved a measurement accuracy of about 35 μm in its first deployment, and the surface could be set to an overall precision of 85 μm in 1986 [44].

Still, very few cosmic radio sources are sufficiently strong to serve as useful signal sources for the requirements posed at short wavelengths. Extensive use has been made of the beacon signal of communication satellites, of which many transmit in the 11 GHz band. The signal of these is narrowband and strong, allowing a rather simple receiver system to be employed. The geostationary position of most satellites provides only one elevation angle for the measurement, its value being dependent on the latitude of the antenna. Several large antennas, both radio telescopes and communication ground stations, have been measured with a separate small reference antenna placed next to the test antenna. Some of the authors of the original paper [41] have offered a commercial service to measure large antennas. An example is the resetting of the surface of the 100-m diameter Effelsberg radio telescope in 1986 [45]. While the 22 GHz maser source in Orion significantly decreased in strength, the appearance in 1991 of the Italian ITALSAT satellite, with a beacon at 39 GHz at an elevation angle of 43°, was a godsend for the Millimeter Radio Telescope in Southern Spain. Over the next decade,

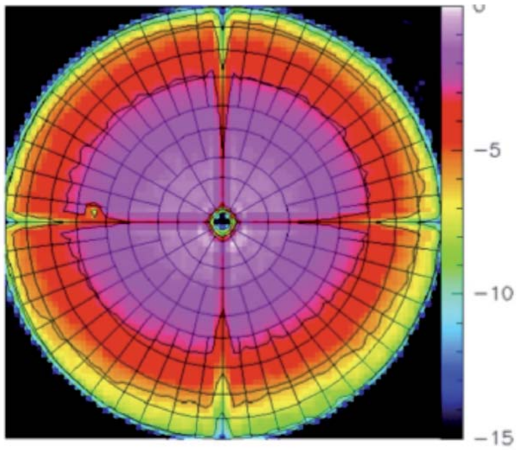


Figure 16a. An example of an ALMA antenna measured with "Astroholography" on Saturn at 84.2 GHz: the amplitude distribution.

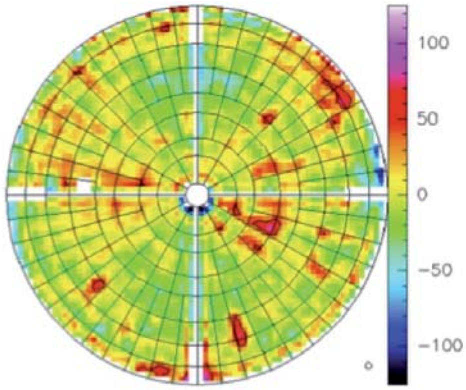


Figure 16b. An example of an ALMA antenna measured with "Astroholography" on Saturn at 84.2 GHz: the phase map transferred to surface deviation, scale in µm. The resolved red patches of high deviation reflect problems with the adjusters, since corrected.

ITALSAT was used to improve the surface setting of the telescope [46]. A significant surface improvement after microwave holography of the Yebes 40-m telescope was reported in [47].

In some cases, several satellites at different azimuth angles have been used to obtain a surface map at a number of elevation angles. This is particularly interesting for the study of elevation-dependent gravitational deformations in the telescope's structure. The Green Bank Telescope was measured with the signals from three Intelsat transponders transmitting near 12 GHz. The 2200 surface-panel actuators were adjusted to yield an overall surface error of about 220 µm rms over the 100 m diameter reflector [48].

The Lincoln Experimental Satellites (LES 8 and LES 9), at a frequency of about 37 GHz, were used for the measurement of the 14-m FCRAO millimeter telescope in Massachusetts and the 12-m NRAO millimeter telescope on Kitt Peak in 1984. It was the sole source for the initial setting of the Heinrich Hertz (sub-millimeter) Telescope (HHT) on Mt. Graham, Arizona [49]. The geocentric orbit of these satellites, as seen from Earth, is an analemma (about the shape of the number 8), and covers a range in elevation angle from 30° to 65° at the telescope's location. Surface maps collected at these extreme angles thus provide information on the gravitational deformation of the reflector over this elevation range. Unfortunately, the LES satellites have ceased operation. However, there are several satellites with beacons in the 20 GHz - 50 GHz range that are suitable for the measurement of millimeter telescopes. For the measurement of submillimeter telescopes, operating at frequencies as high as 1 THz and requiring a surface accuracy of < 20 µm, satellite beacons are not readily available. Even the strongest celestial sources, the planets, do not always provide a sufficient signal-to-noise ratio for the relatively small antennas of 10 m - 20 m diameter.

As was pointed out before, the ideal signal source is a strong cosmic source of small angular extent (ideally, a "point source"), and for the antenna under test to be an element of an interferometric array of similar antennas. This was indeed the case with the first holography on a radio telescope by Scott and Ryle [42]. This situation also applies to the Atacama Large Millimeter Array (ALMA) in Northern Chile. ALMA consists of 50 highly accurate reflector antennas of 12 m diameter and a surface precision specification of 25 µm (goal 20 µm) rms [4]. The surface of each of the individual antennas has been measured and set with near-field holography at the Operations Support site at 3200 m altitude, to be described in the next section. Each completed antenna was transported along a road to the operations area at 5000 m altitude. There obviously is a need for checking the surface precision after transporting or storm situations and to monitor the surface quality over time. To this end full-phase holography, locally called *Astroholography*, is carried out with half of the antennas being simultaneously measured, while the other 25 deliver the reference signal. Planets radiate strongly at short mm-wavelengths, but their angular size is often too large for useful interferometry. If, in a fortuitous situation, a planet can be used, a highly accurate surface map with a high spatial resolution of the order of a few decimeters can be obtained. An example of such a measurement is shown in Figure 16, where an ALMA antenna was measured using Saturn as signal source at a frequency of 84.2 GHz (ALMA internal report). One can see strong deviations within a panel, which in this case were caused by problems with the panel position adjusters. If one uses point sources, such as quasars or masers, the lower source intensity limits the achievable spatial resolution to the order of one meter. This still gives a good impression of the overall stability of the reflector surface over time. Repeatability of a few micrometers has been obtained in this way.

The interest in the radio holography method has not been limited to radio astronomers. Space research organizations are dependent on powerful ground stations for control and data exchange with a growing arsenal of space probes and satellites at ever increasing distance. At

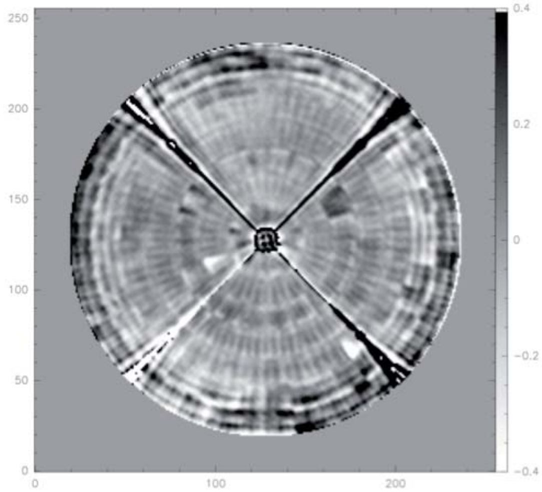


Figure 17a. Surface maps of the 30-m Millimeter Radio Telescope obtained from "full-phase" holography at 39 GHz: signal source in the far field, ITALSAT at 43° elevation angle.

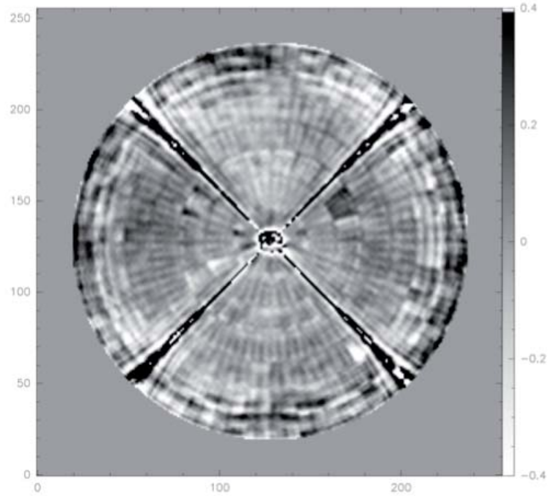


Figure 17b. Surface maps of the 30-m Millimeter Radio Telescope obtained from "full-phase" holography at 39 GHz: signal source in the near field, with the transmitter at 3 km distance and 11° elevation. The scales for Figures 17a and 17b are identical, the phase range is ±0.4 rad. The black panel at one-third out and 2 o'clock was offset by 1 mm for calibration purposes.

the Jet Propulsion laboratory (JPL), the operator of the network of NASA space research ground stations, the holography method was further developed with theoretical work by Rahmat-Samii [50] and development of a full-phase measurement system, capable of being ported between the antennas of the Deep Space Network. A description of the method, equipment and measurement results was presented by Rochblatt and Seidel [51]. Rochblatt summarized the extensive JPL activities in the JPL Descanso Book Series, Volume 10, Chapter 8 (downloadable from the JPL Web site) [52].

4.5 Full-Phase Holography in the Near Field

When neither a satellite beacon nor a cosmic source of sufficient intensity is available, it is necessary to take recourse to an Earth-bound transmitter. Among the first was a measurement of the Texas 4.9-m millimeter telescope on Mt. Locke at 2000 m altitude. There, a transmitter at 1700 m altitude and 12.9 km distance, close to the far-field distance of 13.8 km, provided the signal [53]. The frequency was 86 GHz and a measurement accuracy of 4 µm, based on repeated measurements, was reported. However, an Earthbound transmitter will, in most cases, be located in the Fresnel region *(near field)* of the antenna, which complicates the analysis of the measurements. Contrary to a source near infinity, such as a geostationary satellite (30000 km) or a cosmic source, the proximity of the source causes additional phase effects in the received wavefront that will have to be corrected in the data analysis. This requires knowledge of the distance to the source and the precise optical and mechanical geometry of the antenna. These disadvantages are offset by the strength of the transmitter signal and the simplicity of the receiver, being essentially monochromatic. Over time, the necessary corrections have been identified and worked into the analysis algorithms, and the method can be used reliably for distances of only several hundreds of meters from an antenna of diameter of the order of 10 m, operating at short millimeter wavelengths. Morris presented an excellent review of the methods and results up to 1984 [54]. Figure 17, taken from a paper by Morris et al. [46], shows two surface maps of the Millimeter Radio Telescope, one taken with ITALSAT as the far-field source, the other with an Earthbound transmitter at the same frequency at only 3 km from the antenna. The two measurements were taken within a few days and show an excellent quantitative similarity, indicating the proper functioning of the near-field system. At that time, September 1998, the surface showed an rms error of 70 µm.

A full-phase system with a transmitter at about 800 m distance was used on the James Clerk Maxwell Telescope on Hawaii. This submillimeter telescope is placed in an astrodome with a thin Goretex membrane covering the opening, to reduce wind and temperature influences. Reflections on the membrane proved problematic, and led to a more elaborate system with two frequencies at 80 GHz and 160 GHz, each of which could be "chirped" to remove the spurious reflections. The final result is shown in Figure 18. In the phase map on the left, the surface panels were clearly resolved and some outliers were marked by the white or dark brown color. In the amplitude map, one can see illumination taper, weak diffraction rings from the edge of the subreflector, and the gaps between the panels [55].

In the case of the ALMA antennas, a measurement of the reflector with an accuracy of not worse than 10 µm is required. This was achieved with a full-phase near-field holography system. The transmitter, at a frequency of 100 GHz, was placed on a 50 m high tower at a distance

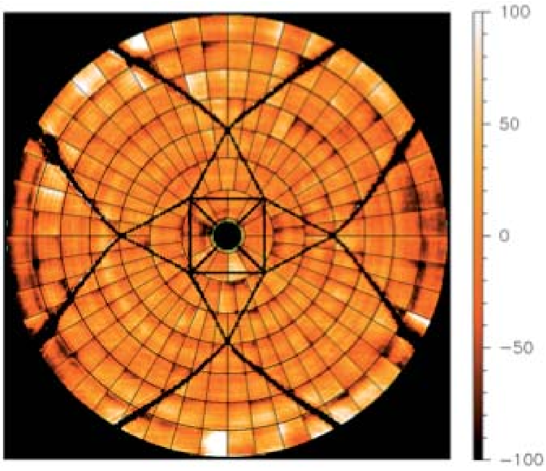


Figure 18a. A near-field full-phase measurement of the surface map of the James Clerk Maxwell Telescope in µm.

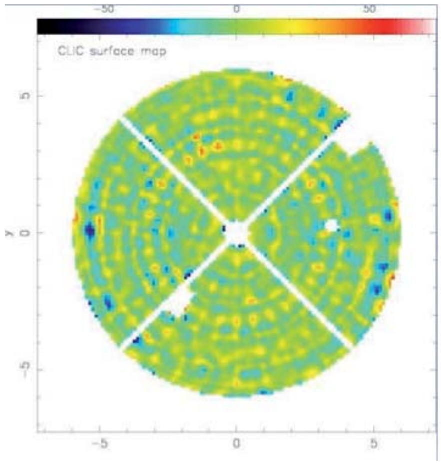


Figure 19a. Near-field full-phase holographic maps of an ALMA antenna: the final surface map with an rms error of 11.9 µm.

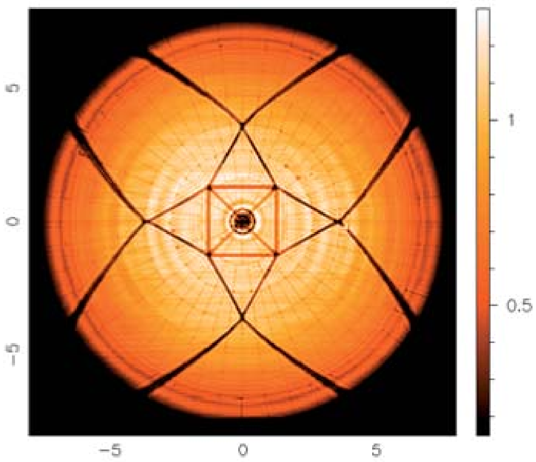


Figure 18b. The normalized amplitude of the aperture distribution corresponding to Figure 18a. The amplitude plot shows the outline of the panel gaps and the shadows of the intricate “octopod” subreflector support structure (R. Hills, personal communication).

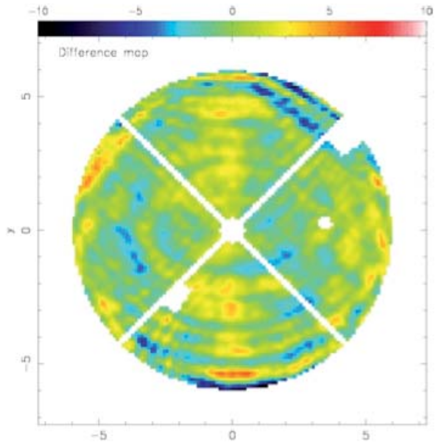


Figure 19b. The difference between two consecutive measurements of the ALMA antenna with an rms error of 1.6 µm. Note the different intensity scales between Figures 19a and 19b, and also the blocked area (white) of the quadripod and subreflector, as well as two faulty panels that were removed from the data before analysis.

of about 300 m, providing an elevation angle of about 10°. As an example, Figure 19 (internal ALMA/ESO report) shows the surface map of one antenna together with the difference between two consecutive measurements, taken a few hours apart. The surface had an rms deviation from the perfect profile of 12 µm, while the difference map indicated a repeatability of better than 2 µm rms, and showed rather large-scale deviations. Small temperature effects or atmospheric fluctuations could cause these.

Similar measurements of the ALMA prototype antennas were presented by Baars et al. [56]. That paper included the detailed mathematics of the near-field method, and described the equipment, measuring routine, data analysis, and reflector-setting procedures. The pictures of Figure 20 show the experimental setup.

4.6 Phase Retrieval – “Out-of-Focus” (OOF) Holography

For those cases where the installation of a separate reference antenna is not possible or inconvenient, an alternative procedure, called phase-retrieval holography, was developed. Departing from an algorithm introduced in X-ray crystallography by Misell [57], in 1984 Morris [43] presented a method to retrieve the phase function from a pair of power beam maps taken by the antenna with the feed in two different axial locations. The method is also known as out-of-focus (OOF) holography. The required SNR is an order of magnitude higher than in the full phase case.

Figure 20a. A radio holography setup for the ALMA prototype antennas at the VLA site in New Mexico: the receiver feed in the prime focus box with the feed illuminating the reflector. Note the absorbent material around the feed to suppress multipath radiation.

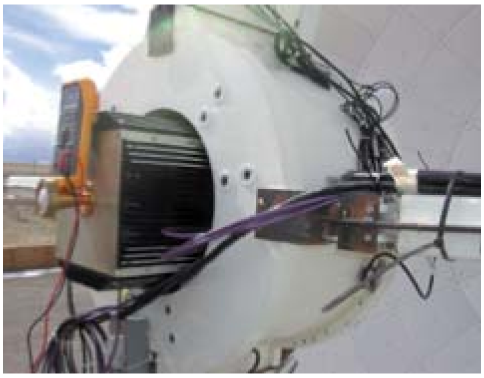
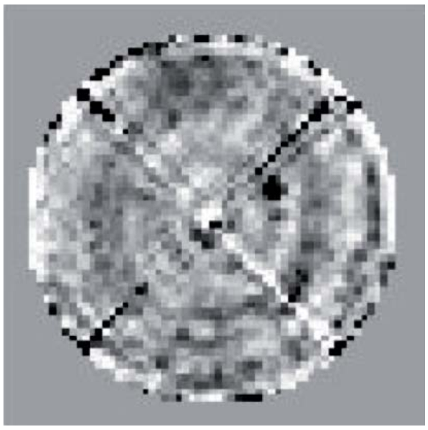


Figure 20b. A radio holography setup for the ALMA prototype antennas at the VLA site in New Mexico: the rear section of the receiver package with the reference horn on the left.

Figure 20c. A radio holography setup for the ALMA prototype antennas at the VLA site in New Mexico: the transmitter on a 50 m high tower pointed at the reflector. The VLA antennas are in the background.

In 1988 Morris et al. [58] successfully demonstrated the phase-retrieval method on the 30-m Millimeter Radio Telescope by measurements at 86 GHz with a signal source in the near field. Figure 21 shows a comparison between



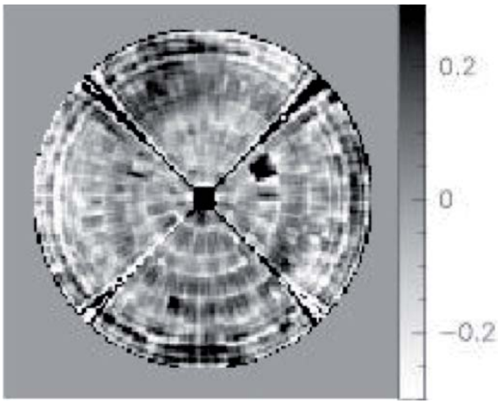


Figure 21. A comparison of phase retrieval (a) and full phase (b) measurement of the Millimeter Radio Telescope reflector. The dark panel under the upper-right quadripod shadow was purposefully offset by 1 mm. The map in (b) was measured at a higher spatial resolution, clearly visible in the plot.

surface maps obtained with phase-coherent and phase-retrieval measurements at 39 GHz from the ITALSAT satellite [46]. The similarity was quite good and numerically well within the estimated measurement accuracy.

The method was further developed by Nicolic and colleagues at Cambridge, UK [59]. By describing the surface errors as a linear combination of Zernike polynomials, the numerical inversion of the measured beam patterns led to the Zernike coefficients of the actual deformed surface. A measurement of the James Clerk Maxwell Telescope submillimeter telescope showed that large-scale surface errors could be reliably determined with a signal-to-noise ratio of 200, significantly smaller than required for the application of the Misell algorithm. The use of cosmic sources and standard astronomical receivers then became feasible, enabling the measurements of the surface shape at different elevation angles. This approach is restricted to relatively large-scale surface deviations, and will normally not be helpful for the setting of individual surface panels. The advantage to trace large-scale deformations in time by the operational astronomical system enables frequent correction of these errors, provided the surface panels are supported by remotely controllable adjusters. As mentioned

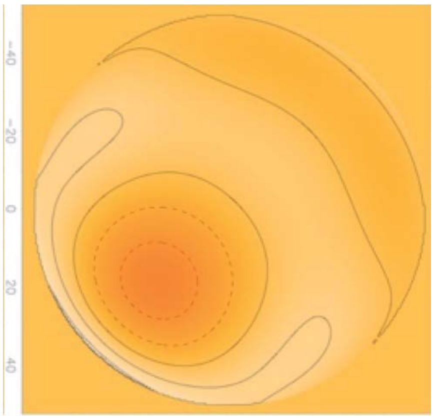


Figure 22a. A demonstration of the OOF method: the wavefront error resulting from a known deformation of the primary reflector. Contours are drawn at a surface interval of 275 µm. The scale is about ±1 mm.

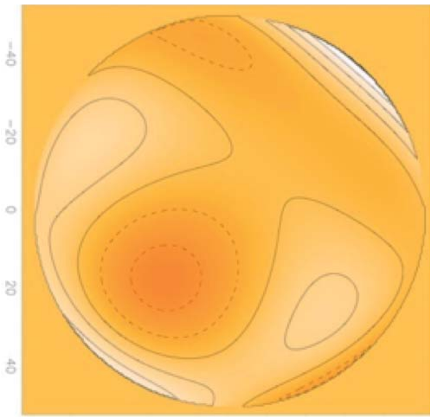


Figure 22b. A demonstration of the OOF method: the measured wavefront error using the OOF holography technique. Contours are drawn at a surface interval of 275 µm. The scale is about ±1 mm.

earlier, several recent large telescopes offer this possibility, and it was adopted for a fast measurement of the large-scale deformations of the 100 m diameter Green Bank Telescope (GBT) [60]. These deformations are caused by gravity, and change significantly with elevation angle. Temperature gradients in the structure also lead to deformations, and the relatively short time needed for a surface measurement (about 20 minutes) could enable "tracking" the slowly varying thermal effects in the structure.

A result of a measurement is shown in Figure 22. Here, a known deformation, shown on the right, was introduced into the surface, and the deformation map, derived from the OOF measurement, is shown on the left. The measurement was performed at 7 mm wavelength, taking about 30 minutes of time, and achieved an accuracy of about 70 µm rms [60]. It is a viable way to correct in quasi-real time large-scale surface deformations of large reflectors with remotely controlled motorized adjusters.

4.7 Shearing Interferometer

For the measurement of the Caltech Submillimeter Telescope, a method widely used in testing optical mirrors was adapted for millimeter wavelengths: the shearing interferometer, also known as the Twyman-Green interferometer. A functional drawing of the scheme is shown in Figure 23. For the description, we borrow from an earlier text by the author [63]. The paraboloid, P_1 re-images the primary reflector onto two flat mirrors, M_1 and M_2, via a beam splitter, BS. The beams reflected from M_1 and M_2 are recombined, and brought to the detector in the final focal plane via the off-axis paraboloid P_2. Mirror M_2 can be rotated about two axes perpendicular to the incoming wavefront. Because the primary reflector is imaged onto M_2, a rotation of M_1 is equivalent to a change in the pointing direction of the primary reflector. Seen from the detector in the focal point, the fixed mirror M_1 thus directs a beam towards the source, while the moving mirror M_2 scans a second beam to off-axis positions. The image mirrors M_1 and M_2 represent the elements of an interferometer as used in the holographic system described above. In this case, the focal plane field distribution is sampled off-axis by virtue of the moving mirror M_2. A Fourier transformation of the focal plane field distribution delivers the aperture field distribution. This measurement will thus provide the same information as the usual holographic interferometry. Because the relative phases of the two beams are present in the interferogram at the detector, only a single detector is needed, and even an incoherent detector such as a bolometer can be used. Because the primary reflector is imaged onto mirror M_2 and the wavefront from a point on the primary surface is sheared laterally by a rotation of M_2, the authors coined the name "shearing holography" for this measurement method. A full description of the method, along with experimental results, was presented by Serabyn et al. [64]. No wider use of this method has come to the attention of the author.

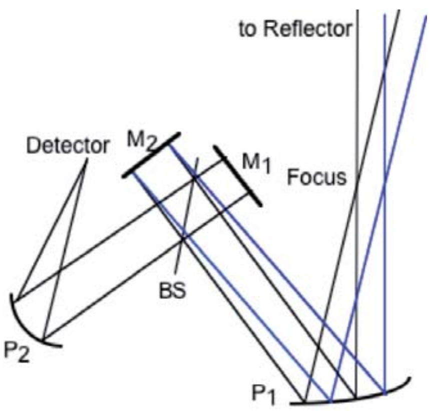


Figure 23. The layout of the shearing interferometer. P_1 and P_2 are off-axis paraboloids, BS is the beam splitter, and M_1 and M_2 are plane mirrors. M_2 can be rotated about two axes perpendicular to the incoming beam; the blue lines indicate an off-axis beam from M_2.

Table 3. Telescopes with reflectors measured by radio holography.

Telescope Location	Diam. (m)	Method	Source	Freq. (GHz)	Resolution (m)	Accuracy (μm)		Ref.
						Measurement	Surface	
Cambridge	18	FP-FF	CS-q	1.4	1.0	100	–	42
Texas mm	5	FP-FF	T	86	0.05	5	–	53
NRAO-AZ	12	FP-FF	S-LES	37	0.2	20	–	rep
NRAO-VLA	25	FP-FF	CS-q	5	1.4	300	–	rep
Onsala	20	PR-FF	CS-m	22	1.6	140	–	62
MPIfR-Effels.	100	FP-FF	S-OTS	11.5	0.5	50	500	45
IRAM-MRT	30	FP-FF	CS-m	22	0.7	25	75	44
IRAM-MRT	30	PR-NF	T	86	0.5	65	85	58
IRAM-MRT	30	FP-FF	S-Itals.	39	0.25	10	50	46
MPIfR-HHT	10	FP-FF	S-LES	37	0.1	<10	12	49
UK-JCMT	15	FP-NF	T	80/160	0.3	<10	25	55
ALMA-proto.	12	FP-NF	T	95		10	17	56
ALMA-Chile	12	FP-NF	T	95		<5	11	rep
Yebes-Spain	40	FP-FF	S	11.5	0.4	–	200	47
GBT - WVA	102	PR-FF	CS-q	43		70	–	59

Method: FP = full phase, PR = phase retrieval, FF = far field, NF = near field
Source: T =(local) transmitter, S = Satellite, CS = cosmic source, q = quasar, m = maser

4.8 Summary of Radio Holography

Radio holography has become the most widely used method for the characterization and optimization of paneled reflector antennas. The examples of the foregoing sections were meant to be indicative of the development and progress of the method. In the earlier days, the main purpose was the precise measurement and following adjustment of the panels of the reflector. This requires a rather high spatial resolution over the aperture, and hence a beam measurement over a substantial angle from the beam axis. For this the application of a full-phase system is advantageous. While a signal source in the far field of the antenna requires a minimum in corrective measures before the Fourier transformation to the aperture field, the complications of locating the source close to the antenna in the near field have been fully worked out and can routinely be applied to the data. A significant advantage of a near-field measurement is the shortness of the transmission path through the atmosphere and the resulting decrease in phase variations caused by atmospheric turbulence. More recently, large and highly precise radio telescopes, particularly those operating at (sub)millimeter wavelengths, include remotely controlled adjusters to align the surface panels to the desired surface. This offers the possibility of correcting known errors in real time, the obvious example being the counteraction of elevation-angle-dependent structural deformation due to gravity that can be calculated with the aid of a finite-element analysis of the structure. The major time variable deformation normally is caused by temperature gradients in the structure. The temperature field can be mapped by a set of strategically placed sensors in the structure. Introducing this in the finite-element model delivers the additional structural deformation that can be corrected by motorized adjusters [61]. Because the temperature field is predominantly large-scale, a surface map on this scale can be obtained by a relatively small holography beam map. For this procedure, a quick out-of-focus (OOF) beam map obtained on celestial signal sources has been shown to be feasible, as demonstrated on the Green Bank Telescope [60]. Depending on the temperature behavior over time, short OOF measurements could thus provide surface corrections in real time.

In Table 3, we summarize the major varieties of the holographic method, and list examples of telescopes at which they were applied together with the achieved accuracy and a reference, where available. Table 4 presents a timeline of the development and application of radio holography.

5. Conclusion

The holographic method has been the predominant means of measuring reflector antennas since the mid-eighties. Recent improvements in both digital photogrammetry and the application of flexible and accurate laser-scanners have become competitive alternatives, as illustrated in earlier sections. The choice of a particular method depends on the main purpose of the measurement activity. For instance, during assembly of the reflector, the placement of the panels can be monitored in real time by a laser tracker. We mentioned in Section 2.2 the plan to install a laser-scanner system on the Green Bank Telescope for continuous monitoring of wind and thermally induced deformations, and to make corrections to the panel positions in real time without the need to interrupt astronomical observations. In Section 3 we saw that photogrammetry

Table 4. Timeline of the Development of Radio Holography

1966:Smith – paper with full description of interferometric principle [36]
1971:Napier – Bates papers of holographic radiation pattern measurement with indications of application on reflector antennas [39, 40]
1973:Hartsuijker et al. – Complete antenna pattern of Dwingeloo telescope by interferometry; amplitude only, no surface map possible [37]
1976:Bennett et al. – basic full description of holographic method [41]
1977:Scott&Ryle – first use with cosmic source on Cambridge 1 mile array [42]
1983:Davis et al. – Texas mm telescope at 3.5 mm wavelength, 13 km range [52]
1985:Morris – theoretical paper on phase retrieval holography [43]
1985:Morris et al. – Millimeter Radio Telescope measurement with 22 GHz H2O maser cosmic source; full-phase with 2 m reference dish [44]
1985:Rahmat-Samii – simulation algorithms and application to JPL measurements [49]
1986:Godwin et al. – Effelsberg measurement with satellite source at 11 GHz [45]
1988:Morris et al. – comparison Millimeter Radio Telescope measurement with full phase and phase retrieval, includes the near field effects in phase retrieval [57]
1992:Rochblatt & Seidel – JPL system for NASA deep space network antennas [50, 51]
1994:Baars et al. – HHT submm telescope with LES satellite, accuracy <10 µm [48]
2001:Hills et al. - James Clerk Maxwell Telescope near field – full phase [55]
2002:Nikolic et al. – Out-Of-Focus (OOF) phase retrieval on submm James Clerk Maxwell Telescope [58]
2002:Morris et al. – review of several methods on Millimeter Radio Telescope over many years [46]
2005:Nicolic et al. – OOF holography OOF at 7 mm cosmic source on the Green Bank Telescope [59]
2004:Baars et al. – near field at 3 mm of ALMA prototype antennas [55]
2011:Hills et al. - ALMA, near field at 3 mm, production antennas, repeatability 2-3 µm
2011:Lucas et al. – ALMA "astro-holography" on celestial sources; in regular use.

is a versatile measuring method that enables quick results at different elevation angles to determine gravitational deformation. However, the obtainable accuracy is not (yet) sufficient for the most precise submillimeter telescopes. While further improvements in photogrammetry and laser-scanner technology will be achieved, it is likely that radio holography will remain the favorite method for radio astronomers. The similarity of the needed equipment with standard radio-astronomy receivers is advantageous, in particular when the antennas of multi-element arrays need to be measured, as for instance in the case of ALMA, the Square Kilometre Array (SKA), and the new generation Very Large Array (ngVLA).

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Effect of Mountain Clutter on a VHF (206.5 MHz) Wind Profiler in the Central Himalayas

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Abstract

A modern, indigenously developed VHF (206.5 ± 2.5 MHz) wind-profiler radar, operating in the Himalayan region, was installed at Aryabhatta Research Institute of Observational Sciences (ARIES) near Nainital, Uttarakhand (29.4N; 79.5E; 1793 m amsl) India. This profiler was named the Aries ST RADar (ASTRAD). The profiler was installed within a 30 m × 30 m two-story building for better utilization of available space on a hilly terrain, surrounded by high-rise mountains. In an innovative way, 12 clusters of 49 elements were placed on the rooftop with the required precision in forming a quasi-circular aperture. Activation and integration of the clusters of the system progressed with extensive calibration of each individual transmitting/receiving module (TRM) connected with each antenna. During activation, the presence of a strong central patch in the Doppler-spectrum-like clutter, close to 0 Hz, was encountered. Based on experiments, it became clear that the reflected strength of the RF signal in the VHF band was significant due to the mountain terrain. A metal fence 3.5 m-4 m height was designed and installed at the perimeter of the rooftop to minimize the strength and to gain improvement in the detectability of the weak backscattered atmospheric signal. In this article, technical details of the system and design steps of the fence that led to overcoming the issue of clutter are summarized.

1. Introduction

The Himalayan region plays a crucial role in determining the meteorological conditions of the Indian subcontinent [1]. For an in-depth understanding of the atmosphere in the Himalayan region, continuous observation of the wind patterns is therefore required, as it helps in understanding the atmospheric dynamics. However, there have been no such data for the region for decades. To fill this gap, the ASTRAD wind profiler was set up at ARIES. Since the first development, the wind-profiler radar (WPR) has proven to be an excellent tool for the continuous observation of various processes occurring in the atmosphere [2-4]. The ASTRAD wind-profiler radar continuously captures the wind parameters (wind speed and direction) of the atmosphere in the region with high temporal and spatial resolution. To use the advantages of less galactic or cosmic noise (~1000 K) [5] as compared to the 50 MHz (~6000 K) [6] band, while at the same time ensuring that the scale size is in the inertial sub-range, the ASTRAD was designed for operation at a carrier frequency of 206.5 MHz in the VHF band. In addition, the 200 MHz band can detect both background wind-echo and echoes due to falling hydrometeors in a single spectrum. These specific advantages make the ASTRAD a cost-effective solution for probing the atmosphere well beyond the tropopause in all-weather conditions over the region.

2. System Description

ASTRAD is a pulse-Doppler radar and a fully coherent active-aperture phased-array system that is capable of analyzing the backscattered electromagnetic waves as a result of the change in refractive index to measure the Doppler shift from different heights. The 588-element active phased-array system uses Yagi-Uda antennas as the radiating elements. It has the capability of electronic beam-steering from 0° to 30° along off-zenith, and 0^0 to 360° along azimuth, with a step of 1°. The network of transmitting/receiving modules (TRMs) generates the required peak power to achieve height coverage from 0.5 km to 20 km,

Table 1: ASTRAD System specifications

Operating Frequency	206.5 MHz
Antenna and antenna array	A quasi-circular array having equilateral triangle grid of 588 three-element Yagi-Uda antennae with 12 clusters each in hexagon pattern consisting 49 elements
Antenna aperture	490 m^2
Antenna gain	34 dBi
Beam width (one way)	3.3^o
First side-lobe level	-17.7 dB with uniform distribution
Beam scanning capability	Azimuth: 0-360^o in steps of 1^o; Off Zenith: 0-30^o insteps of 1^o
Transmitter peak power	235 kW
Peak power of each TR unit	400 W
Max. duty cycle	13 %
Receiver and signal processing	4 channels DDC based system
Dynamic range	70 dB

with variable height resolutions. The specifications of the radar are given in Table 1. As the transmitting/receiving modules are kept close to the radiating elements, both the transmitting and receiving losses are lower compared to passive array systems. This leads to a low receiving noise figure and a high transmitting efficiency. The operation of the radar is accomplished with the help of a radar controller that sets the different parameters of the experimental configuration for operating the radar in different modes, with selectable waveforms and signal-processing schemes.

Data visualization and data storage software runs on a dedicated high-end PC for real-time processing of the raw data captured after sampling of the signal scattered back from the atmosphere. The same software generates different data products, such as the power spectrum and different moments (m_0 , m_1 , and m_2) for scientific research.

3. Installation and Activation

The ASTRAD system is housed in a two-story building surrounded by elevated hills in three directions (north, east, and west). The active aperture antenna array, comprising 588 elements, was placed on the rooftop of the 30 m × 30 m building (Figure 1). During activation of the system, it was noticed that even with only 400 W peak power radiating using a single transmitting/receiving module, a strong patch, close to 0 Hz, was visible during the entire radar's receiving time, up to the maximum height set in the particular experiment (Figure 2). Moreover, this patch spread over multiple Doppler bins with an increase of the radiated power. This phenomenon was peculiar, as with a single transmitter it is theoretically not possible to get strong echoes from a height of ~15 km (Figure 2). Due to this echo, clear-air radar spectra of return signals were not traceable, and they resulted in incorrect estimation of wind components due to false detection of the close-to-0 Hz signal as the maximum-power signal in all range bins, from minimum to maximum altitude, irrespective of the Doppler profile.

It was therefore essential to minimize the strength of the echo patch to derive the correct wind information. A detailed investigation was initiated to understand the cause behind this patch. A set of experiments were conducted

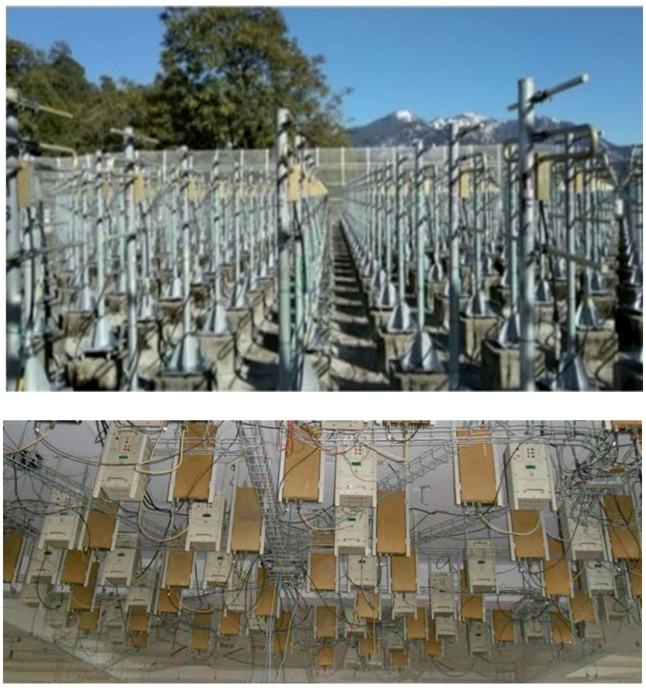

Figure 1. (a) The antenna array on the rooftop and (b) the transmitting/receiving modules hanging from the ceiling of the floor below.

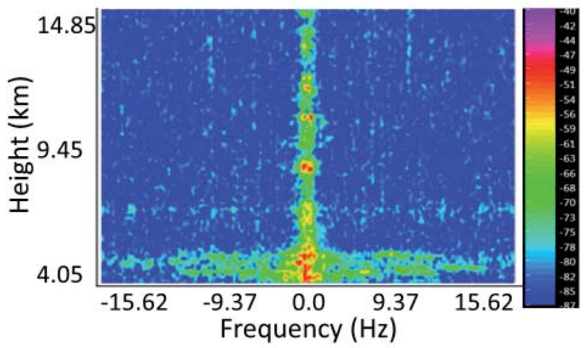

Figure 2. A typical receiving period power spectrum after radiation of one transmitting/receiving module at around 1600 hours. The color bar shows the magnitude in dB.

at different locations within and outside the institute. In the beginning of the investigation, through experiments it was understood that the subsystems of the radar had no role behind the appearance of the patch. In particular, to rule out any effect due to the existing high-power amplifier (HPA) of the transmitting/receiving module, a transmitting/receiving module with a new high-power amplifier was used and a spectrum with a similar patch was recorded without any improvement. Later, to understand any effect of the elevation of the surrounding mountains above the location of the radar transmitter, both a single and a group of seven transmitting/receiving modules were used for radiation at a place with a different altitude (Figure 3). At the end of the investigation, it was concluded with evidence that the source of the patch was external, and could be the result of multiple reflections of the RF signal in the VHF band from the surrounding hilly terrain. The reflection could occur when RF energy emitted from the sidelobes of the antenna array hit the nearby mountains.

On the other hand, the main lobe of the antenna was pointed well above the mountain ranges, since it pointed towards the zenith, with the possibility of being shifted up to a maximum of 30° off-zenith. There therefore was no impact on the main lobe due to the mountain.

After multiple reflections from the mountains, the reflected RF signal entered into the system during the receiving period of the radar, resulting in the observed clutter. Furthermore, it was concluded that the strength of the clutter varied with the elevated height of the hilly terrain above the antenna's location and the power radiated from the active transmitter (Figure 3b).

4. Design of a Metal Fence

Once the possible cause of the patch was understood, it was then essential to minimize the strength of the patch to improve the detectability of the weak Doppler signal scattered back from the atmosphere. In order to do so, a metal-grid fence, which works as a shield around the

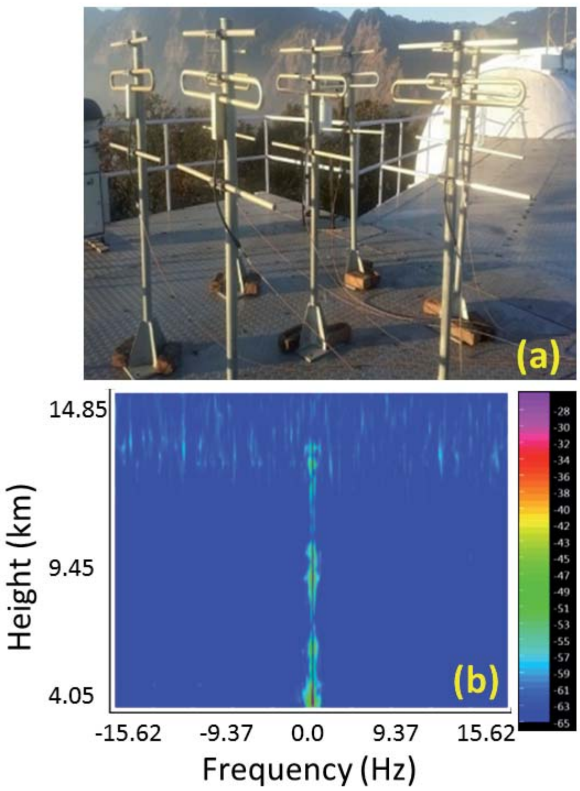

Figure 3. An additional experiment carried out using a group of seven antennas (a) at a site elevated compared to the present ASTRAD location, and (b) the resultant lesser patch observed (compare with Figure 2) during this experiment in the afternoon (around 1600 hours). The color bar shows the magnitude in dB.

antenna array, was designed and installed so that the RF energy radiated from the sidelobe of the antenna array was attenuated. Although the "ideal" shield would be a conducting metal sheet with no openings, such a solution was not practical since it increased the cost and weight of the fence many-fold. A wire-mesh fence was therefore adopted, as it was flexible and appropriate for building a large structure.

The mesh of the fence had square-grid bonded wire because it gave more mechanical strength and continuity. The physical structure of the square-grid wire mesh is shown in Figure 4.

The shielding effectiveness (*SE*) of such a wire mesh depends on the dimensions of the grid and the thickness of the wires, as well as the angle of incidence of the wave [7]. For plane waves in the far field of an antenna, the shielding effectiveness of such a wire mesh can be estimated as [8]

$$SE = 20\log\left[\lambda/2g\right] \text{ where } g \ll \lambda , \qquad (1)$$

with g being the grid spacing, as shown in Figure 4, and λ being the wavelength at the operating frequency. Here, λ is ~1.45 m at the operating frequency of the radar, i.e., 206.5 MHz.

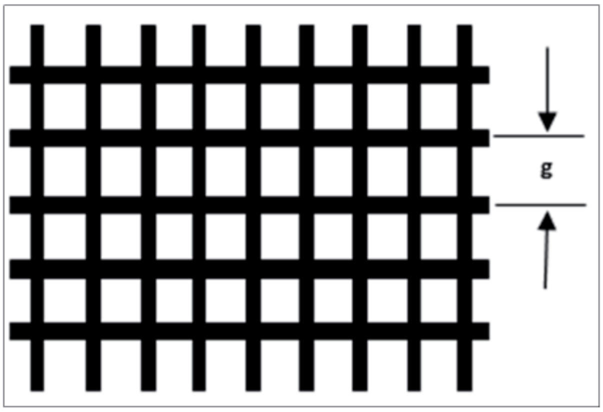

Figure 4. A bonded-grid wire mesh with spacing *g*.

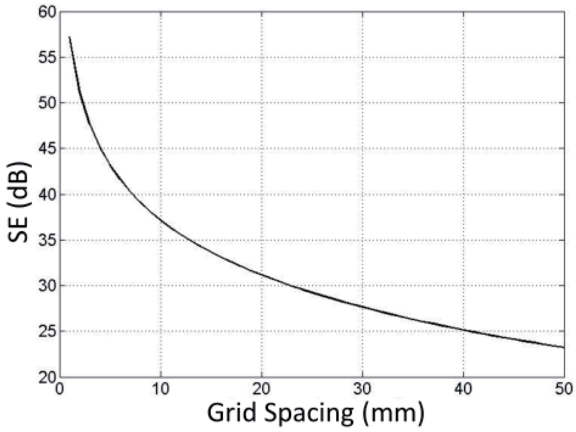

Figure 5. The variation of the shielding effectiveness (*SE*) with grid spacing.

Alternatively, in the far field, the shielding effectiveness of such a wire mesh can be approximated using the concept of slot-antenna theory and can be expressed as [9]

$$SE = 20\log\left[\lambda/2l\right], \qquad (2)$$

where l is the maximum linear dimension of the aperture of a slot antenna and equivalent to the grid size, g, of the bonded wire mesh shown in Figure 4.

Using Equation (1), the shielding effectiveness at 206.5 MHz with respect to the grid spacing in mm was calculated as shown in Figure 5.

The electromagnetic shielding effectiveness of a wire mesh is effective when the mesh's grid size is much smaller compared to the operating wavelength [10]. However, lowering the grid size increases the cost and weight of a grid's mesh. After a study and based on the availability of materials, balancing the cost and performance of the mesh, a grid size of $g = 25$ mm ($< \lambda/58$) was selected. The height of the fence was decided after studying the topography and elevation of the mountainous region around the radar site. In Figure 6a, the typical topography to the north of the radar site is shown, where mountain peaks are much above the location of the antenna array. In contrast, the height of the mountain peaks towards the southeast (Figure 6b) is down below the array's location. After a detailed survey of the topography, the fence height was finalized at 4 m towards north and 3.5 m in the other three directions so that the lower sidelobes of the antenna array factor (AF) (Figure 7) pattern did not directly hit the elevated mountains during radiation along zenith/off-zenith directions.

The fence consisted of a structural steel framework with galvanized iron wire mesh, a grid of $g = 25$ mm, and copper-strip grounding connected to Earth pits. The

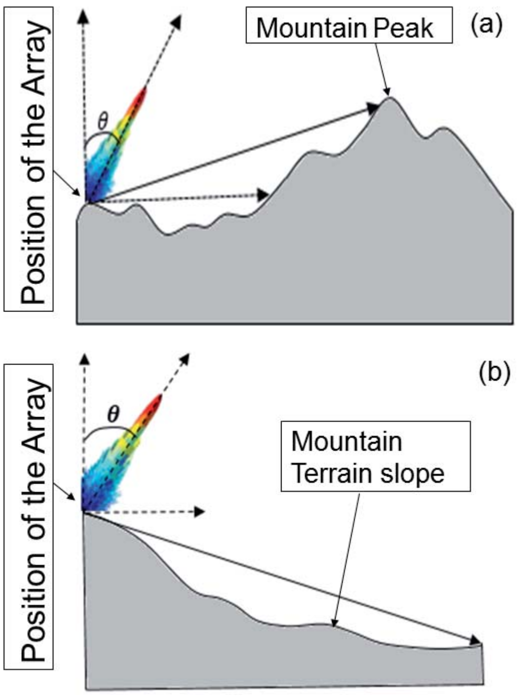

Figure 6. The topographical features around the radar site. Examples of the (a) north and (b) south-east sides are shown.

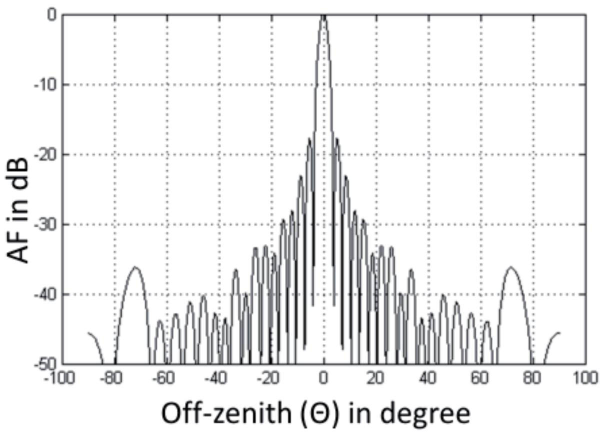

Figure 7. The array factor (AF) pattern at an azimuth of 0° and off-zenith (θ) of 0°.

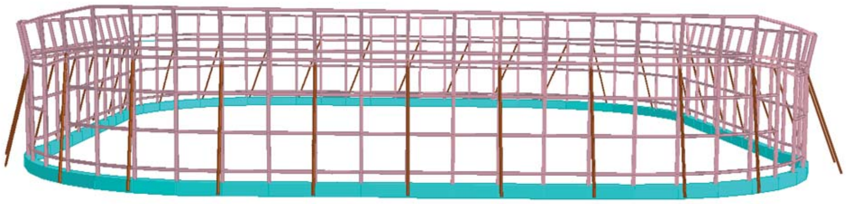

Figure 8. A diagram of the fence installed around ASTRAD.

structural steel framework was made of 100 mm × 100 mm × 6 mm vertical posts with a 200 mm × 200 m × 8 mm base plate anchored on the building rooftop, using four self-anchored anchor bolts. All vertical posts were connected by horizontals and diagonal members. After installation of a steel framework close to the edge of the 30 m × 30 m rooftop of the building, reinforced cement concrete beams 300 mm × 300 mm in size were cast by connecting all of the vertical posts to increase the stiffness and bonding to the existing slab.

The fence can bear wind loads up to 200 kmph. A diagram of the fence showing all vertical and horizontal posts is depicted in Figure 8.To minimize any effects due edge diffraction [11], the edges of the fence were made blunt and the top of the fence was slightly tilted outward opposite to the array. Figure 9 shows a "bird's-eye" view of the fence after installation along with the 588 elements array of ASTRAD on the top of the building.

5. Performance Improvement

To estimate the shielding effectiveness (*SE*) of the fence, RF power inside and outside the fence was measured after installation when a fixed power was radiated from a single antenna at the carrier frequency from a distance of more than 2λ. In terms of measured RF power, the shielding effectiveness in dB was estimated to be ~22 dB to 25 dB using the following equation [12]:

$$SE(\mathrm{dB}) = 10\log\left(P1/P2\right), \quad (3)$$

where $P1$ is the received RF power without a fence and $P2$ is the received RF power with a fence.

The performance of the fence was tested by capturing the spectrum of one transmitting/receiving module with one antenna when ~400 W peak power was radiated within and outside of the fence. The spectra are shown in Figure 10. This showed that the strength of the patch close to 0 Hz was significantly reduced and became negligible with the fence. With lowering the strength of the patch in the center, false peak selection in range bins was minimized, which ultimately improved the wind profiles captured by the system.

Generally, the standard signal processing schemes are applied to derive wind and other parameters [13, 14]. Since there was some clutter signal present despite the mounting of the metal fence around the array as discussed in the paper, we applied a specially designed digital filter to remove the remaining clutter signal. The clutter signal has the special characteristic of being present throughout all range bins from minimum to maximum altitude. The filter finds the specific pattern of returned signal above the noise floor and replaces that by the averaging of the signal of adjacent Doppler bins.

Figure 9. A "bird's-eye view" of the fence on the building's rooftop.

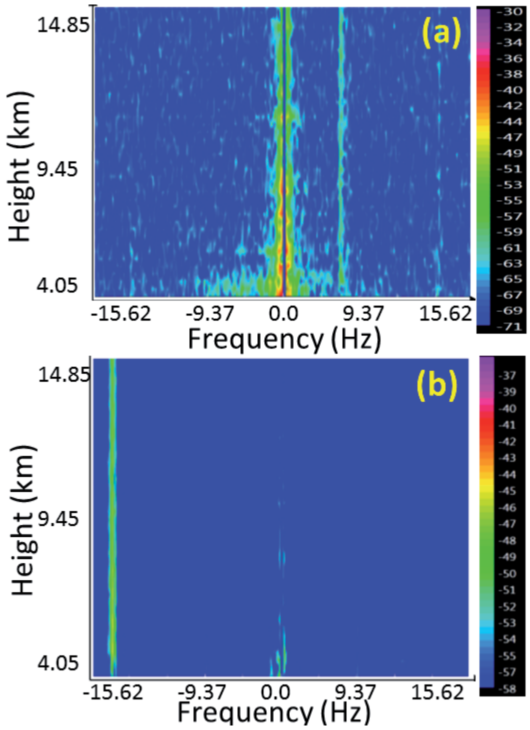

Figure 10. The spectrum of one transmitting/receiving module (a) outside and (b) inside of the fence, as observed on 13 February 2017 at around 1600 hours. The color bar shows the magnitude in dB.

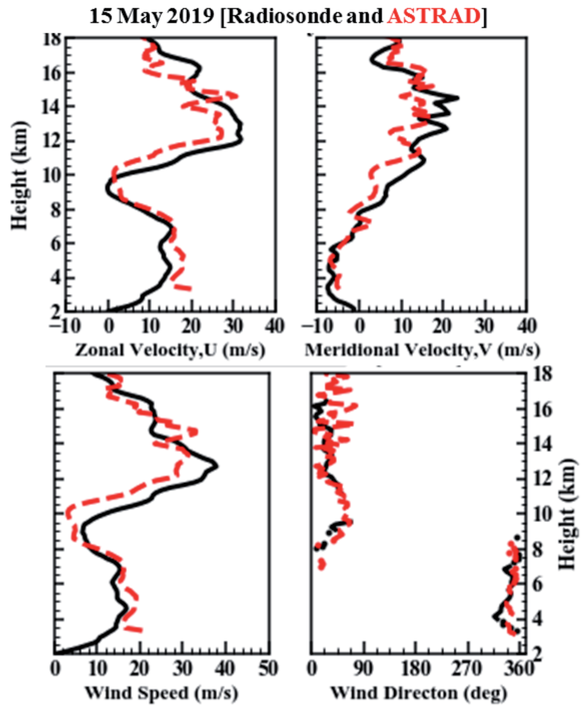

Figure 11. A comparison of wind parameters derived from ASTRAD (red) data with the same parameters obtained from a GPS radiosonde (black).

Currently, ASTRAD is being successfully operated on a regular basis. A comparison of the radar winds with wind data from a GPS radiosonde at the same site has been made, and showed reasonably good agreement (Figure 11). These observations were also used for the estimates of the turbulence parameters for this region [15]. The vertical line at about 8 Hz in Figure 10a and at about -15 Hz in Figure 10b of the 0 Hz Doppler is RFI that appears on the power spectrum during the experiment.

6. Conclusion

In this report, the source of the strong signal close to 0 Hz that was affecting the wind-profiler radar's performance was investigated. The investigation revealed that in the VHF band, the reflection of the RF signal from mountains was a significant and strong signal close to 0 Hz on the Doppler spectrum that may be understood as multi-reflection terrain clutter. The performance of the radar system was hence improved by installing a metal-grid fence around the antenna array. The dimensions of the fence were decided after a series of experiments. The shielding effectiveness (*SE*) of the fence was estimated through experiments and found to be close to the theoretical design value.

7. Acknowledgements

The ARIES ST Radar was set up by a grant from SERB, DST, Government of India. We are thankful to the Director, ARIES for support and encouragement to this project. We are very grateful to the Project Management Committee, chaired by Prof. B. M. Reddy, for continuously guiding the progress of the ST Radar project. Suggestions from different committees, including PDR and performance evaluation committees, have been very useful, and we thank them all. We also thank the Electronics Corporation of India for their help in establishing the ASTRAD facility. We are thankful to ARIES Radar team for their active participation in conducting the experiments presented in this paper. We are grateful to two anonymous reviewers for their useful comments.

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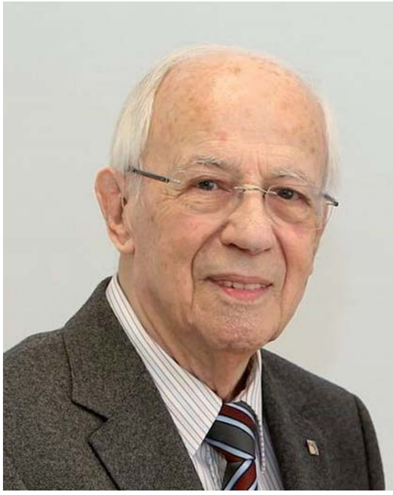
In Memoriam: Siegfried J. Bauer 1930 - 2021

We are deeply saddened to inform the URSI community that Prof. Emeritus Dr. Siegfried J. Bauer, 91, passed away peacefully at his home in Graz on Sunday, September 19, 2021.



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Siegfried (for his American friends, in short, just Sig) Bauer was born on September 13, 1930, in Klagenfurt, Austria, and grew up in nearby Griffen in the wonderful southernmost Austrian province of Carinthia. After grammar school in Griffen and secondary boarding school at the Abbey St. Paul/Lavanttal, he earned his PhD in Physics, Geophysics, and Meteorology with a dissertation on experimental ionospheric radio measurement techniques with Prof. Otto Burkard at the University of Graz in 1953.

Shortly after graduation, he joined the US Army Signal Corps Research and Development Laboratory in Fort Monmouth, New Jersey, to work on weather radar and sferics. After one year in the US, he returned back to Austria to prepare for a longer stay there. He married his girlfriend, Inge, and together they returned to the US. There he resumed his work at the Army Laboratory, this time performing research with the Diana moon radar. Working in Fred Daniels' group, he used the radar antenna in Belmar, New Jersey, as a transmitter and receiver at the electrical engineering institute of the University of Illinois at Urbana-Campaign. The Faraday rotation of the radio waves traversing the ionospheric plasma caused by the Earth's magnetic field led to information about the state of the ionosphere. The results of these investigations were presented at the spring meetings of URSI in Washington, DC.

After six years at the military laboratory, he joined the then recently established NASA Goddard Space Flight Center (GSFC), Greenbelt, Maryland, in 1961. For the first four years, he worked on sounding-rocket campaigns, mainly from Wallops Island, Virginia, and on preparations for the Canadian Alouette Topside Sounder. In 1965, he was promoted to head of the Planetary Ionospheres Branch (later renamed the Ionospheric and Radio Physics Branch), and in 1970, to Associate Chief of the Laboratory for Planetary Atmospheres. During this time, his research also encompassed the German Aeros 1 and 2 satellites, launched in 1972 and 1974, respectively. From 1975 to 1981, he served as Associate Director of Sciences at GSFC. His research interests shifted to the upper atmosphere of Venus, investigated by the Pioneer Venus mission, as he was chosen as one of the mission's Interdisciplinary Scientists.

In September 1981, Prof. Bauer succeeded his doctoral thesis adviser, Prof. Otto Burkard, as Professor of Meteorology and Geophysics at the University of Graz (a chair held by Alfred Wegener in the 1920s), where he educated geophysics/physics students in the field of space sciences/geophysics/meteorology until his retirement in 1998. From 1985 to 1987, he was Dean, and from 1987 to 1989, Vice Dean of the Natural Sciences Faculty, of the university.

Supplementary to his university enrollment, he was head of the Department of Physics of Near-Earth Space of the Space Research Institute of the Austrian Academy of Sciences in Graz (1982 to 1998) and its Vice Director. Between 1983 and 1990, he served in several advisory committees for the European Space Agency. From 1984 to 2011, he was the Austrian National Representative to COSPAR and a member of its Bureau from 1986 to 1994. From 1983 to 2011, he served as Austrian delegate to URSI.

During his career, Prof. Bauer was co-investigator of several scientific instruments on space probes. He was thereby responsible for the successful data analysis and interpretation (e.g., on Ariel 3, Aeros 1 and 2, Pioneer Venus, Mars Global Surveyor, and the Titan entry probe Huygens in the Cassini mission).

He was elected a member of the Austrian Academy of Sciences (1983), the International Academy of Astronautics (1986), and the Academia Europaea (1992). His scientific work was honored by being named Fellow of the American Association for the Advancement of Sciences (1970), Fellow of the American Geophysical Union (1978), and Honorary Fellow of the Royal Astronomical Society (2011). He received the Erwin-Schrödinger Award of the Austrian Academy of Sciences (1991) and the David Bates Medal of the European Geophysical Society (2000).

In 1974, Siegfried Bauer received the NASA Medal for Exceptional Scientific Achievement. Since 1996, he was a member of the "Kurie für Wissenschaft" (curia for science) of the most prestigious award for science and arts in Austria (Österreichisches Ehrenzeichen für Wissenschaft und Kunst, Austrian Decoration for Science and Art).

Siegfried Bauer was author of two textbooks on the upper atmospheres of planets, editor of several books, and author/coauthor of more than 150 scientific publications in the scientific fields of ionospheres, aeronomy, and global environmental problems.

After his retirement, he continued his scientific work and remained active in his scientific fields of interest. Even in his last years, he investigated the ionospheric effects of hurricanes, a topic on which he published a now so-called "sleeping beauty paper" in 1958.

As students, colleagues, and friends, we not only lost a prominent scientist and mentor, but also a remarkable person. Through his work, he was an inspiration and model for "several generations" of scientists who were lucky enough to work, discuss, and/or communicate with him.

He is survived by his beloved wife, Inge; his daughter, Sonya, with husband Richard and their family; and especially his grandchildren, Christopher, Martin, Michael, and Catherina. The urn burial ceremony was private and took place on September 27, 2021.

Expressions of condolence can be directed to me via e-mail at bruno.besser@oeaw.ac.at, and will be collected and handed over to his family.

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Book Review

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Antenna and Sensor Technologies in Modern Medical Applications edited by Yahya Rahmat-Samii and Erdem Topsakal, New York, Wiley/IEEE Press, 2021, ISBN: 9781119683308.

The role of engineering technologies in various aspects of human health and well-being is expanding at a remarkable rate. Whether it is in routine health screening, diagnostics, monitoring, intra-operative guidance, delivery of treatments, drug and vaccine discovery, or just lifestyle enhancement, the ever-increasing importance of engineering technology is undeniable. In particular, devices and techniques that take advantage of electromagnetic (EM) principles are among the key enablers of medical technologies, providing otherwise-unavailable methods for information collection, information transmission, and treatment and intervention. The areas of influence of EM are numerous; we are not just talking about microwave imagining, which is perhaps one of the earliest applications of EM in biomedicine. Many other innovative application areas have emerged in the recent past, including implantable devices, new antenna materials for enhancing traditional applications, wireless power transfer, wearables, and the like.

It is difficult to parse through and keep track of all of how EM is revolutionizing modern medical applications. Just try searching for "electromagnetics in medicine" in Google Scholar! Even after recognizing these different areas of impact, there are many layers of detail and sophistication with which one can understand, and therefore push the envelope of advancement within, these technologies. The book *Antenna and Sensor Technologies in Modern Medical Applications* (Figure 1), edited by Profs. Yahya Rahmat-Samii and Erdem Topsakal, addresses these two challenges, especially as regards antennas and sensors, and achieves an exceptionally successful result.

Rahmat-Samii and Topsakal, two of the leading researchers in electromagnetics and, in particular, in applications of EM in medicine, have assembled an outstanding lineup of contributions from top experts in this field. Each of the thirteen contributed chapters addresses a unique class of topics. Each chapter provides a brief yet highly informative background, in many cases providing the historic perspective that puts the current state-of-the-art technical material in context. The contributing authors have done an excellent job in starting from high-level material of general interest, then getting progressively detailed in explaining a diverse set of methods, techniques, or devices. Each chapter contains a comprehensive literature review on its topic, selecting to focus on a representative subset as the inevitably limited page budgets have allowed. Whether the reader is new to the topic area of a given chapter or an expert, there is plenty of informative content to peruse.

There are multiple cross-cuts one can take in reading the book. As I was reading the different chapters, I didn't necessarily come up with a preferred sequence. However, depending on the reader's interest, it may be beneficial to consider the chapters based on various groupings of the overarching topic areas. For example, one can focus on chapters that are relevant to medical diagnostics, quality-of-life enhancements, implantable devices, wearables, or therapeutics, keeping in mind that there may be various other groupings and many overlaps.

For medical diagnostics, consider starting with Chapter 2, on the role of novel flexible antennas for magnetic resonant imaging (MRI) to enable more compact and targeted observation scenarios. Alternatively, you may wish to start with Chapter 6, which focuses on ingestible devices that allow a less intrusive alternative to endoscopy, and one that may be able to provide more accurate and targeted diagnostic results.

On the topic of sensors and systems for quality-of-life enhancement, Chapter 3 provides excellent coverage on a range of sensors and techniques for human-motion capture. Many areas of daily life benefit from the knowledge of human movement, including senior-care, recovery from sports injuries or surgeries, entertainment and gaming, and

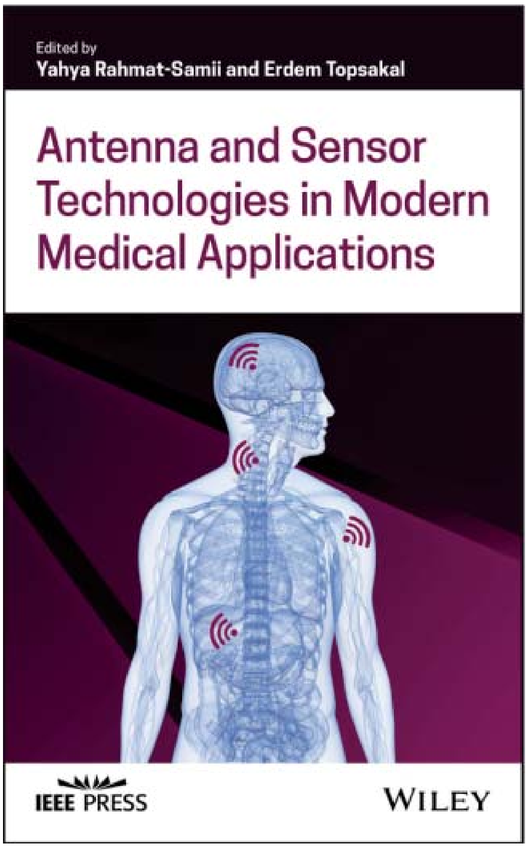

Figure 1. The cover of *Antenna and Sensor Technologies in Modern Medical Applications*.

athletic training. This topic also overlaps with chapters that focus on wearables, namely, Chapters 11, 12, 13, and 14.

For implantables, Chapters 4, 5, 7, and 8 provide a wealth of information on the latest devices and applications. In Chapter 4, you will find in-depth material on EM optimal design of antennas and wireless links for battery-free brain-implantable devices based on both inductive coupling and far-field radiation. Options for integrating these two complementary approaches are presented. Chapter 5 presents methods for both in-vitro and in-vivo testing of implantable antennas and options for materials used for building them, such as tissue-mimicking gels. Chapter 7 covers the topic of ultra-wideband channel characterization for an implanted sensor used for liver monitoring (post-transplant surgery). Chapter 8 describes inductive power transfer and the successful example of applying it to transmit power to prosthetic systems, such as an artificial retina.

For wearables, you can find an interesting diversity of topics in Chapters 11, 12, 13, and 14. Chapter 11 focuses on fabricating wearables by additive manufacturing and three-dimensional printing, for example via the use of inkjet-printing. Chapter 12 describes some of the recent electronic textile technologies, which allow the integration of computing, sensing, and communication electronics into fabrics and clothing. One such method takes advantage of embroidering conductive threads as a means of integrating RF circuits and sensors into clothing fabric. Chapter 13 discusses readout techniques for fully passive sensors, such as some wearables. In Chapter 14,wireless wearable biomarkers are discussed, allowing physiological monitoring at the point-of-person. These would include measurement of chemical signals, preconditioned on the development of appropriate small chemical sensors.

If your interest is in the area of therapeutics, Chapters 9 and 10 are where you find excellent material. Chapter 9 focuses on precision wireless drug delivery under the umbrella of "Precision Medicine." This is an emerging area, especially in the treatment of conditions that require frequent interventions and the repeated use of pharmaceuticals. The ability to deliver high concentrations of drugs to targeted sites, such as tumors, thereby avoiding systemic ingestion of potentially toxic chemicals, can have many benefits to the patients. Recent developments in microchip and micro-machined devices make it possible to achieve this precision drug delivery via transdermal and implantable devices. A very different class of therapeutics is described in Chapter 10, where minimally invasive microwave ablation antenna designs are discussed. The authors show how the miniaturized interstitial antennas allow the surgeons to reduce the invasiveness and increase the flexibility of ablation treatments.

For those of us working in the applications of EM in health and medicine, *Antenna and Sensor Technologies in Modern Medical Applications* is an excellent resource. It should be considered a necessary addition to our working library!

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[Editor's note: An earlier version of this book review originally appeared in the October 2021 issue of the *IEEE Antennas and Propagation Magazine*. The review is reprinted with permission from IEEE.]

Et Cetera

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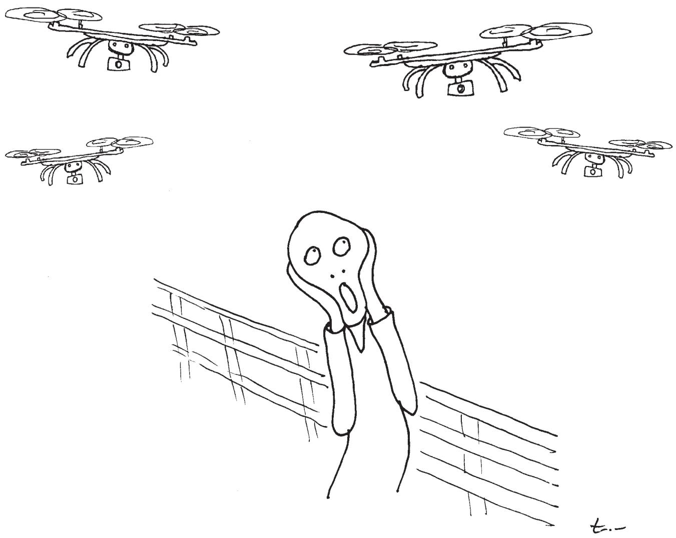

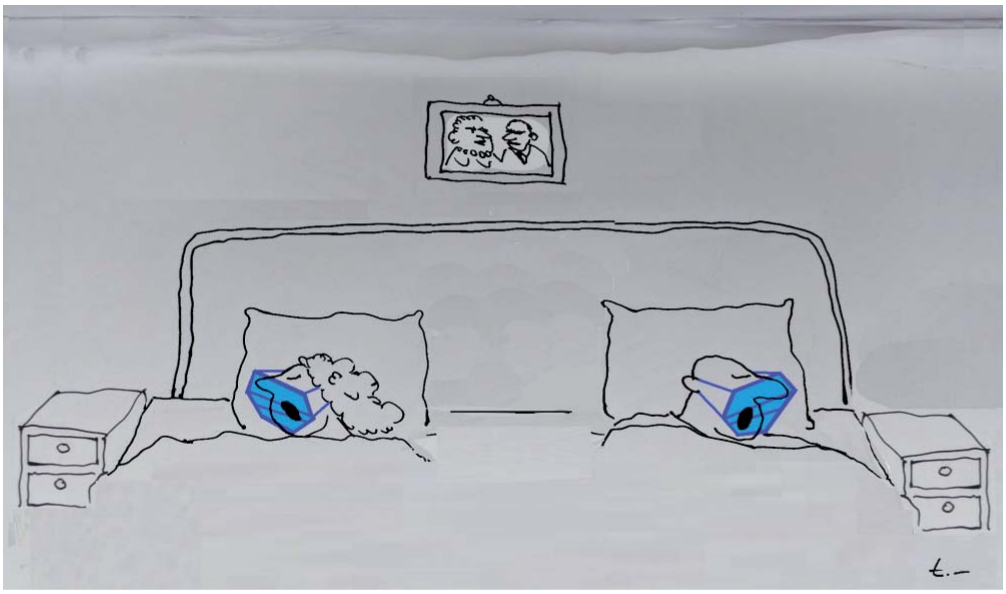

Solution Box

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SOLBOX 21: Near-Zero-Index Shells Constructed By Using Dielectric Rods

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1. Introduction

In the previous issue of SOLBOX (SOLBOX-20), we discussed periodic arrangements of dielectric rods with interesting electromagnetic properties [1]. As computational simulations demonstrate, when material and geometric properties – such as the shapes, sizes, and periodicities of the rods – are properly selected, these arrangements can behave like homogeneous objects with near-zero refractive indices. In SOLBOX-20, this phenomenon was shown by constructing triangular prisms and investigating the refraction of electromagnetic beams through them. Using cylindrical rods with 3.75 mm radius, 17 mm center-to-center periodicity, and 8.8 relative permittivity (corresponding to alumina), near-zero refractive index values could effectively be obtained at 10.3 GHz. As also shown in the same numerical set, modifying the material of the rods, i.e., using 4.0 relative permittivity, dramatically changed the behaviors of the structures, which seemed to possess ordinary refractive index values just above unity. Specifically, without using an appropriate material, such an arrangement of rods did not provide near-zero-index (NZI) characteristics, while the effective relative permittivity induced in the environment simply corresponded to that of a diluted material in vacuum.

Considering that near-zero-index properties can be achieved via relatively simple structures (obviously with certain limitations, such as lack of perfect homogeneity, frequency dependency, and excitation sensitivity), one can imagine a plethora of applications to put these designs into action, as exemplified in the literature [2-7]. For example, in [8], we presented computational simulations of ideal shells (made of homogeneous materials with assumed near-zero permittivity and permeability values) that were used to generate directive beams, in addition to the analyses of the corresponding array models. As a simple explanation (e.g., considering Snell's law), when electromagnetic waves enter a near-zero-index object, they leave perpendicularly to its surface. This leads to a remarkable result in terms of beam generation when the surface of the object (outer surface of the shell) is planar. Furthermore, if the cavity region of the shell (where the source is located) is cylindrical, waves entering and leaving the shell are in phase (as no phase accumulation occurs inside the shell), which can result in very directive beams. The best results are typically achieved when both the permittivity and permeability of the shell are equally small to further eliminate impedance mismatches at its surfaces (vacuum-to-material and material-to-vacuum), while epsilon-near-zero and mu-near-zero shells may benefit from cavity resonances, provided that the dimensions of the source region are carefully selected.

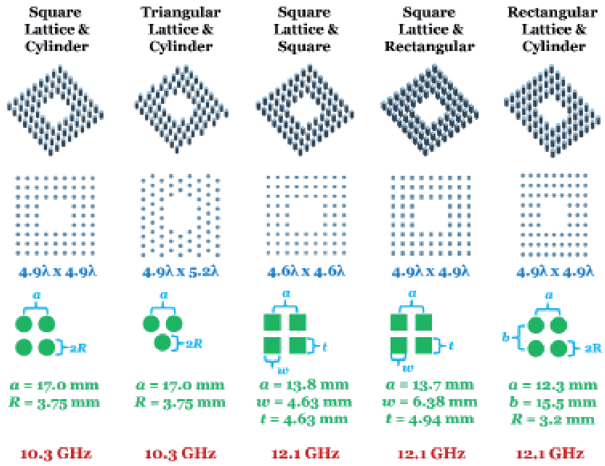

Figure 1. Shell designs consisting of dielectric rods to be used as beam generators when excited by Hertzian dipoles located in their source regions. Different lengths, (λ ,2 λ and 3 λ) were considered for the rods. The relative permittivity of the rods was 8.8 for the first two designs, while it was 9.8 for the last three. The shells were assumed to be located in vacuum.

In this issue of SOLBOX, we consider near-zero-index shells constructed by using dielectric rods. Considering our earlier experience on homogeneous models in [8] (as well as in SOLBOX-17 [9]) and rod arrangements in SOLBOX-20 [1], these shells are expected to function as beam generators with many favorable properties in practice, as they depend on simple isotropic excitations while being completely detached from these sources (electrically isolated, rotatable, replaceable, and even reconfigurable). On the other hand, even when using suitable materials, the geometric properties of the unit cells (rods) and their arrangements are very critical to achieving desired radiation characteristics. Although theoretical analyses are available for two-dimensional models, practical shells are three-dimensional structures involving finite rods, leading to deviations from ideally expected characteristics, particularly when they are strongly excited via nearby sources. Once again, computational tools provide essential information on the designed structures before their realizations in real life. In addition to the five different designs presented in this issue (SOLBOX-21), sample solutions are provided as references for readers who wish to use their own implementations to analyze these interesting structures.

2.1 Problem SOLBOX-21

In SOLBOX-21, we defined five distinct structures involving different arrangements of different dielectric rods with 8.8 or 9.8 relative permittivity. As depicted in Figure 1, each structure involved a cavity region at its center, where a source was located for the excitation. In the numerical results presented below, Hertzian dipoles aligned in the direction of the rods were employed. The dimensions of the structures were similar, whereas their designs (rods and their arrangements) were different from each other, leading to various electromagnetic characteristics. The first design involved cylindrical rods (3.75 mm radius) arranged in a square lattice with 17.0 mm center-to-center distance. In terms of the cell structure, this design was hence similar to the prisms considered in SOLBOX-20 [1]. The second design consisted of the same cylindrical rods, while a triangular lattice with 17.0 mm horizontal and vertical periodicities was used for their arrangement. As shown in Figure 1, this structure did not possess a horizontal line symmetry. The first two structures consisted of rods with 8.8 relative permittivity and were designed to operate at 10.3 GHz, while the next three consisted of rods with 9.8 relative permittivity and were more suitable to be used at 12.1 GHz. The third design involved rods with 4.63 mm × 4.63 mm square cross sections arranged in a square lattice with 13.8 mm periodicity. On the other hand, the fourth design consisted of rods with 6.38 mm × 4.94 mm rectangular cross sections arranged in a square lattice with 13.7 mm periodicity. Finally, cylindrical rods with 3.2 mm radii were used to construct the fifth design, which was based on a rectangular lattice with 12.3 mm horizontal and 15.5 mm vertical periodicities. For the lengths of the rods, we considered three different values, i.e., λ , 2λ, and 3λ, where λ represents the wavelength in the host medium (vacuum). Note that the wavelengths (and so the metric lengths of the rods) were different for the first two and the last three designs.

The first three designs described above behaved as nearly isotropic shells, whereas the fourth and fifth designs possessed anisotropic characteristics. The anisotropy of the fourth design was caused by the rods that have rectangular cross sections. For the fifth design, the rectangular lattice (i.e., different periodicities in the horizontal and vertical directions) led to the anisotropic behavior, as also verified in the sample results. Finally, we recall that these types of rod arrays typically demonstrate epsilon-and-mu-negative (EMNZ) characteristics with near-zero values for both permittivity and permeability induced in the medium. However, the anisotropic (fourth and fifth) designs had epsilon-and-mu-negative characteristics in one direction, while they possessed epsilon-near-zero (ENZ) characteristics in the other direction on the array plane.

3. Solution to Problem SOLBOX-21

3.1 Solution Summary

Solver type (e.g., Noncommercial, commercial): Noncommercial research-based code developed at CEMMETU, Ankara, Turkey

Solution core algorithm or method:
Frequency-domain MLFMA
Programming language or environment (if applicable):
MATLAB + MEX

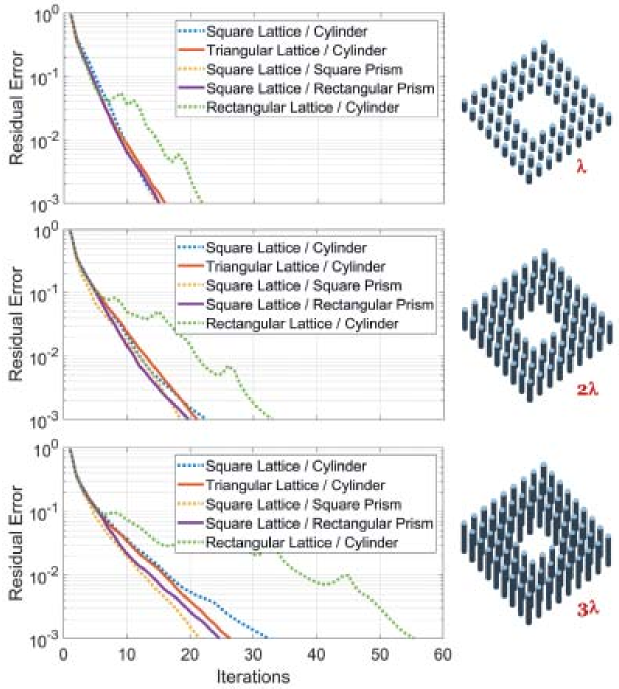

Figure 2. The convergence histories in the iterative solutions of the electromagnetic problems involving the shells described in Figure 1. The residual errors were plotted with respect to iterations in the main solutions of the three-layer scheme.

Computer properties and resources used:
2.5 GHz Intel Xeon E5-2680v3 processors (using 4 cores)

Total time required to produce the results shown (categories: <1 sec, <10 sec, <1 min, <10 min, <1 hour, <10 hours, <1 day, <10 days, >10 days): <10 hours for the largest problem

3.2 Short Description of the Numerical Solutions

A frequency-domain Multilevel Fast Multipole Algorithm (MLFMA) [10] was employed for the analyses of five different designs with three different rod lengths (a total of 15 problems) defined in SOLBOX-21. Similar to the simulations in SOLBOX-20, the electric-magnetic current combined-field integral equation (JMCFIE) [11, 12] was preferred as the formulation, while the Rao-Wilton-Glisson functions were employed to expand the equivalent currents. Discretization elements (triangles) were generally selected smaller than $\lambda/10$; however, denser triangulations were needed and used to accurately model cylindrical rods. Consequently, the numbers of unknowns varied in a wide range from 38,016 (the third design with λ rods) to 327,456 (the fifth design with 3λ rods). Initial experiments on the structures showed that their iterative solutions were challenging, even though JMCFIE is a second-kind integral-equation formulation. A multilayer iterative strategy [13] was therefore followed to achieve faster solutions. Specifically, a three-layer inner-outer scheme was employed, as follows:

- A main (layer-0) solution was performed by using a flexible Generalized Minimal Residual Method (GMRES) and the conventional MLFMA with two digits of accuracy. This solution was preconditioned by inner (layer-1) iterative solutions. Note that one preconditioner solution was needed for each iteration of the main solution.

- A layer-1 solution was performed by using a flexible Generalized Minimal Residual Method and an approximate MLFMA with 0.3 approximation factor. The residual error was selected as 0.4 (40%). Such an inner solution was further preconditioned by inner (layer-2) iterative solutions. Again, note that one preconditioner (layer-2) solution was needed for each iteration of a layer-1 solution.

- A layer-2 solution was performed by using a Generalized Minimal Residual Method and an approximate MLFMA with 0.0 approximation factor (corresponding to near-zone interactions). The residual error was selected as 0.3 (30%). This kind of solution was further accelerated via a block-diagonal preconditioner, as it was already available to be naturally extracted from the tree-structure of the MLFMA.

In both the MLFMA and its approximate versions, far-zone and near-zone interactions were determined via a one-box-buffer strategy. The parameters of the inner-outer strategy described above (approximation factors and inner residual errors) were determined heuristically based on initial tests, since they usually depend on the problem type. However, once customized, the strategy provided efficient solutions and fast outer iterative convergences, leading to results that were also less contaminated by the accumulation of rounding errors (deviation of the observed residual from the true residual), in comparison to the standard iterative solutions.

Figure 2 presents convergence histories in iterative solutions of the 15 different problems. The residual errors were plotted with respect to iterations in the main (layer-0) solutions, until the target error of 0.001 was reached in each case. For the structures involving λ rods, only the fifth design (cylindrical rods in a rectangular lattice) required more than 20 iterations. The required numbers of iterations naturally increased as the rods became longer and the problem sizes grew. Nevertheless, efficient solutions were obtained even for the structures involving 3λ rods, four of which required only 22-33 iterations. The most challenging case seemed to be the fifth design with 3λ rods (discretized with 327,456 unknowns), which was the only structure that needed more than 50 iterations among the 15 problems.

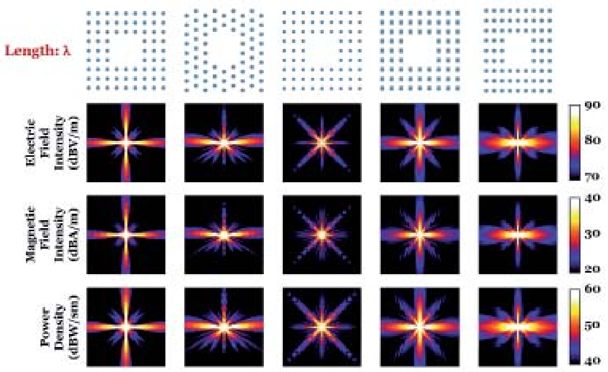

Figure 3. The electric-field intensity, magnetic-field intensity, and power-density distributions obtained for the shell structures involving λ rods. Each plot shows the values in a 100 λ x100 λ region around the structure.

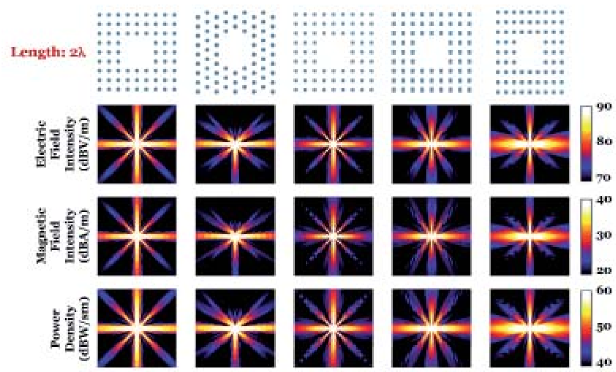

Figure 4. The electric-field intensity, magnetic-field intensity, and power-density distributions obtained for the shell structures involving 2 λ rods. Each plot shows the values in a 100 λ x100 λ region around the structure.

3.3 Results

Figure 3 presents the results for the structures consisting of λ rods. For each structure, the electric-field intensity, magnetic-field intensity, and power-density values were sampled in a 100 λ x 100 λ region on the array planes. We recall that the first two designs (involving rods with 8.8 relative permittivity) were investigated at 10.3 GHz, while the last three (involving rods with 9.8 relative permittivity) were considered at 12.1 GHz. In addition, each structure was excited via a Hertzian dipole with unit dipole moment. For the visualization of the intensity and density values, 20 dB dynamic ranges were used. Our observations were as follows:

- The first structure led to four strong beams that emerged from the flat surfaces of the represented shell, as expected due to its near-zero-index characteristics, in addition to some minor sidelobes in diagonal directions.

- When the second structure was used as a shell, two main beams were created in the horizontal directions, while there were many significant sidelobes. We noted that due to the triangular lattice, two of four sides of this structure did not represent planar surfaces. These surfaces hence did not produce proper beams, even though near-zero-index characteristics were maintained via cylindrical rods (as demonstrated by two beams from the planar sides). In fact, such corrugations on two sides, which naturally occur for the triangular lattice, can be used to suppress undesired beams, depending on the application [8].

- For the third structure, we observed dramatic effects of unit cells, i.e., rod shapes and periodicities. This structure could not produce any major beam: instead, eight beams with relatively weak strengths were generated. Although not shown in this contribution, further investigations on this design revealed that fine-tuning cross-sectional dimensions such as 5.36 mm × 5.36 mm and periodicity such as 14.1 mm led to four clear beams, as a further verification of the sensitivity of near-zero-index characteristics to unit-cell dimensions.

- In the case of the fourth structure, four main beams, as well as four sidelobes between them, were clearly visible. With a close examination, one could observe that the pair of beams in the horizontal directions were slightly different from the other pair in the vertical directions, due to the anisotropic characteristics of the structure.

- Being the second structure with anisotropic properties, the fifth design led to two sharp but minor beams in the vertical directions, while the beams in the horizontal directions were dispersed and accompanied by sidelobes.

In Figure 4, we consider intensity and density distributions obtained for the structures involving 2 λ rods. Although some main characteristics were maintained, we observed interesting changes in the behaviors of the designs when the rods were enlarged to 2 λ. In general, all radiations were strengthened in comparison to those provided by the structures with λ rods, since less power could escape from the top and bottom openings of the cavity regions, leading to increased field and density values on the array planes. For the first design, the sidelobes were combined into single beams in the diagonal directions, while the main beams still dominated the overall radiation. On the other hand, with 2 λ rods, the third design generated stronger beams in the horizontal and vertical directions, in comparison to its performance with λ rods. Since all of the plots in Figure 4 provided information only on the two-dimensional radiation characteristics (on the array planes), we further considered the three-dimensional plots in Figure 5. In these complementary results, the electric-field intensity values in the far zone were plotted, considering all observation directions to reveal the overall radiation characteristics of the designs. The color range was designated to represent values from 1000 V to 15000 V. We observed that in addition to main and sidelobes on the

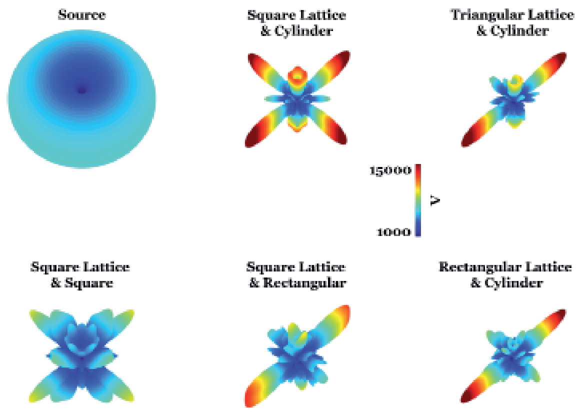

Figure 5. The electric-field intensity in the far zone obtained for the shell structures involving 2λ rods. Colors were used to represent field values with respect to observation directions.

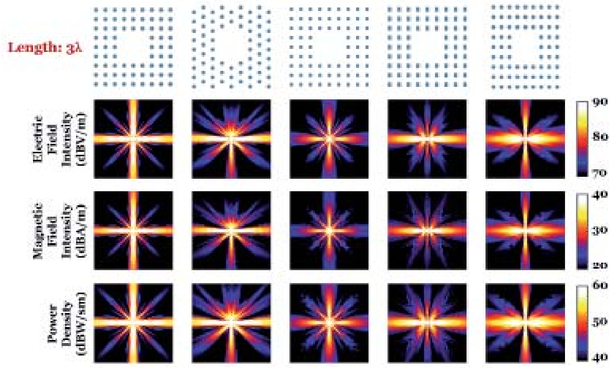

Figure 6. The electric-field intensity, magnetic-field intensity, and power-density distributions obtained for the shell structures involving 3λ rods. Each plot shows the values in a 100 λ x100 λ region around the structure.

array planes (shown in Figure 4), there were many other lobes in various directions. Considering the first design, upward and downward radiations (as the source region was not closed from above or below) that contained nulls at the poles were remarkable. Similar radiations existed for the other structures, while the main lobes were clearly visible in all cases. We also noted the relatively poor performance of the third design in comparison to others, despite the improvement in the radiation characteristics of this design by enlarging the rods.

Figures 6 and 7 next present two-dimensional and three-dimensional radiation plots when the designs had 3λ rods. By increasing the length of the rods, the sidelobes were significantly reduced for the first design. As shown in the three-dimensional electric-field intensity plot in Figure 7, this structure provided four strong beams, along with insignificant sidelobes in various directions (including upward and downward radiations that were reduced in comparison to the radiation of the same design with 2λ rods). The second design provided two strong beams and many sidelobes, while the most significant one was perpendicular to the main beams. The fourth and fifth designs had quite bi-directional patterns, thanks to the anisotropic nature of these structures. Finally, the relatively poor performance of the third design persisted when the rods had **3**λ lengths.

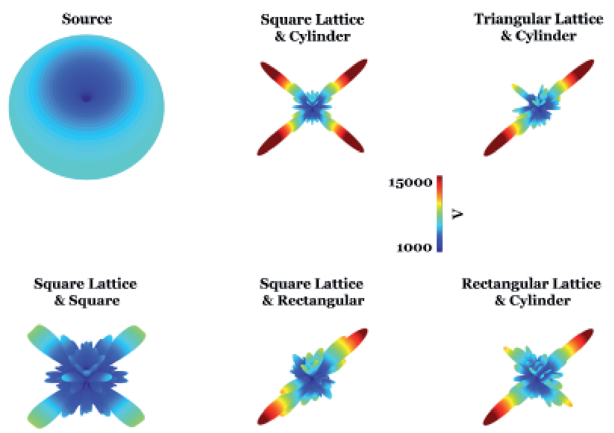

Figure 7. The electric-field intensity in the far zone obtained for the shell structures involving 3λ rods. Colors were used to represent field values with respect to observation directions.

For more quantitative comparisons, Figure 8 depicts the far-zone electric-field intensity with respect to observation angle on the array plane for each design consisting of 3λ rods. The results for the first two designs (10.3 GHz) were plotted together on the left-hand side, while the results for the third, fourth, and fifth designs (12.1 GHz) are illustrated on the right-hand side. The electric-field intensity values due to the sources (Hertzian dipoles) without shells were also included for comparison. In these results, we observed that the third design mainly suppressed radiation to generate four main beams, while the others provided intensity values well above the corresponding Hertzian dipole. For a bi-directional pattern via anisotropic structures, the fourth design seemed to be better than the fifth design, considering sidelobe levels. For the second design, it was remarkable that the radiation was effectively suppressed at 90°, while the radiation at 270° was still significant so that this design may even be categorized as a tri-directional beam generator.

In conclusion, the results in Figures 3-8 clearly demonstrated the variety of radiation characteristics that can be obtained by using different rod dimensions and arrangements in constructing shell structures with near-zero-index characteristics. The beam-generation properties of these three-dimensional structures depended not only on the cross-sectional geometries of the rods but also on their lengths, which indicated the need for fast computational tools to support theoretical and analytical design procedures.

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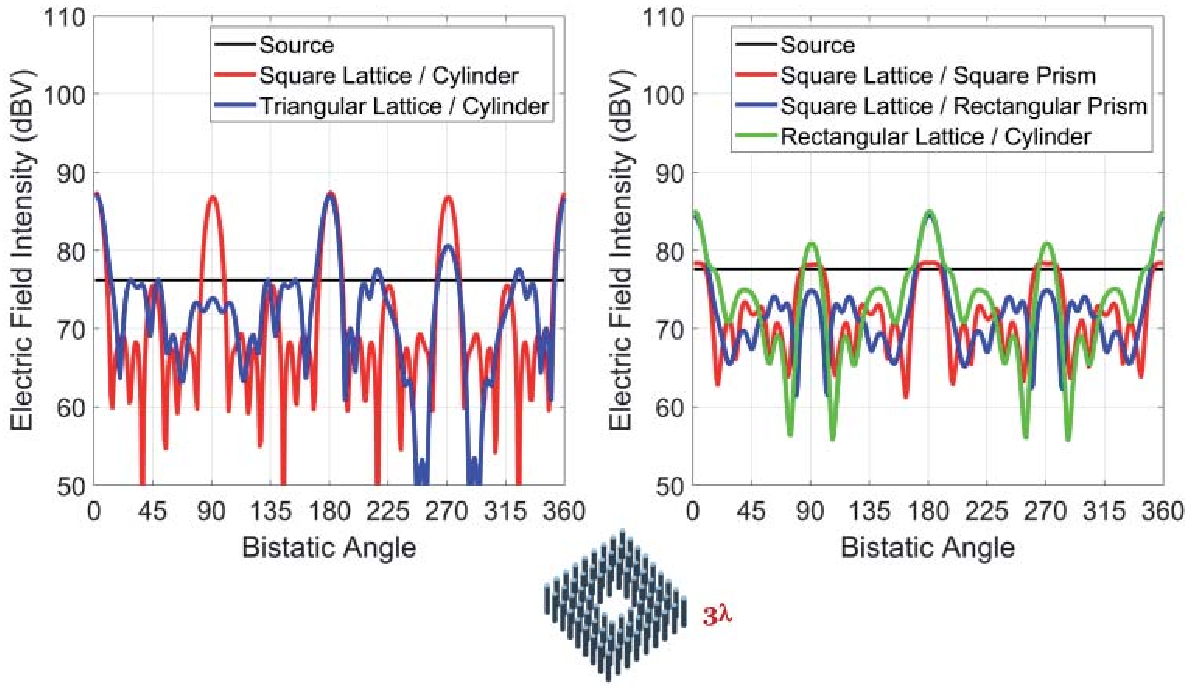

Figure 8. The far-zone electric-field intensity with respect to observation angle on the array plane for the shell structures involving 3λ rods.

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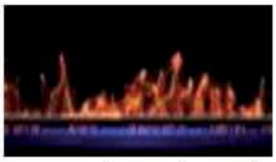
Commission B – Fields and Waves
Antenna arrays, Antennas: recent advances and future outlook, Antenna theory, design and measurements, Cognitive radio, Complex media (bandgap structures, biological and geophysical media, metamaterials, and others), Educational methods and tools, Electromagnetic interaction and coupling, Guided waves and waveguiding structures, High-frequency techniques, Imaging, inverse scattering and remote sensing, Mathematical modeling of electromagnetic problems, Microstrip antennas and printed devices, Multiphysics electromagnetics, Nanoscale electromagnetics, Nonlinear electromagnetics, Numerical methods (differential- and integral-equation based, hybrid and other techniques), Optical phenomena, Optimization techniques in electromagnetics, Propagation phenomena and effects, Rough surfaces and random media, Scattering and diffraction, Theoretical electromagnetics, THz antennas and propagation, Transient fields, effects, and systems, Ultra-wideband electromagnetics, Wireless communications and other topics of interest.

Commission C – Radiocommunication Systems and Signal Processing



Cognitive radio and software defined radio, Distributed sensor networks and sensors array processing, Energy-efficient ("green") communications, Information theory, coding, modulation and detection, MIMO and MISO systems, Novel radio communication systems, Physics-based signal processing, Radar target detection, localization, and tracking, Radio localization and positioning, Signal and image processing, Spectrum and medium utilization, Statistical signal processing of waves in random media, Synthetic aperture and space-time processing, Wireless networking and other topics of interest.

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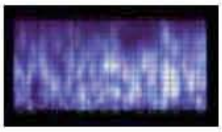
Commission E – Electromagnetic Environment and Interference



Communication in the presence of noise, Crosstalk, Electromagnetic compatibility education, Electromagnetic compatibility measurements and standards, Electromagnetic noise of natural origin, Electromagnetic radiation hazards, High-power effects of transients on electronic systems, Spectrum management and utilization and other topics of interest.

Commission F – Wave Propagation and Remote Sensing
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Foreword

Recently, I have been trying to widen the topics of this column, which in the past have been more focused on those relative to Commission B, Fields and Waves, due to my background. The contribution to this issue, "The Roots of Modern Cryptography: Leon Battista Alberti's 'De Cifris'," by Stefano Selleri (University of Florence), is more aimed at Commission C, Radiocommunication Systems and Signal Processing. This is because it deals with encryption and code breaking, topics that are as hot as ever in this era, in which all kinds of bank transactions, signatures of agreements, and so on occur via the Internet. This is indeed an expansion of the contribution by G. Pelosi and S. Selleri, "Florence and a Leap in Cryptography: The Leon Battista Alberti Cypher Disk," presented at IEEE HISTELCON 2021, Moscow, Russia, 10-12 November 2021.

Figure 1a. San Martino, a parish of Galgalandi, in which Leon Battista Alberti was prior from 1432 up to his death

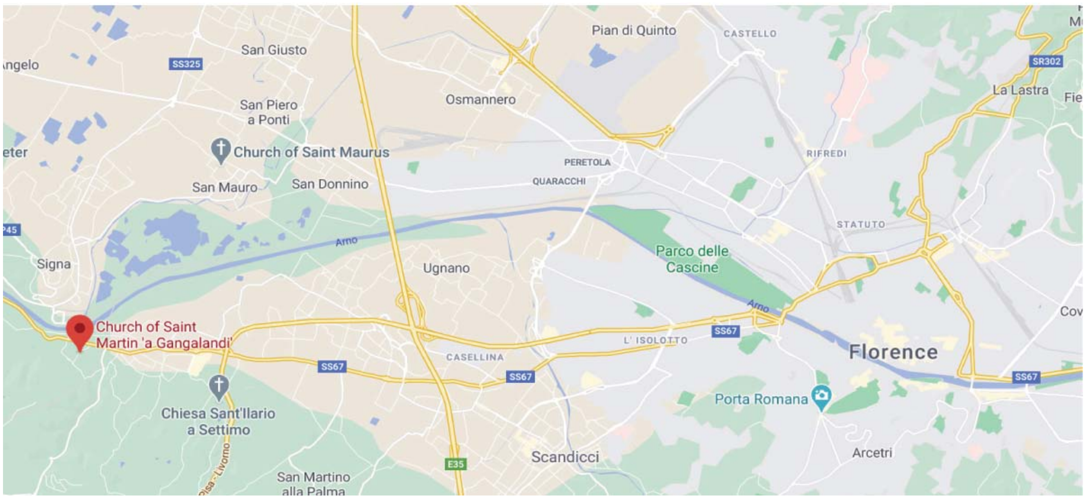

Figure 1b. A map showing the location of the parish of Galgalandi with respect to Florence.

Figure 2a. Alan Turing [London, England, 23 June 1912 – Wilmslow, England, 7 June 1954].

Figure 2b. Henry Du Pré Labouchère [London, England, 9 November 1831 – Florence, Italy, 15 January 1912].

As the paper shows, it is remarkable how secret communications basically used a simple substitution of letters from its beginning, in ancient times, up to the idea of Leon Battista Alberti [1404-1472]. Born in Genova – but Florentine since his parents were banned from Florence a few years before his birth – in 1466 Alberti invented poly-alphabetic ciphering, with a random change of the ciphering alphabet within a message. He introduced the concept of the ciphering disk to quickly and efficiently change the coding.

Poly-alphabetic ciphering was born in Italy, and possibly in Florence, where Alberti often was when not in Rome (Figure 1). It was popularized by Vigenère, to whom the idea was indeed credited for some time. Poly-alphabetic ciphering is harder but not impossible to decipher, its strength relying on the length of the keyword used for ciphering. It has been used worldwide until very recently. It most notably was use, with an "electrical" version of Alberti's disk, in the famous encrypting machine, Enigma, used by Germany during World War II.

It is well known that Alan Turing (Figure 2) broke through the Enigma's coding and, indeed, in so doing

Figure 4a. The statue of Alan Turing in Manchester, holding an apple.

Figure 4b. The Apple Inc. logo, an apple with a bite out of it.

Figure 3a. The "Villa Cristina" in an old photo.

Figure 3b. An aerial view of the School of Engineering, with the part that was formerly the "Villa Cristina" highlighted.

started the whole new science of electronic computing. What it is less known is that there is a second link between cryptography and Florence. Alan Turing was condemned in 1952 to medical treatment for his homosexuality, according to the "Labouchere Amendment" of 1885. This amendment was abrogated only in 1967. Besides Turing, Oscar Wilde [Dublin, Ireland, 6 October 1854 – Paris, France, 30 November 1900] also spent two years at punitive hard labor for the same reason.

Labouchere owned a Villa in Florence, the "Villa Cristina" from the name of a previous owner, Christina Temple-Bowdoin. He used to spend much time in Florence and indeed, after his retirement, he settled in "Villa Cristina" until his death. The Villa Cristina passed through many owners, who transformed and expanded it to host a hotel and then a seminary. It was eventually acquired by the University of Florence in 1980 as the new location of the School of Engineers. Indeed it still is, and I am writing these lines there (Figure 3).

To return to cryptanalysis and Alan Turing, it is known that he finally committed suicide by eating a poisoned apple. Indeed, his statue at Sackville Gardens in Manchester, England, next to the Shena Simon Campus of Manchester University, where Turing worked after World War II, holds an apple in his hand (Figure 4). It is a hypothesis that indeed the logo of Apple Inc., an apple with a bite out of it, is an homage to Alan Turing, father of computers, even if Apple itself denies it.

The Roots of Modern Cryptography: Leon Battista Alberti's "*De Cifris*"

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Abstract

hile cryptography is almost as old as writing, its earliest applications were rather trivial and relatively easily broken via statistical analysis, as Al-Kindi proved in the VIIIth century. Modern ciphers deceive statistical analysis thanks to complex algorithms and ciphering keys. The very first concept of these can be found in a 1466 manuscript by Leon Battista Alberti, the importance of which was for many years overlooked. This paper focuses on the work by Alberti and its impact, within the framework of a brief and necessarily incomplete history of cryptography.

1. Introduction

Cryptography is the practice of enciphering and deciphering of messages in secret code in order to render them unintelligible to all but the intended receiver. While this art is very old, as the second section of this contribution briefly summarizes, ciphers were elementary and hence easy to break. Indeed, it is astonishing for we moderns that the greatest general of antiquity, Julius Caesar, sometimes simply wrote his message in Latin but using the Greek alphabet, since there was no one among his enemies that knew the Greek alphabet [1]:

> ...ibi ex captivis cognoscit, quae apud Ciceronem gerantur quantoque in periculo res sit. Tum cuidam ex equitibus Gallis magnis preamiis persuadet, uti Ciceronem epistulam deferat. Hanc Graecis conscriptam litteris mittit, ne intecepta epistula nostra ab hostibus consilia cognoscantur...
>
> ...there, he [Caesar] learns from the prisoners what is happening near Cicero and what danger he is in. Hence he convinces with great rewards a knight of the Gauls to bring a letter to Cicero. He writes the letter in Greek characters so that if it falls into enemy hands it does not reveal his plans...

Even if Caesar also used a more-refined technique, he, as all ancient and middle-aged people, used what is called *mono-alphabetic* substitution. This is easy to break if the message is long enough and the language in which the clear text is written is known.

It was in the Renaissance that we had a true leap forward in cryptography, when Leon Battista Alberti developed the ideas of a substitution cipher that changes *within* a same message. He thus invented *poly-alphabetic* substitution; *super-enciphering*, which further reduces the chances of statistical analysis; and a ciphering disk able to automate the ciphering-deciphering process.

The concepts of Alberti were sadly not finalized into a truly secure algorithm, and his contributions were overlooked by contemporaries. Some of his ideas were indeed for long credited to Blaise de Vigenere, who, on the other hand, in 1586, gave practical instructions for poly-alphabetic ciphering. Indeed, the ideas of Alberti were behind all mechanical ciphering algorithms, the most complex of which are the crypto machines *Enigma* and *Lorenz*, developed in Germany during World War II.

2. Ancient Cryptography

The oldest way of conveying a ciphered message of which we have historical evidence is the scytale, used by the Spartans and described by Plutarch [2]. This consisted of a rod on which a thin strip of parchment was wound, with letters written along its axis, one per wind of the strip. The receiver, having a rod of the same diameter, was able to immediately reconstruct the message (Figure 1). Plutarch wrote that Lysander [Sparta, Greece, c. 441 B.C.[1]– Haliartos, Greece, 395 B.C.] was reached in 404 B.C. by a wounded messenger, the only one of five that survived the crossing of Persian territory. The messenger handed his belt to Lysander, who wound it along his scytale to read that Farnabazo was planning to attack him. Lysander hence had the time to prepare his army and eventually won the battle.

To remain in Greece, Polybius [Megalopolis, Greece, ca. 200 B.C. – Somewhere in Greece, 118 B.C.] suggested

1 For the sake of simplicity, only before Christ (B.C.) will be indicated in dates; when no specification is given, Anno Domini (A.D.) is implied and suppressed.

Figure 1a. A reconstruction of a scytale.

	1	2	3	4	5
1	Α	Β	Γ	Δ	Ε
2	Ζ	Η	Θ	Ι	Κ
3	Λ	Μ	Ν	Ξ	Ο
4	Π	Ρ	Σ	Τ	Υ
5	Φ	Χ	Ψ	Ω	

Figure 1b. Polybius' table.

the usage of a "matrix" of characters named the *Polybius Square* (Figure 1), where the coding of messages was done using the row-column numbers of each letter [3]. Due to the limited number of symbols (the numbers 1 to 5), this was a code that could also be used for optical-torch-based communications.

In ancient bibles, some words were ciphered using one of the oldest examples of a substitution cipher, or ATBSH. This was obtained by substituting the first letter of the Aramaic alphabet (Aleph) with the last (Taw), the second (Beth) with the penultimate (Shin), and so on. In practice, this was a mono-alphabetic substitution with a reversed alphabet.

The first widespread use of a substitution cipher in military applications appeared in the writings of Gaius Julius Caesar [Rome, Italy, 13 July 101 B.C. – Rome, Italy, 15 March 44 B.C.] (Figure 2), where the second alphabet was not reversed as in the ATBASH cipher, but rather shifted by a pre-determined number of letters [4]. This *shift mono-alphabetic substitution* remained the best ciphering method for all antiquity and the Middle Ages. Mono-alphabetic ciphers, even more general than Caesar's – since they exploited *shuffled* alphabets, not just shifted alphabets – were also found, for example, in India. The art of *Mlecchita vikalpa* is a mono-alphabetic ciphering with a shuffled alphabet, and is credited to date back to the IVth century B.C., as it was cited even if not detailed among the 64 arts that should be studied by learned people in the *Kāma Sūtra* [5].

During the Middle Ages, no significant evolution in ciphering techniques took place, but Arabs were working on code breaking. The oldest treatise on this was due to Al-Kindi [Kufa, Iraq, ca. 801 – Baghdad, Iraq, ca. 873] (Figure 2) who proved how code breaking for simple mono-alphabetic substitution was relatively easy if the language of the original message is known, and a statistical analysis is applied to the ciphered message and checked against the letter frequencies in such a language [6].

3. The Renaissance of Cryptography: Leon Battista Alberti

Leon Battista Alberti [Genoa, Italy, 14 February 1404 – Rome, Italy, 25 April 1472], was a polymath as were many Renaissance geniuses: architect, historian, humanist, mathematician (Figure 3).

Figure 2a. Gaius Julius Caesar.

Figure 2b. Abū Yūsuf Yaʿqūb ibn Isḥāq al-Kindī.

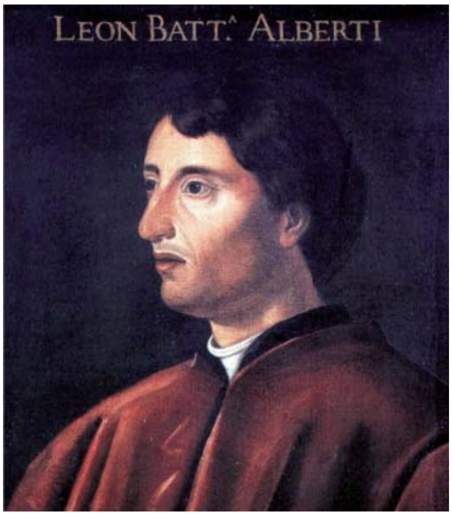


Figure 3a. A painting depicting Leon Battista Alberti (Uffizzi Gallery, Florence), attributed to Cristofano Dell'Altissimo, who never met Alberti, being born in 1525.

Figure 3b. The statue of Leon Battista Alberti in the Uffizzi front porch, were the statues of 28 eminent people of the Florentine Renaissance are on show. The statue is by Giovanni Lusini, sculpted in 1850.

Although born in Genoa, his parents were rich merchants from Florence and banned from the city for political reasons, which was quite common in Italy in the Middle Ages and the Renaissance. He studied in Venice and then in Padua, at the school of the humanist Gasparino Barzizza, where he learned Latin and perhaps also Greek. He then moved to Bologna, where he studied law, simultaneously dedicating himself to music, painting, sculpture, mathematics, and literature.

After the death of his father (1421), Alberti had some hard years because his relatives did not want to recognize his hereditary rights nor favor his studies. Anyway, he actually graduated in law (1428). In his years in Padua and Bologna, he befriended many important intellectuals such as Paolo Dal Pozzo Toscanelli and Tommaso Parentuccelli (future Pope Nicholas V). He was then in Rome (1431-1433) and, after the ban on his family was relieved, in Florence and Ferrara (1434-1443). He was then returned to Rome, but continued working in Florence, Rimini, and Mantua, from 1444 up to his death.

Most celebrated as an architect, he designed the Tempio Malatestiano in Rimini, conceived the main square in Pienza, and the churches of Sant'Andrea and San Sebastiano in Mantua. In Florence, he designed the upper facade of Santa Maria Novella church and of Palazzo Rucellai (Figures 4 and 5). He also designed part of the San Martino a Galgalandi parish, next to Florence. Alberti was actually rector of the parish from 1432 up to his death.

Figure 4. The Palazzo Rucellai.

Figure 5. The Santa Maria Novella: the facades in both Figures 4 and 5 were designed by Leon Battista Alberti in Florence.

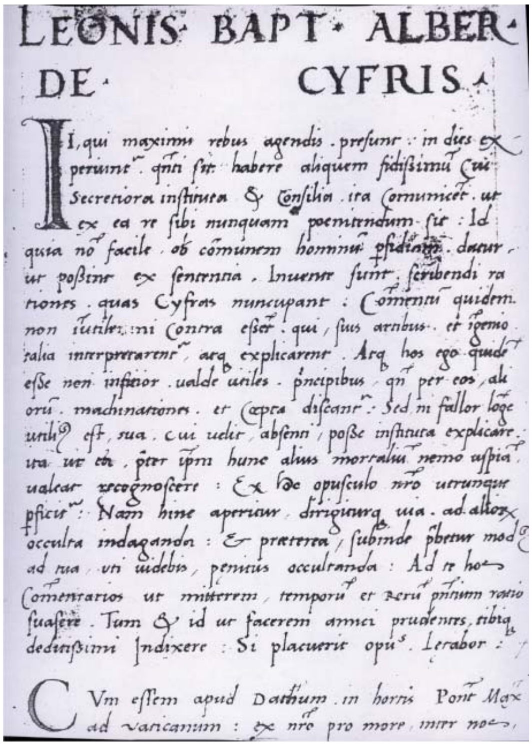

LEONIS BAPT ALBER
DE CYFRIS

Figure 6. The first page of one of the existing manuscripts of [10]. Note that in this case, the title was spelled "Cyfris," while the usual spelling is "Cifris."

Agnolo Pandolfini, a close friend of Alberti, was buried there. Alberti actually lived of these prebendary, which were not limited to San Martino a Galgalandi, while he worked for the pope as an *Abbreviator*, a writer of the Papal Chancery who adumbrated and prepared in correct form Papal bulls, briefs, decrees, etc. Leon Battista Alberti was indeed also a writer, among the first in the Renaissance to write on arts. His main literary works were on architecture [7], painting [8], and sculpture [9].

However, among the many other activities, in 1466 or 1467 (the date is uncertain), Alberti composed a text on cryptography [10]. Fifteen manuscript copies of this are still existent, each with slight differences, also in the title, due to copyists. An English translation is available [11]. The relevance of the text was underestimated up to the XXth century. While it was known for the first description of the cipher disk, it also contains a refined analysis of the language, aimed both at deciphering – as it was in the Al-Kindi treatise [6] – and at improving ciphering, by providing important new contributions [12].

The incipit of the text clearly states the aims of Alberti: to provide governors with a way to communicate in a secure way with their most trusted collaborators (Figure 6). In particular, two ideas were notable: the idea of using a *poly-alphabetic* cipher in place of the weak, mono-alphabetic, Caesar's code in use up to Alberti time; and the idea of *super-encipherment*.

Poly-alphabetic ciphering means that when ciphering the text, the ciphering alphabet is *changed* during encoding. If cleverly used, this makes frequency analysis impossible, since a same letter is translated into a different letter by each different ciphering alphabet. Alberti was not very practical, and proposed to change the code at random – which is smart – every two or three words, and to indicate the change in rotation in his disk within the ciphered message – which is less smart, indeed, an unexpected letter in writing that could easily give hints to attackers.

Super-encipherment, in Alberti's concept, is to substitute common phrases with numbers, up to four digits, but containing only the digits from 1 to 4 contained in the disk. This even more messes up the frequency of letters and avoids frequency-based code breaking.

Alberti wrote about the disk description [10]:

Scribendi autem ratio occultissima et commodissima, quam imprimis probemus, haec est. Facio circulos duos duabus tabellulis aeneis, unum maiorem qui stabilis

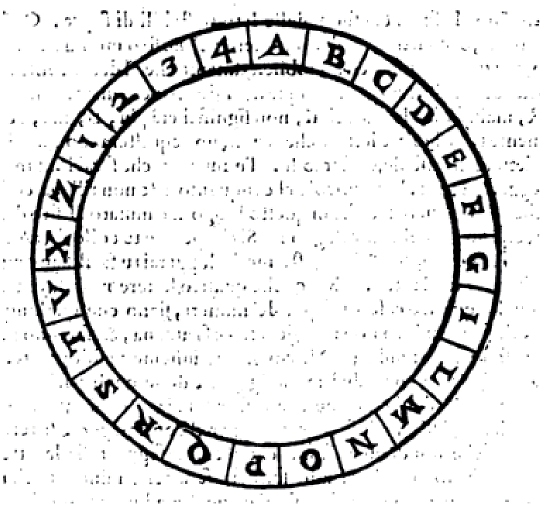


Figure 7a. Alberti's disk from the first printed edition of the *De Cifris*.

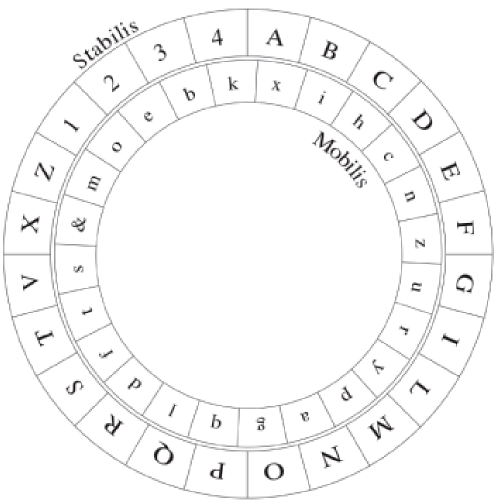
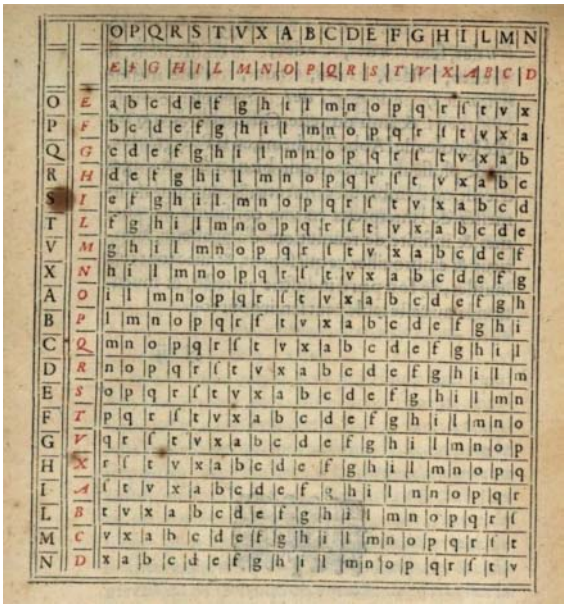


Figure 7b. Alberti's disk from its critical online edition [10].



		O	P	Q	R	S	T	V	X	A	B	C	D	E	F	G	H	I	L	M	N
		E	F	G	H	I	L	M	N	O	P	Q	R	S	T	V	X	A	B	C	D
O	E	a	b	c	d	e	f	g	h	i	l	m	n	o	p	q	r	ſ	t	v	x
P	F	b	c	d	e	f	g	h	i	l	m	n	o	p	q	r	ſ	t	v	x	a
Q	G	c	d	e	f	g	h	i	l	m	n	o	p	q	r	ſ	t	v	x	a	b
R	H	d	e	f	g	h	i	l	m	n	o	p	q	r	ſ	t	v	x	a	b	c
S	I	e	f	g	h	i	l	m	n	o	p	q	r	ſ	t	v	x	a	b	c	d
T	L	f	g	h	i	l	m	n	o	p	q	r	ſ	t	v	x	a	b	c	d	e
V	M	g	h	i	l	m	n	o	p	q	r	ſ	t	v	x	a	b	c	d	e	f
X	N	h	i	l	m	n	o	p	q	r	ſ	t	v	x	a	b	c	d	e	f	g
A	O	i	l	m	n	o	p	q	r	ſ	t	v	x	a	b	c	d	e	f	g	h
B	P	l	m	n	o	p	q	r	ſ	t	v	x	a	b	c	d	e	f	g	h	i
C	Q	m	n	o	p	q	r	ſ	t	v	x	a	b	c	d	e	f	g	h	i	l
D	R	n	o	p	q	r	ſ	t	v	x	a	b	c	d	e	f	g	h	i	l	m
E	S	o	p	q	r	ſ	t	v	x	a	b	c	d	e	f	g	h	i	l	m	n
F	T	p	q	r	ſ	t	v	x	a	b	c	d	e	f	g	h	i	l	m	n	o
G	V	q	r	ſ	t	v	x	a	b	c	d	e	f	g	h	i	l	m	n	o	p
H	X	r	ſ	t	v	x	a	b	c	d	e	f	g	h	i	l	m	n	o	p	q
I	A	ſ	t	v	x	a	b	c	d	e	f	g	h	i	l	m	n	o	p	q	r
L	B	t	v	x	a	b	c	d	e	f	g	h	i	l	m	n	o	p	q	r	ſ
M	C	v	x	a	b	c	d	e	f	g	h	i	l	m	n	o	p	q	r	ſ	t
N	D	x	a	b	c	d	e	f	g	h	i	l	m	n	o	p	q	r	ſ	t	v

Figure 8. The Vigenère ciphering table, from a XVIIth century edition of [15].

dicitur, alterum minorem quem appellamus mobilem. Excedit autem stabilis mobilem ex suae diametri parte nona. Totas circumferentias amborum circulorum divido in partes coaequales quattuor et viginti. Hae partes domicilia nuncupantur.

The way for writing secret and safely, which we prove, is this. I fabricate two rings from two sheets of brass, one larger, which we call fixed, the other smaller, which we term movable. The fixed diameter is one ninth larger than the movable. I divide the circumferences of them both in twenty-four equal parts. These parties I call homes.

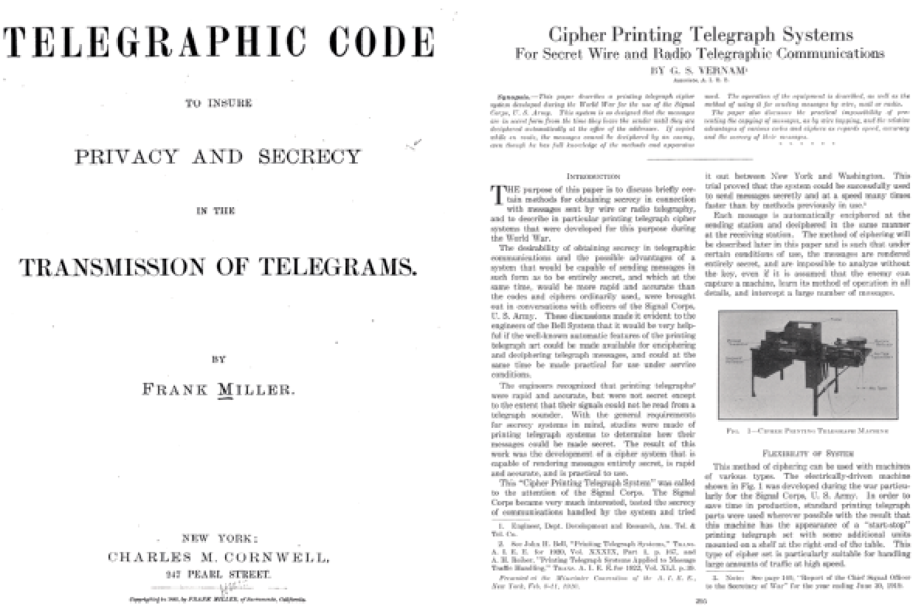
There then followed a rather lengthy description of the utilization of the disk, a reproduction of which is in Figure 7, and of which we give only a couple of citations:

Prius de indice mobili. Sit verbi gratia inter nos constitutus index ex mobili tabella k. Statuam tabellam formulae uti quidem scribenti mihi libuerit, puta ut k ipsa statuta sub maiuscula B et sequens sub sequenti. Ad te igitur scribens primam omnium scribam B maiusculam sub qua indicem k in formula scripturus posuerim; id indicabit ut id quoque tu in provincia volens nostra legere, formulam quae apud te gemella est versionibus aptes usque sub B itidem sit index ipse k. Hinc demum caeterae omnes litterae minores in epistola inventae superiorum stabilium vim et sonos significabunt

The case of the mobile disk. Let there be among us, and shall be established, for example, the index ask of the movable disk. And I have established the formula, for example, that k is under the uppercase B and the following letters follows. So I write you first letter B uppercase, to let you know that index k is under it; so that it will tell you that you, far away, wanting to read my message, having an identical device, set the formula where B corresponds to the index k. Finally, all other literature were found under the letter sounds indicate the upper permanent force

Then, about changing the alphabet:

Cum autem tres quottuorve dictiones exscripsero mutabo nostra in formula situm indicis versione circuli, ut sit index ipse k fortassis sub R. Ergo in epistola inscribam maiusculam R inde igitur k significabit non amplius B sed R et quae sequentur singulae superiorum stabilium



TELEGRAPHIC CODE

TO INSURE

PRIVACY AND SECRECY

IN THE

TRANSMISSION OF TELEGRAMS.

BY

FRANK MILLER.

NEW YORK:

CHARLES M. CORNWELL,

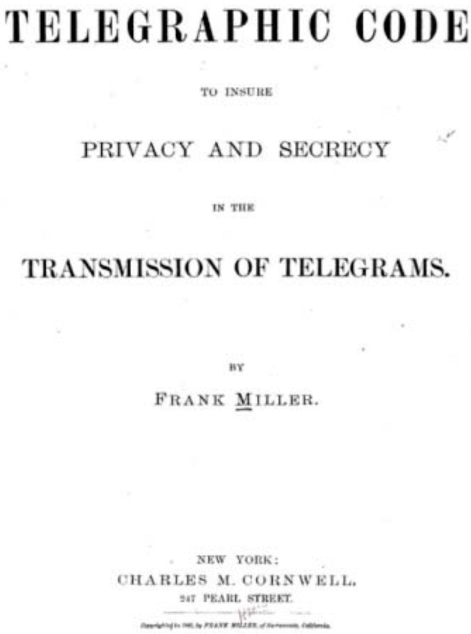
247 PEARL STREET.

Cipher Printing Telegraph Systems

For Secret Wire and Radio Telegraphic Communications

BY G. S. VERNAM

Figure 9. The first pages of Miller's book [18] and the Vernam article [19] introducing perfectly secure coding.



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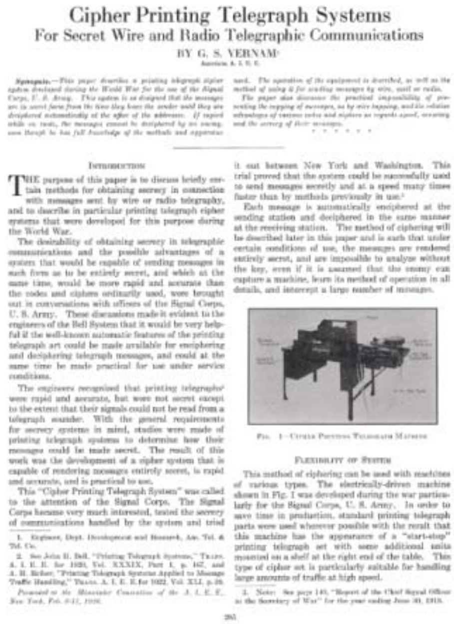

Cipher Printing Telegraph Systems
For Secret Wire and Radio Telegraphic Communications
BY G. S. VERNAM

Figure 10. (l) The first pages of the papers by Miller (1882 [18]) and (r) by Vernam (1926 [19]).

novissima suscipient significata. Tu idem in provincia interlegendum admonitus inventa maiuscula eam scies nihil aliud importare ex se nisi ut moneat mobilis circuli situm atque indicis collocationem isthic esse immutatam. Ergo tu quoque sub ea indicem collocabis, eo pacto facillime cuncta perleges et perdisces.

Having written three or four words I will change our formula of the position of the index of the circle, so that the index k is for example under R. Hence I will write an uppercase R. From now on k will mean R and not B any more and letters following will have new meanings. You, far away, will find an uppercase letter with no meaning, except that it is to notify itself and to imply a change of the movable disk. Therefore if you place that letter under the index k, this way it is very easy to read.

Indeed in this case what will be later known as the "key" of the cipher is a single character. The rule for changing the alphabet is random, which is not very strong since whomever had read the treatise could decipher the message with just 26 guesses, at worst, on the first key! A slightly better cipher is given later on, where it is the fixed (uppercase) letter to be fixed and changes are better hidden in the ciphered text. This is the weakest point in a treatise, which, on the other hand presents the brightest idea in cryptography that occurred in the last fifteen centuries [13, 14] and which, sadly, went overlooked.

It was Blaise de Vigenère [Saint-Pourc¸ ain-sur-Sioulè, France, 5 April 1523 – Paris, France, 19 February 1596], more than a century later, who had success in promoting poly-alphabetic ciphering [15]. His approach consisted in agreeing on a keyword, and repeating it as much as the string is as long as the message, then for each letter in the message the ciphering alphabet is selected as the row of the table in Figure 8. In this way the same letter is ciphered with a *different* letter, based on its position relative to the keyword.

The weak points here are that the number of alphabets used for coding is small (equal to the number of letters in the keyword), and that the same letter is coded the same way if it occurs in correspondence of the same letter of the keyword. As a result, ironically, even if Vigenere's table-based code gained exceptional notoriety and was considered unbreakable, it was indeed weaker than Alberti's more "random" approach, where the substitution alphabet was not changed on a regular basis. The Vigenere code was indeed used even for many years after Friedrich Wilhelm Kasiski [Schlochau, Poland, 29 November 1805 – Neustettin, Poland, 22 May 1881] published his algorithm for deciphering poly-alphabetic ciphers [16].

4. Modern Times

The Vigenere code, and in general all poly-alphabetic ciphers with a "short" key, can be attacked via the Kasiski approach. This first discovers the length of the key and then applies frequency analysis separately to each alphabet. The Kasiski approach is useless if the key is infinite in length or, as is the same, if it is as long as the message, but never repeating. Such an idea was due to Frank Miller [1842 – 1925][2] [18] (Figure 10), even if it is commonly credited to Gilbert Sandford Vernam [Brooklyn, New York, 4 April 1890 – Hackensack, New Jersey, 7 February 1960] (Figures 10 and 11), who indeed gave a full algorithm [19]

[2] Miller could have been born in Milwaukee, Wisconsin, but indeed this information, as well as full dates, are unknown [17].

Figure 11a. Gilbert Sandford Vernam.

Figure 11b. Arthur Scherbius.

The weak point for these algorithms lies in the necessity of sharing the key, which must be long, truly random, and used only once. However, the strong point, as Claude Elwood Shannon [Petoskey, Michigan, 30 April 1916 – Medford, Massachusetts, 24 February 2001] proved, is that it is absolutely secure [20].

In the meantime, Arthur Scherbius [Frankfurt, Germany, 30 October 1878 – Berlin, Germany, 13 May 1929](Fig. 11) patented on 23 February 1918 a cipher machine based on rotating wired wheels [21] (Figure 12). This was a "rotor machine" that was to put pen and paper back in the drawer of cryptographers. His "model A" was quite large, followed by Model B. Finally, with Model C, the machine was fully portable and letters were indicated by lamps. He called his machine *Enigma*, which is the Greek word for "riddle," and aimed it at the commercial market. The German Navy adopted it in 1926, and the German army and aviation adopted it a few years later.

Scherbius' Enigma provided the German Army with the strongest cryptographic cipher in the world at that time, and the military communications of the Germans were optimally protected during World War II. The disks of the machine (Figure 12) indeed performed a simple mono-alphabetic cipher, but the key idea of Scherbius was to have the disk rotate by one step after each letter. This would call for a poly-alphabetic cipher with a (fixed) key as long as the disk. To improve security, there were three disks (and more in later modified models) so that the second disk would advance one step after a full turn of the first, and the third would do one step after a full step of the second. This, given the 26 letters of the alphabet, leads to a key 17576 characters long. The introduction of a reflector, forcing the letter to go through and back the three disks, added complexity and allowed symmetric utilization. Writing a clear message gave a ciphered one; typing a ciphered message gave back the clear message.

Finally, by selecting the initial position of the rotors on the basis of a three (or more) pre-determined letter keyword, the coding was made stronger, since a different ciphering scheme would be used on a daily basis. Furthermore, a set of plugs allowed the further exchange of some letters (Figure 12).

Deciphering the Enigma is a many-times-told story [21, 22], first done by Polish mathematicians and then by Alan Mathison Turing [London, England, 23 June 1912 - Wilmslow, England, 7 June 1954] at Bletchley

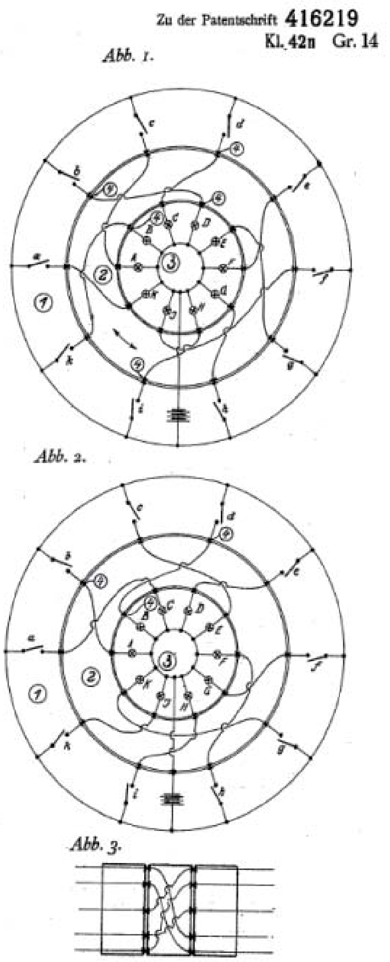

Figure 12a. A schematic of the rotor of the Enigma machine, from the original patent [20].

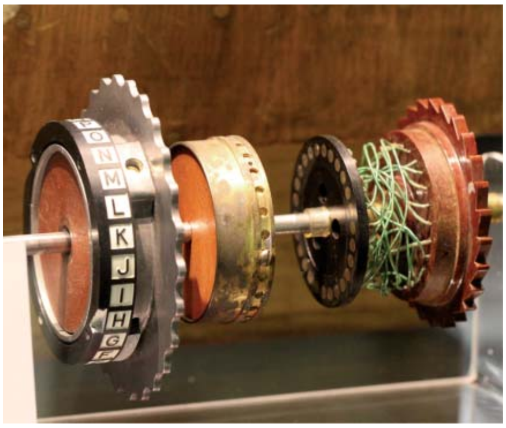

Figure 12b. An exploded view of a rotor of the Enigma machine, showing wires and contacts.

Park in England. This was possible not so much because of a weakness in the Enigma machine, but because of weaknesses in its usage, with repetition in words within the same message and phrases repeated identically in different messages. This allowed the decryption of German Air Force messages, which proved weaker, since 1939 with a limited success, and then, with increasing success in the following years, up to a pace of 4000 messages per day.

The German Navy Enigma was harder to decode, due to more rigid security procedures applied. The capture from U-110 in 1941 and U-599 in 1942 of working Enigma machines with three and then four rotors and relative codebooks for U-boats by the Royal Navy helped a lot [23].

The German Lorenz SZ40/42 also worked on a very similar principle, but with 12 rotors and an alphabet of 32 symbols represented as binary digits. This was stronger than Enigma, and thanks to the binary code, the receiving machine could print the message in clear without assistance. However, it was too cumbersome to replace Enigma on the battlefield or in vehicles. Breaking Lorenz's cipher was also done, but humans needed four days to decipher a message, which made the information too old to be useful. When Colossus, the first programmable computer, came into play (1944), fast decryption of the Lorenz code was possible, and this indeed marked the birth of electronic computing.

Of course, cryptography did not end with World War II. Indeed, it is everyday more important to secure Internet transactions. The weak points of Vernam codes and other codes – that is, the necessity of sharing a key – have been resolved by public-key cryptography, conceived by Martin Hellman [New York, New York, 2 October 1945], Ralph Merkle [Berkley, California, 2 February 1952], and Whitfield Diffie [Washington, DC 5, June 1944], late in the seventies [24, 25]. These are the strongest ciphers currently used.

Figure 12c. A three-rotor Enigma machine (probably 1939).

5. Conclusion

Even if now surpassed, Alberti's work was a leap forward in cryptography. Its importance could be equaled only by public-key coding, since variations over the poly-alphabetic substitution introduced by Alberti, and popularized by Vigenère, were at the basis, with their strengths and weaknesses, of all ciphering techniques up to a few decades ago.

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“Time Travel” Column

Starting in February 2022, the *Microwave Journal* (https://www.microwavejournal.com/) will host a “Time Travel” column (Figure 1) dedicated to historic highlights. These will be limited to a single page in the magazine, including a few references for further study. The size should be 300 to 400 words, with one or two (maximum) photos or figures. The column will be published quarterly.

Submissions directly to Gary Lerude at the *Microwave Journal* (glerude@mwjournal.com) are welcome. Please contact him with the idea of the topic to treat first to avoid duplicates.

Of course, any longer historical contributions will be very welcome in our *Radio Science Bulletin* pages!

Figure 1. The logo for the Time Travel column.

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Pitting Politics Against Science: Conspiracy or Groupthink

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The onset of the coronavirus in early 2020, lasting through the end of the year and beyond, has undoubtedly rendered 2020 an incredible year in many ways. The COVID-19 coronavirus has caused a devastating global pandemic, with rapidly increasing case counts and deaths worldwide. The number of confirmed cases and fatalities exceed 83,113,878 and 1,812,218 globally. In the US, there were 19,821,487 and 343,818 confirmed cases and deaths as of the end of 2020 [1]. It boggles the mind how COVID-19 descended into a conspiracy theory, pitting politics against science, while millions of lives are lost and so many more are suffering from grief and pain, pointlessly. It does not seem to make sense!

Why? Is it because science got wrapped up in politics, or is it politics interfering with science? Perhaps the better or more practical questions are how much politics is to be influenced by scientific findings, or should politics intervene when science upset the established political order to justify governmental action? These questions are not new or groundbreaking.

Nicolaus Copernicus, the 16th century Polish astronomer, set forth the revolutionary view that the Earth revolved around the sun, and proposed a model of the universe that places the sun rather than the Earth at the center of the universe. About a half-century later, Galileo turned his telescope to the heavens. He saw the Milky Way with numerous stars, the pockmarked surface of the moon, and that Jupiter has four moons of its own. Galileo traveled to Rome to meet with church leaders to present his discoveries that lent support to Copernicus' revolutionary view and ready to make the case for heliocentrism: that the Earth moved around the sun.

Instead, Galileo was condemned by the Holy Office of the Inquisition of heresy for having held a believe that the sun is the center of the universe, which was "false" and contrary to the Sacred and Divine Scripture. It was a dangerous idea, and one that cost Galileo his freedom. He was sentenced to imprisonment and followed by confinement for the rest of his life.

One may shrug off these ancient and modern incidents as episodic and proclaim them as absurd! Nothing is new under the sun. Make no mistake, if it has not been found, it is there to be discovered. If it has not happened, it is only a matter of time.

Fast forward to the 21st century: in 2011, the World Health Organization (WHO)'s International Agency for Research on Cancer (IARC) classified exposure to RF radiation as 2B – a possible cancer-causing agent to humans. The IARC had evaluated then-available scientific studies and concluded that while evidence was incomplete and limited, especially regarding results from animal experiments, epidemiological studies of humans reported that increased risks for gliomas (a type of malignant brain cancer) and acoustic neuromas (or acoustic schwannomas – a non-malignant tumor of auditory nerves on the side of the brain) among heavy or long-term users of cellular mobile telephones were sufficiently strong to support a classification of being a possibly carcinogen in humans for exposure to RF radiation [2, 3].

In 2018, the National Toxicology Program (NTP) of the US National Institute of Environmental Health Science (NIEHS) reported observations of two types of cancers in laboratory rats with life-long exposure to RF radiation used for 2G and 3G wireless cellular mobile telephone operations [4, 5]. This was the largest health-effect study ever undertaken by NIEHS/NTP for any agent. A 12-member peer-review panel of independent scientists, convened by NIEHS/NTP, who evaluated the toxicology and carcinogenesis studies, concluded, among other observations, that there was statistically significant and "clear evidence" that the RF radiation had led to the development of malignant schwannoma in the hearts of male rats.

Shortly after the NTP report, the Cesare Maltoni Cancer Research Center at the Ramazzini Institute in Bologna, Italy, published the results from its comprehensive study on carcinogenicity in rats exposed lifelong to 2G/3G, 1800 MHz RF radiation [6]. The study involved whole-body exposure of male and female rats under plane-wave equivalent or far-zone exposure conditions. A statistically significant increase in the rate of schwannomas in the hearts of male rats was detected for 0.1 W/kg RF exposure. It is critical to note that the recent NTP and Ramazzini RF exposure studies presented similar findings in heart schwannomas and brain gliomas. Two relatively well-conducted RF exposure studies employing the same strain of rats thus showed consistent results in significantly increased cancer risks from mobile-phone exposures.

Recently, a privately constituted group, with self-appointed membership, published a set of guidelines for limiting exposure to RF electromagnetic fields in the 100 kHz to 300 GHz frequency range [7]. The proposed guidelines were based primarily on the tissue-heating potentials of RF radiation to elevate animal body temperatures to greater than 1°C. While recognizing that the two above-mentioned studies used large numbers of animals, best laboratory practice, and exposed animals for the whole of their lives, it preferred to quibble with alleged "chance differences" between treatment conditions and that the measured animal body core temperature changes had reached up to 1°C: apparently implying that a 1°C body core temperature rise is carcinogenic, ignoring the RF exposure. The group then pronounced that when considered either in isolation or within the context of other animal carcinogenicity research these findings do not provide evidence that RF radiation is carcinogenic.

Furthermore, the group had noted that even though many epidemiological studies of RF radiation associated with mobile-phone use and cancer risk have been performed, studies on brain tumors, acoustic neuroma, meningioma, and parotid gland tumors have not provided evidence of an increased cancer risk. It suggested that although somewhat elevated odds ratios were observed, inconsistencies and limitations including recall or selection bias preclude these results from being considered for setting exposure guidelines. The penchant to dismiss and criticize positive results, and fondness for and eager acceptance of negative findings at the same time, are palpable and concerning.

In contrast, IARC's evaluation of the same epidemiological studies ended up officially classifying RF radiation as possibly carcinogenic to humans [2, 3].

An understandable question that comes to mind is how can there be such divergent evaluations and conclusions of the same scientific studies? Humans are not always rational or as transparent as advertised. Scientists are not impervious to conflicts of interest and can be driven by egocentric motivations. Humans frequently make choices and decisions that defy clear logic.

Science has never been devoid of politics, believe it or not: a couple of cases in point.

Most people would readily say that the brilliant, celebrated Albert Einstein was a Nobel Laureate for having received the prize in Physics. When asked about for what subject of research or scholarship he received the prize, the default answer is for the Theory of Relativity, or for his observation that energy and mass are interchangeable (i.e., $E = mc^2$. Rarely would mention be made otherwise. In fact, Einstein received his Nobel Prize in 1922 "for his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect." Today, no knowledgeable physicist would dispute that Einstein deserved the Nobel Prize for his discovery of the photoelectric effect [9]. Therein lies the rub or paradox!

Among the many theories that Einstein had reported in the previous 17 years, his 1905 paper on the photoelectric effect was a relatively minor contribution at the time, and it was the least accepted by the contemporary theoretical physicists. During the selection process in 1921, the Nobel Committee for Physics decided that none of that year's nominations met the criteria as outlined in the will of Alfred Nobel. However, Einstein was so renowned by that time that their failure to have awarded him the Prize had become an embarrassment. The selection was thus a political decision by the Nobel Committee, most notably revealed by the insertion of "for his services to theoretical physics" as a telltale in the award citation. Regardless, the Nobel Committee exhibited courage and made amends for a major error.

The Nobel Prize in Physiology or Medicine for 2003 was awarded jointly to Paul Lauterbur and Peter Mansfield [10] "for their discoveries concerning magnetic resonance imaging." The award made recognition of the two Laureates' pioneering contributions, which led to the applications of magnetic resonance imaging (MRI) in medical diagnostics and research. The discovery was a breakthrough in radiology, which was based on noninvasive and non-ionizing radiation. MRI has significantly improved the diagnosis of numerous diseases, along with reduced risk and discomfort for patients. The announcement also led many to notice the absence of Raymond Damadian for a share of the Nobel Prize [11, 12].

Published records show that Damadian had conceived of noninvasive magnetic-resonance scanning, discovered tissue proton relaxation and density differences that are crucial to MRI, and had achieved the first human whole-body images. Lauterbur devised methods to reconstruct two-dimensional images a year later. Mansfield had developed a faster pulse-sequence technique that differed from Lauterbur's reconstruction method another couple of years later. It appears unequivocal that all three scientists made important contributions in launching medical MRI. Why, then, was the Nobel Prize awarded to two scientists?

There was apparent disciplinary allegiance, or groupthink, within the magnetic-resonance research community. Science got wrapped up in politics and interfered to label the earlier contributions as insignificant or less consequential. Unfortunately, this time, the Nobel Committee did not manage to either confront or mitigate a needless dispute.

Biases *can* impair *rational* judgment and lead to poor decisions. Emotions *can* keep humans from *being rational* and prevent us from arriving at obvious conclusions. At times, humans systematically make choices and decisions that defy clear logic. Regrettably, the herd mentality or groupthink is as rampant today as ever.

Some years ago, I had commented that "science has become partisan. And the corollary, if science becomes partisan, is it science or politics, or would it be political science?" [8]. Perhaps, it is simply a matter of being politically correct of the willing!

When decisions are not arrived at by prudently balancing the facts or are made via impaired *rational* judgment this could lead to poor decisions through biases. Sometimes, the poor decisions may impact only a small number of individuals as a result. However, in cases like the COVD-19 coronavirus pandemic, millions of people may suffer the unjust and needless consequences.

The cellular mobile communication and associated wireless technologies have proven beyond any debate their direct benefit to humans. However, as for the verdict on the health and safety of billions of people who are exposed to unnecessary levels of RF radiation over extended lengths of time or even over their lifetime, the jury is still out! The ALARA – as low as reasonably achievable – practice and principle should be followed for RF health and safety when confronted with such divergent assessments of science.

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[Editor’s note: the above contribution was written at the end of December 2020.]

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Introduction from the Associate Editor

I am happy to introduce important progress for we women in radio science. The US National Committee for the International Union of Radio Science (USNC-URSI) has recently formed a Women in Radio Science Chapter. In the present column, the elected Chair, Reyhan Baktur, tells how the chapter was formed, and presents its members and initial activities. We hope this will spur other URSI Member Committees to form similar chapters.

Women in Radio Science (WIRS): The Newest Chapter of USNC-URSI

Our mission: to recruit, encourage, and promote inclusivity, gender diversity, and technical excellence in the radio-science community.

1. Overview

WIRS is the first women-led chapter of USNC-URSI, with goals of promoting the work and leadership of women in radio science, providing earlier career members resources and networking, and offering mentorship for members at all states of their careers. The WIRS chapter is not only valuable for better representation of women, but also crucial in narrowing the gender gap in the radio-science community, and greater motivation for all genders and underrepresented groups. From its first mentoring panel and reception, WIRS received a great amount of positive response and inquiry from students and early career members of all genders. It provides a unique forum for members to find support and to voice their concerns. As the WIRS includes members from all USNC-URSI Commissions, it is intrinsically diverse, and therefore assures that activities organized by WIRS has broader representation and vivid subjects that are of interest to a larger audience. WIRS is there instrumental in uniting all Commissions of USNC-URSI and promotes the Internet of knowledge.

2. Timeline

- Supported by Dr. Ross Stone, Dr. Asta Pellinen-Wannberg started the Women in Radio Science column in the *Radio Science Bulletin* in 2015. The column features successful female scientists in radio science from all around the world.

- Dr. Piergiorgio L. E. Uslenghi promoted the first WIRS workshop and reception at the 2018 AT-RASC. Dr. Anthea Coster presented the value of the scientific work and the dramatic escape of Lise Meitner from Nazi Germany, in which Anthea's grandfather was involved. The talk was a great success.

- At the 2019 USNC-URSI business meeting (Boulder, CO), USNC-URSI and the National Academies proposed to start a chapter of Women in Radio Science, with activities to involve more women in technical and leadership roles. The USNC-URSI Executive Committee supported the idea.

Figure 1. Reyhan Baktur.

Figure 2. Zoya Popovic.

- The first ever Women in Radio Science chapter of the national committee of URSI was founded in 2019.
- WIRS's first activity: co-organizing the WIE-WIRS reception at the 2020 IEEE APS-URSI meeting was held. WIRS provided the keynote speaker and panel discussion.
- The first WIRS business meeting was held at the 2021 URSI Meeting at Boulder, CO, through a virtual meeting platform. A full board of officers was elected.
- A call for memberships was sent out in 2021 following the business meeting.

3. Officers and Founding Members

3.1 Officers

- Chair: Reyhan Baktur (Figure 1), Utah State University, Commission B, e-mail: Reyhan.baktur@usu.edu.
- Vice-Chair: Zoya Popovic (Figure 2), University of Colorado Boulder, Commission D, e-mail: Zoya.Popovic@colorado.edu.
- Secretary: Jeanne Quimby (Figure 3), National Institute of Standards and Technology, Commission A, e-mail: jeanne.quimby@nist.gov.
- Membership Chair: Emily Porter (Figure 4), University of Texas Austin, Commission K, e-mail: Emily.Porter@austin.utexas.edu.

3.2 Founding Members

WIRS would like to acknowledge and honor the founding members, who supported the establishment of the WIRS chapter and provided helpful insights:

- Commission G: Sigrid Close (Stanford University), Kate Zawdie (Naval Research Laboratory)
- Commission H: Ashanthi Maxworth (University of Saskatchewan)
- Commission K: Asimina Kiourti (The Ohio State University), Susan Hagness (University of Wisconsin Madison), Mahta Moghaddam (University of Southern California)

Figure 3. Jeanne Quimby.

Figure 4. Emily Porter.

Figure 5. Cynthia Furse.

4. Activities

4.1 WIE-WIRS Reception at 2020 IEEE APS-URSI, Virtual Platform

4.1.1 Plenary Speaker: Cynthia Furse, University of Utah

Title: “The Power of Change”

Throughout our lives and careers, we experience so many changes. Some are welcome and planned, others are distressing and chaotic. Change can be very powerful, a true force to be reckoned with. In this time of great change, let’s take a few minutes to think about where we want this change to take us, and what tools we have to guide our futures. Let’s talk about innovation, thinking outside the box, and planning in uncertain times. Let’s talk about change, the power it offers us, and ways to harness that power to take us where we want to go.

About the featured speaker: Cynthia M. Furse (Figure 5) is a Professor of Electrical and Computer Engineering and past Associate Vice President for Research at the University of Utah. Prof. Furse received her BS in Electrical Engineering with a Mathematics minor in 1985, MS in 1988, and PhD in 1994 from the University of Utah.

She has taught electromagnetics, wireless communication, computational electromagnetics, microwave engineering, antenna design, entrepreneurship, and introductory electrical engineering (for which she coauthored an open source textbook), and has been an early leader in the development of the flipped classroom. Prof. Furse counts her greatest career achievements in the successes of her students. In addition to students in her classes, she has served as the major advisor for 27 PhDs, 56 MS students, 174 undergraduate researchers, and 12 high school research students, including one exceptional young woman who won the International Science Fair. Her extensive research on how electromagnetic fields propagate in complex lossy scattering media has been applied in medical applications in the human body, geophysical prospecting, ionospheric plasma, aircraft wiring networks, and photovoltaic systems. She is a founder of LiveWire Innovation, Inc., a spin-off company based on her research, commercializing devices to locate intermittent faults in live electrical systems.

Prof. Furse is a Fellow of the IEEE and the National Academy of Inventors. She is a past AdCom member for the IEEE Antennas and Propagation Society and past Chair of the IEEE AP-S Education Committee. She has received numerous teaching and research awards, including the 2009 IEEE Harriett B. Rigas Medal for Excellence in Teaching and the 2019 University of Utah Distinguished Teaching Award. Dr. Furse and her husband, Larry, are the proud parents of a grown son and daughter, and grandparents to eight vibrant grandchildren.

4.1.2 Q&A with the Panelists

Following the plenary presentation by Prof. Furse, WIE and WIRS organized a Q&A session with three invited panelists. Questions from audience included how to maintain research productivity during the pandemic, how to handle rejections of papers and grants, how to plan out a graduate study, and many more.

The panelists were as follows:

Dr. Cynthia Furse, University of Utah.

Dr. Ana Ferreras (Figure 6) is a Senior Program Officer at the US National Academies of Sciences, Engineering, and Medicine (NASEM). She manages the US National Committees for mathematics instruction, crystallography, physics, theoretical and applied mechanics, and radio science. She is also a consultant, evaluator, speaker, professional developer, researcher, fundraising expert, and advisor for organizational leaders in the private

Figure 6. Ana Ferreras.

Figure 7. Melissa Midzor.

sector, academia, and the federal government. She is the leading author of *Company Success in Manufacturing Organizations: A Holistic Systems Approach*. Dr. Ferreras earned a PhD in Industrial Engineering (IE) at the University of Central Florida (UCF). Her doctoral research focused on developing a company success index model to assess and predict organizational performance based on critical success factors such as profit, productivity, efficiency, quality, employee morale, safety, and ergonomics. She also holds an MS in Engineering Management from the Florida Institute of Technology, and a BS in Electrical Engineering from UCF. During her doctoral research, she assisted the IE Department at UCF in reengineering the undergraduate curriculum by developing a national model, new programs, experiential laboratories, and research centers. Dr. Ferreras was a winter 2008 Christine Mirzayan Policy Graduate Fellow with the Center for Advancement of Scholarship on Engineering Education at the National Academy of Engineering.

Dr. Emily Porter is an Assistant Professor with the Department of Electrical and Computer Engineering at The University of Texas at Austin, where she is associated with both the bioECE and Electromagnetics & Acoustics research areas. Dr. Porter was granted her PhD (Electrical Engineering) in 2015 from McGill University, Montreal, Canada. Her PhD work was in the area of Computational and Applied Electromagnetics, and focused on microwave breast health monitoring. She also has an MEng and a BEng in Electrical and Computer Engineering, completed in 2008 and 2010, respectively. More recently, Dr. Porter was an NSERC Postdoctoral Fellow and then an EU Marie-Curie Research Fellow with the Translational Medical Device Laboratory at National University of Ireland Galway, from 2015-2019. Her research interests include the measurement of dielectric properties of biological tissues and the development novel technologies for therapeutic and diagnostic applications of electromagnetic waves. Dr. Porter is the recipient of several prestigious national and international awards, including multiple URSI Young Scientist Awards, the IEEE Antennas and Propagation Society Doctoral Research Award, the Irish Research Council (IRC) "New Foundations" Grant, and the Royal Irish Academy (RIA) Charlemont Grant.

4.2 2021 USNC-URSI, Virtual Platform

4.2.1 WIRS Plenary Speaker: Melissa Midzor

Title: "Taking the Leap and the (RF) Path Less Traveled By"

An obsession with magnets at a young age led Dr. Midzor (Figure 7) to pursue a life in physics and new RF measurement techniques. Her career has spanned developing a new RF microscopy method for nanotechnology, overcoming challenges in electronic warfare protection against adversaries' radars and improvised explosive devices (IEDs), and improving compatibility between federal and commercial wireless systems. Dr. Midzor discussed highlights from these projects, and how her approach of taking career leaps, planning, and pursing her passions led to unique science and career opportunities.

Melissa Midzor is the Program Manager for the National Advanced Spectrum and Communications Test Network. She leads a multi-agency group hosted at NIST, focusing on wireless communication spectrum sharing between commercial and federal systems. Prior to NIST, Dr. Midzor supported the Navy for 15 years in Electronic Warfare (EW) and Spectrum compatibility across the joint services. She served as Director for EW Integrated Laboratories at NAWCWD, and at the OSD Electronic Warfare and Countermeasures Office, developing EW threat environments and tools to evaluate current and future RF technologies. She was appointed the first Senior Scientific Technology Manager (SSTM) of S&T EW at NAVAIR. She received her PhD in Physics from Caltech in nanotechnology and imaging, and also holds BAs in Physics and Sociology from the University of Colorado-Boulder.

4.2.2 WIRS Business Meeting

The first WIRS business was held in January 2021. A full board of officers was elected. Guests invited to the meeting included URSI members, young professionals such as earlier career members, and students.

4.2.3 WIRS Social Program

A social program was held on the following day after the business meeting. The WIRS social/reception featured a Chair and Share from Mentors session, where prominent female mentors in radio science shared their stories and answered questions from audience. The mentors included:

- Dr. Cynthia Furse, University of Utah.

Figure 8. Mahta Moghaddam.

Figure 9. Susan C. Hagness.

- Dr. Ana Ferreras

- Dr. Zoya Popović, who received her DiplIng from the University of Belgrade, Serbia, in 1985, and the MS and PhD from Caltech, Pasadena, California, in 1986 and 1990, respectively. Her doctoral thesis was on large-scale quasi-optical microwave power combining. She joined the faculty of the University of Colorado in Boulder in August 1990, where she became a full Professor in 1998, and received the Hudson Moore Jr. endowed professorship in 2006. She was named Distinguished Professor in 2010 and to the Lockheed Martin Endowed Chair in 2017. She has developed five undergraduate and graduate electromagnetics and microwave laboratory courses, and coauthored (with her late father) *Introductory Electromagnetics* for the junior-level core course for electrical and computer engineering students, translated into several foreign languages. Her research interests include high-efficiency linear microwave power amplifiers, low-loss broadband microwave and millimeter-wave circuits, medical applications of microwaves, intelligent RF circuits, active antenna arrays, cryogenic circuits, microwave radiometry, and wireless powering for low- power sensors. She was a Visiting Professor at the Technische Universitat Muenchen, Munich, Germany, in 2001 and 2003, and at Supaero (ISAE), Toulouse, in 2014, and a Chair of Excellence at Carlos III University in Madrid, Spain, in 2018.

- Dr. Jeanne Quimby is the project leader for the Device-level Anomaly Detection to Forensic Security Electromagnetic Emissions (DARE2FORESEE) project. She and the team assess wireless telecommunication devices for cybersecurity vulnerabilities at the radio access network and the device sub-component level.

She received her PhD and MS from The Ohio State University and a BS from the University of California at San Diego. Dr. Quimby currently serves as the Commission A Chair for the US National Committee for the International Union of Radio Science (USNC-URSI) and the Vice-Chair of IEEE P2982 – Millimeter-Wave Channel Sounder Verification.

- Dr. Mahta Moghaddam (Fellow, IEEE) (Figure 8) is the Ming Hsieh Chair in Electrical and Computer Engineering, Director of New Research Initiatives at the Viterbi School of Engineering, Co-Director of the Center for Sustainability Solutions, and Distinguished Professor at the University of Southern California, Los Angeles, CA. Prior to that, she was at the University of Michigan (2003-2011) and NASA Jet Propulsion Laboratory (JPL, 1991-2003). She received the BS in 1986 from the University of Kansas, Lawrence, Kansas with highest distinction, and the MS and PhD in 1989 and 1991, respectively, from the University of Illinois at Urbana-Champaign, all in Electrical and Computer Engineering. She has introduced new approaches for quantitative interpretation of multi-channel radar imagery based on analytical inverse scattering techniques applied to complex and random media. She was a Systems Engineer for the Cassini Radar and served as Science Chair of the JPL Team X (Advanced Mission Studies Team). Her most recent research interests include the development of new radar instrument and measurement technologies for subsurface and subcanopy characterization; development of forward and inverse scattering techniques for layered random media, especially for root-zone soil moisture and permafrost applications; geophysical retrievals using signal-of-opportunity reflectometry; and transforming concepts of radar remote sensing to medical imaging and therapy systems.
  Dr. Moghaddam is a member of the NASA Soil Moisture Active and Passive (SMAP) mission Science Team and a member of the NASA Cyclones Global Navigation Satellite System (CYGNSS) Science Team. She was the Principal Investigator of the AirMOSS NASA Earth Ventures 1 mission. She served as the Editor-in-Chief of the *IEEE Antennas and Propagation Magazine* from 2015 to 2019, and as President of the IEEE Antennas and Propagation Society for 2020. Dr. Moghaddam is a member of the National Academy of Engineering.

- Dr. Susan C. Hagness (Fellow, IEEE) (Figure 9) received the BS degree with highest honors and the PhD degree in Electrical Engineering from Northwestern University, Evanston, IL, in 1993 and 1998, respectively. Since

1998, she has been with the Department of Electrical and Computer Engineering at the University of Wisconsin-Madison, where she currently holds the title of Philip D. Reed Professor. She served as Associate Dean for Research and Graduate Affairs in the College of Engineering between 2014 and 2017, and is currently serving as the Chair of the Department of Electrical and Computer Engineering. She is also a faculty affiliate of the Department of Biomedical Engineering, and a member of the UW Carbone Cancer Center. Dr. Hagness served as an elected member of the IEEE Antennas and Propagation Society (AP-S) Administrative Committee from 2003 to 2005; Associate Editor for the *IEEE Antennas and Wireless Propagation Letters* from 2002 to 2007; Technical Program Chair of the 2012 IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting; Member (2009, 2018), Vice-chair (2010-12), and Chair (2013-14) of the IEEE AP-S Fellows Evaluation Committee; Member of the IEEE AP-S Awards Committee (2011-13) and the AP-S Field Awards Committee (2018-2019); and Member of the IEEE Engineering in Medicine and Biology Society Fellows Committee (2016, 2019). She also served as Chair of Commission K of the United States National Committee (USNC) of the International Union of Radio Science (URSI) from 2009 to 2011; and Member (2019) and Chair (2016) of the USNC-URSI Junior Awards Committee. She currently serves as a USNC-URSI Member-at-Large (2018-2020) and Member of the IEEE AP-S/USNC-URSI Joint Meetings Committee (2018-2020). She was selected as a Fellow in the Committee on Institutional Cooperation (CIC, now the Big Ten Academic Network) Academic Leadership Program in 2014-15 and elected to the Board of Directors, ASEE Engineering Research Council (2016-2018). She currently holds the position of Treasurer on the Board of Directors of the Electrical and Computer Engineering Department Heads Association (ECEDHA) (2019-2020). Dr. Hagness was the recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE) presented by the White House in 2000. In 2002, she was named one of the 100 top young innovators in science and engineering in the world by the MIT Technology Review magazine. She is also the recipient of the UW-Madison Emil Steiger Distinguished Teaching Award (2003), the IEEE Engineering in Medicine and Biology Society Early Career Achievement Award (2004), the URSI Isaac Koga Gold Medal (2005), the *IEEE Transactions on Biomedical Engineering* Outstanding Paper Award (2007), the IEEE Education Society Mac E. Van Valkenburg Early Career Teaching Award (2007), the UW System Alliant Energy Underkofler Excellence in Teaching Award (2009), the Physics in Medicine and Biology Citations Prize (2011), the UW-Madison Kellett Mid-Career Award (2011), the UW-Madison College of Engineering Benjamin Smith Reynolds Award for Excellence in Teaching Engineers (2014), the Sven Berggren Prize from the Royal Physiographic Society of Lund, Sweden (2015), the UW-Madison Women Faculty Mentoring Program Slesinger Award for Excellence in Mentoring (2017-18), and the UW-Madison College of Engineering Byron Bird Award for Excellence in a Research Publication (2018). Her student mentorees have received numerous research recognitions, including three first prize awards in URSI student paper competitions.

The social program concluded with everyone dancing to the song “Try Everything” by Shakira.

About the WIRS events organizer: Dr. Reyhan Baktur is an Associate Professor of the Electrical and Computer Engineering (ECE) department at Utah State University. Her research interests include antennas and microwave engineering with a focus on antenna design for small satellites. Prof. Baktur has been active in USNC-URSI and IEEE AP-S, serving AP-S' Education Committee and Commission B of USNC. She is the Chair of the USNC-URSI's newest chapter, Women in Radio Science, and has organized the first two WIRS events.

URSI Commission Triennial Reports Available

The triennial reports of the Scientific Commissions of URSI are available for downloading from the URSI Web site (www.ursi.org). They can be accessed by going to the drop-down tab for the individual Commission under Scientific Commissions at the top of the home page, and then clicking on the Commission Reports tab. The reports for the most-recent triennium may be accessed directly by using the following URLs:

https://www.ursi.org/files/CommissionReports/X_17-21.pdf

where *X* is the letter A through H or J or K, denoting the Commission.

Maxwell Foundation Newsletter Available

The summer edition of the Clerk Maxwell Foundation Newsletter is available for downloading at

https://clerkmaxwellfoundation.org/Newsletter_2021_Summer.pdf.

The issue contains an "Homage to Heinrich Hertz" by D. O. Forfar, Trustee of the Foundation.

President's Address at the XXXIV URSI GASS

Before delivering some remarks in French and English, which are the official languages of URSI, I take the liberty to greet the Participants in Italian, my native language.

Cari Colleghi, Signore e Signori:

E' un gran piacere ed onore di accettare la Presidenza dell'URSI nel mio paese natale. Desidero ringraziare gli organizzatori per una magnifica GASS.

Discours du Président à l'AGSS de l'URSI

Rome, Italie - 4 septembre 2021

Chers participants à la 34ème Assemblée Générale et au Symposium Scientifique de l'URSI, Distingués invités, Mesdames et Messieurs:

Il y a quelques jours, les représentants des pays membres de l'URSI m'ont élu président de cette merveilleuse organisation scientifique pour les deux prochaines années, jusqu'à la prochaine AGSS de l'URSI à Sapporo, au Japon. Lorsque j'ai quitté ma ville natale de Turin, la première capitale de l'Italie, pour m'installer aux Etats-Unis il y a plus de soixante ans, je n'aurais jamais pu imaginer que je me trouverais aujourd'hui à Rome, la troisième et éternelle capitale de mon pays natal, pour me voir offrir ce grand honneur et cette responsabilité. J'accepte cet honneur avec humilité, conscient des responsabilités qu'il implique. Lorsque Jules César est rentré à Rome au terme de sa campagne militaire transalpine, son rapport au Sénat romain tenait en trois mots: veni, vidi, vici - je suis venu, j'ai vu, j'ai vaincu. Le discours que je vous adresse aujourd'hui ne sera pas aussi concis, mais je vous promets qu'il s'efforcera de l'être.

Pour paraphraser Charles Dickens, nous vivons la pire des époques et la meilleure des époques. J'ai bon espoir et je suis optimiste que cette terrible peste, qui rappelle tant les romans d'Albert Camus et d'Alessandro Manzoni, qui a ravagé tout le tissu social pendant près de deux ans, sera bientôt derrière nous, et que l'URSI continuera sans entrave à répondre à nos attentes scientifiques et humanitaires au cours de son deuxième siècle d'existence. Il est juste et approprié que ce deuxième siècle de l'URSI commence dans le pays qui a vu la naissance de la méthode expérimentale avec Galilée, de la radiotélégraphie avec Marconi, et de tant de contributions fondamentales à l'électromagnétisme par Volta, Galvani, Ferraris et d'autres scientifiques.

L'URSI occupe une place unique dans le monde scientifique, car ses activités couvrent tous les domaines des radiosciences sans barrières entre les sous-domaines, ce qui permet à l'URSI de s'occuper non seulement des domaines traditionnels, mais aussi d'évoluer en douceur et rapidement vers de nouvelles initiatives interdisciplinaires. Cependant, l'URSI doit faire face à une concurrence croissante de la part de nombreuses organisations internationales. Pour prospérer, l'URSI doit renforcer ses activités dans quatre secteurs : le recrutement de jeunes scientifiques, la promotion de la diversité, les réunions scientifiques pour échanger des idées et des collaborations entre scientifiques du monde entier, et les publications d'archives.

Ces dernières années, j'ai convaincu le Comité national américain de l'URSI de parrainer financièrement, et le Conseil de l'URSI d'accepter, les concours d'articles d'étudiants lors des AGSS 2008, 2011, 2014, 2017, 2020 et 2021 et de l'AT-RASC 2015 et 2018. Par conséquent, la tradition d'organiser un concours de communications d'étudiants lors des symposiums phares de l'URSI est désormais bien établie et, avec notre soutien de longue date aux jeunes scientifiques et l'introduction de représentants des jeunes chercheurs en tant que membres des commissions, elle a entraîné une très forte augmentation de la participation des étudiants et des jeunes chercheurs à ces symposiums. J'ai l'intention de proposer au Bureau de l'URSI des initiatives supplémentaires pour sensibiliser les jeunes du monde entier aux radiosciences et les inciter à y participer.

La diversité est extrêmement importante, non seulement d'un point de vue moral, mais aussi pour la survie à long terme d'une organisation scientifique. En paroles et en actes, nous devons nous engager individuellement et collectivement à rejeter toute discrimination fondée sur la race, l'ethnie, le sexe et l'orientation sexuelle, l'invalidite', la nationalité, l'idéologie religieuse et politique ou les idées scientifiques. Nous devons également nous engager à mener la recherche scientifique dans une atmosphère exempte de principes idéologiques.

Dans le cadre de mes fonctions de président et de coprésident du programme technique de l'AT-RASC 2018, j'ai invité le professeur Pellinen-Wannberg à organiser un atelier spécial sur les femmes dans les sciences de la radio (WIRS). L'atelier a été très réussi, il a fourni un prototype pour des activités similaires à l'avenir et, espérons-le, galvanisera la participation des femmes aux activités de l'URSI. Après cet atelier, le premier chapitre WIRS a été créé aux États-Unis, suivi d'un chapitre en Italie. J'ai l'intention de proposer au Bureau de l'URSI de coordonner les activités et d'apporter un soutien financier à la création de sections WIRS dans tous les pays membres, dans le but ultime d'accroître la participation des femmes aux activités scientifiques et aux rôles organisationnels au sein de l'URSI.

Pendant mes deux mandats de vice-président de l'URSI, j'ai insisté auprès du Bureau sur le fait que l'URSI avait besoin d'une conférence internationale annuelle, et pas seulement d'une AGSS tous les trois ans. Le Conseil a accepté ma suggestion et m'a confié la responsabilité de l'AT-RASC 2015 et 2018 en tant que président et coprésident du comité de programme ; ces réunions ont été un grand succès sur le plan scientifique et un succès modéré sur le plan financier. Le Conseil de l'URSI envisage maintenant de faire de l'AP-RASC une conférence de l'URSI à part entière. En tant que co-président de l'AP-RASC 2016 à Séoul et de l'AP-RASC 2019 à New Delhi, je me suis fortement engagé et continuerai à m'engager pour le développement de cette conférence en tant que colloque URSI à part entière.

La présence de l'URSI dans les publications d'archives a été souhaitée. L'URSI dispose du *Radio Science Bulletin*, édité de manière experte par Ross Stone. Sa seule autre publication était la revue *Radio Science* qui, cependant, appartient à l'American Geophysical Union. Il était évident pour moi que l'URSI avait besoin d'un organe de publication pour tous les domaines couverts par les dix commissions, qui soit entièrement détenu et géré par l'URSI. J'ai proposé au Conseil la création des *Radiosciences Letters* de l'URSI (RSL), une publication rapide en libre accès au format électronique d'articles courts rigoureusement révisés contenant des résultats originaux dans tous les domaines des radiosciences. En juin 2018, le Conseil a accepté ma suggestion et m'a nommé premier rédacteur en chef de cette nouvelle revue, qui en est à sa troisième année d'existence. Je demande instamment à tous les auteurs contribuant à cette AGSS 2021 de soumettre les travaux présentés à Rome à la RSL ; vos soumissions sont nécessaires pour assurer le succès de notre nouvelle revue.

Ainsi, il me semble que l'URSI est maintenant bien positionnée pour accroître ses activités dans les quatre domaines cruciaux que j'ai mentionnés précédemment. Cependant, pour réussir, l'URSI a besoin de la coopération enthousiaste de chacun d'entre vous, tant dans le domaine scientifique que dans le domaine organisationnel de notre Union. Au cours des deux prochaines années, le Secrétariat poursuivra son travail sous la direction experte de Peter Van Daele qui a été réélu au poste de Secrétaire Général et sera aidé par Inge Heleu et Inge Lievens. Le Conseil de l'URSI a élu Patricia Doherty, Kazuya Kobayashi, Giuliano Manara et Ari Sihvola comme vice-présidents de l'URSI pour la prochaine période biennale. Ils apportent une riche expérience au Conseil ; entre autres, je note que le Prof. Doherty est la présidente sortante de la Commission G et la deuxième femme à occuper le poste de vice-présidente dans l'histoire de l'URSI ; que le Prof. Kobayashi est le président sortant de la Commission B, le rédacteur en chef de *Radio Science*, et qu'il a consacré de nombreuses années à l'organisation de l'AP-RASC ; que le Prof. Manara est un ancien président de la Commission B et l'organisateur de l'EMTS 2004 à Pise ; que le Prof. Sihvola, qui entame son second mandat de vice-président de l'URSI, est un ancien président de la Commission B et l'organisateur de l'EMTS 2016 à Helsinki. Joignez-vous à moi pour les féliciter, ainsi que les nouveaux présidents, vice-présidents et représentants en début de mandat des dix commissions de l'URSI.

Je tiens à souligner le travail remarquable accompli au service de l'URSI au cours des quatre dernières années par le Prof. Makoto Ando en tant que Président, par le Prof. Paul Cannon en tant que president sortant, par les Professeurs Willem Baan et Ondrej Santolik en tant que vice-présidents, et par les membres du bureau des dix commissions.

Le succès de 'AGSS de l'année dernière et de l'AGSS de cette année, dans les circonstances difficiles imposées par la pandémie de Covid, aurait été impossible sans le dévouement, l'expertise et l'enthousiasme du Comité d'organisation local, du Comité scientifique et du Secrétariat de l'URSI. Le regretté Professeur Roberto Sorrentino, les Profs. Carlo Carobbi et Guglielmo D'Inzeo et leurs collaborateurs du COL méritent notre gratitude pour le bon déroulement des deux AGSS. Le professeur Alain Sibille et les membres du comité scientifique ont fait un travail impressionnant en préparant le programme scientifique des deux éditions. Sur une note personnelle, je remercie MMs Agnani et Sibille pour leur aide dans la version française de mes remarques. Peter Van Daele, Inge Lievens et Inge Heleu ont fourni l'assistance organisationnelle centrale qui était essentielle pour le succès des deux AGSS. Veuillez-vous joindre à moi pour applaudir le travail accompli par tous ces collègues dévoués.

Je vous remercie tous d'avoir participé à cette AGSS. Je vous encourage à participer aux prochains symposiums phares, l'AT-RASC l'année prochaine à Gran Canaria et l'AGSS 2023 à Sapporo. Je vous souhaite un agréable séjour à Rome et un bon voyage de retour.

Piergiorgio L. E. Uslenghi
Président de l'URSI

President's Address at the URSI GASS

Rome, Italy – 4 September 2021

Dear Participants in the 34th URSI General Assembly and Scientific Symposium, Distinguished Guests, Ladies and Gentlemen:

A few days ago, the representatives of the URSI member countries elected me as President of this wonderful scientific organization for the next two years, until the next URSI GASS in Sapporo, Japan. When I left my home city of Turin, the first capital of Italy, to move to the United States over sixty years ago, I could not have dreamed that I would be here today in Rome, the third and perennial capital city of my native country, to be offered this great honor and responsibility. I accept this honor with humility, mindful of the responsibilities that it implies. When Julius Caesar returned to Rome at the conclusion of his trans-alpine military campaign, his report to the Roman Senate consisted of three words: veni, vidi, vici – I came, I saw, I conquered. My address to you today will not be quite as concise, but I promise that it will try to be brief.

To paraphrase Charles Dickens, this is the worst of times and the best of times. I am hopeful and optimistic that this awful pestilence, so reminiscent of the novels by Albert Camus and Alessandro Manzoni, that has ravaged all fabrics of society for almost two years will soon be behind us, and that URSI will proceed unimpeded to fulfill our scientific and humanitarian expectations during its second century of existence. It is proper and fitting that this second URSI century should begin in the country that saw the birth of the experimental method with Galilei, of radio telegraphy with Marconi, and of so many fundamental contributions to electromagnetism by Volta, Galvani, Ferraris, and other scientists.

URSI has a unique place in the scientific world, because its activities cover all areas of Radio Science without barriers between sub-disciplinary areas, and this allows URSI to cater not only to traditional areas, but also to move smoothly and rapidly into newly forming inter-disciplinary initiatives. However, URSI is facing increasing competition from many international organizations. In order to prosper, URSI needs to strengthen its activities in four sectors: recruitment of young scientists, fostering of diversity, scientific meetings to exchange ideas and collaborations among scientists from all over the world, and archival publications.

In past years, I have convinced the United States National Committee of URSI to sponsor financially, and the URSI Board to accept, student paper competitions at the 2008, 2011, 2014, 2017, 2020, and 2021 GASS, and at the 2015 and 2018 AT-RASC. Consequently, the tradition of having a student paper competition at the URSI flagship symposia is now firmly established and, together with our long-standing support of young scientists and the introduction of Early Career Representatives as officers in the Commissions, has resulted in a very large increase in students' and young researchers' participation at such symposia. I intend to propose to the URSI Board additional initiatives to increase awareness and participation in Radio Science by young people all over the world.

Diversity is extremely important not only from a moral viewpoint, but also for the long-term survival of a scientific organization. In word and deed, we must be individually and collectively committed to reject any discrimination based on race, ethnicity, sex and sexual orientation, disability, nationality, religious and political ideology, or scientific ideas. Also, we must be committed to the conduct of scientific inquiry in an atmosphere free of ideological tenets.

In my roles as General Chair and Technical Program Co-Chair at the 2018 AT-RASC, I invited Prof. Pellinen-Wannberg to organize a special workshop on Women in Radio Science (WIRS). The workshop was very successful, it provided a prototype for similar activities in the future, and hopefully will galvanize women participation in URSI activities. After that workshop, the first WIRS chapter was established in the United States, followed by a chapter in Italy. I intend to propose to the URSI Board that coordination of activities and financial support be provided for the establishment of WIRS chapters in all Member Countries, with the ultimate goal of augmenting participation of women in scientific activities and organizational roles within URSI.

During my two terms as Vice President of URSI, I insisted with the Board that URSI needed a yearly international conference, not just the GASS every third year. The Board accepted my suggestion and put me in charge of the 2015 and 2018 AT-RASC as General Chair and TPC Co-Chair; those meetings were a great success scientifically and a moderate success financially. The URSI Board is now considering making the AP-RASC a fully owned URSI conference. As General Co-Chair of both the 2016 AP-RASC in Seoul and the 2019 AP-RASC in New Delhi, I have been deeply committed and will continue to be committed to the development of this conference as a full-fledged URSI symposium.

The presence of URSI in archival publications has been wanting. URSI has the *Radio Science Bulletin*, expertly edited by Ross Stone. Its only other publication was the journal *Radio Science* which, however, is owned by the American Geophysical Union. It was evident to me that URSI needed a publication outlet for all areas covered by the ten Commissions, that was fully owned and operated by URSI. I proposed to the Board the creation of the *URSI Radio Science Letters (RSL)*, an open-access rapid publication in electronic format of rigorously reviewed short papers containing original results in all areas of radio science. In June 2018, the Board accepted my suggestion and appointed me as the first Editor-In-Chief of this new journal, which is now in its third year of existence. I urge all contributing authors to this 2021 GASS to submit the works presented in Rome to the RSL; your submissions are needed to ensure the success of our new journal.

Thus, it appears to me that URSI is now well positioned to increase its activities in all four crucial areas that I mentioned previously. However, in order to succeed, URSI needs the enthusiastic cooperation of all of you in both the scientific and the organizational realms of our Union. In the next two years, the Secretariat will continue its work under the expert direction of Peter Van Daele who has been re-elected as Secretary General and will be aided by Inge Heleu and Inge Lievens. The URSI Council has elected Patricia Doherty, Kazuya Kobayashi, Giuliano Manara and Ari Sihvola as URSI Vice-Presidents for the next biennium. They bring a wealth of experience to the Board; among other activities, I note that Prof. Doherty is the Immediate Past Chair of Commission G and the second woman to serve as Vice-President in the history of URSI; that Prof. Kobayashi is the Immediate Past Chair of Commission B, the editor of *Radio Science*, and has devoted many years to the organization of AP-RASC; that Prof. Manara is a Past Chair of Commission B and the organizer of the 2004 EMTS in Pisa; that Prof. Sihvola, entering his second term as URSI Vice-President, is a Past Chair of Commission B and the organizer of the 2016 EMTS in Helsinki. Please join me in congratulating them as well as the new Chairs, Vice-Chairs, and Early Career Representatives of the ten URSI Commissions.

I want to acknowledge the outstanding work performed in the service of URSI during the past four years by Prof. Makoto Ando as President, by Prof. Paul Cannon as Immediate Past President, by Profs. Willem Baan and Ondrej Santolik as Vice-Presidents, and by the Officers of the ten Commissions.

The success of last year GASS and this year GASS under the trying circumstances imposed by the Covid pandemic would have been impossible without the dedication, expertise, and enthusiasm of the Local Organizing Committee, of the Scientific Committee, and of the URSI Secretariat. The late Prof. Roberto Sorrentino, Profs. Carlo Carobbi and Guglielmo D'Inzeo and their collaborators on the LOC deserve our gratitude for the smooth running of both GASS. Prof. Alain Sibille and the members of the Scientific Committee have done an impressive job in preparing the scientific program of both GASS. On a personal note, I thank Profs. Agnani and Sibille for their assistance with the French version of my remarks. Prof. Van Daele, Inge Lievens, and Inge Heleu have provided the central organizational assistance that was essential for the success of both GASS. Please join me in a round of applause for the work performed by all these dedicated colleagues.

Thank you all for participating in this GASS. I encourage you to attend the next flagship symposia, the AT-RASC next year in the Gran Canaria, and the 2023 GASS in Sapporo. I wish you an enjoyable stay in Rome and a safe trip home.

Piergiorgio L. E. Uslenghi
President of URSI

Report on Second Space Weather Workshop

The workshop was held on the virtual platform offered by the Ninth Annual IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE) conference on 13-14 October 2021, 17:00-19:00 GMT each day**.** The workshop was open to the space weather community in the broader sense. It was aimed at pinpointing the state-of-the art technologies and initiations facing space weather threats and their impacts in extreme environments, with a particular focus on space and aviation domains.

On average, about 30 colleagues from all over the world participated in the workshop during each of the two days. Many of them had the possibility to actively interact by chat and by microphone. Early Career Researchers and students followed the workshop, as well.

Day one of the workshop was dedicated to the contributed talks (11 in total, with one withdrawal at the very last moment). As the workshop was conceived for a very broad audience of space weather experts – to bridge the communities and cross-fertilize with solutions proposed in the different space-weather domains – the contributing speakers were asked to tune the talks to stimulate interest towards new aspects of space weather among the listeners, and potentially create new links and collaborations. Kirolosse M. Girgis from the Kyushu University (Japan) and Cairo University (Egypt) presented an analysis of the single-event upset (SEU) rates of a low-Earth orbit (LEO) mission due to its passage in the South Atlantic anomaly (SAA) during a geomagnetic storm. He reported how the single-event upset rates were increased by 40% during the recovery phase of the geomagnetic storm. This improved the knowledge about single-event upset prediction, which can save a LEO satellite mission from unexpected proton-induced single-event upset rates during extreme space-weather events.

Olga Maltseva from the Institute for Physics and Southern Federal University (Russia) presented a comparative analysis of different methods for the forecasting of the ionospheric total electron content (TEC), including also neural-network-based methods, such as the gated recurrent units (GRU), and the long-short term memory, using several parameter sets to guide the prediction. Davide Wenzel from the German Aerospace Center (DLR, Germany) presented the DLR network of radio measurements, such as VLF signals, deployed to establish an operational ground-based real-time solar-flare warning system. He also presented experiences in obtaining and working with such data taken by participants in a project of the International Space Weather Camp 2021.

Claudio Cesaroni from Istituto Nazionale di Geofisicae Vulcanologia (INGV, Italy) presented the IONORING (IONOspheric RING) tool. This provides real-time monitoring and modeling of the ionospheric TEC over Italy, by exploiting the Global Navigation Satellite System (GNSS) data acquired by the RING (Rete Integrata Nazionale GNSS) network, managed by INGV. IONORING is one of the algorithms currently running in the Ionospheric Prediction Service (IPS, https://ionospheric-prediction.jrc.ec.europa.eu), as a now-casting product and as input to a tool dedicated to the detection and estimation of the main characteristics of medium-scale traveling ionospheric disturbances (MSTIDs). Additionally, maps from IONORING are part of the product portfolio of the PECASUS consortium (http://pecasus.eu/). This is one of the three global centers providing space-weather advisories according to International Civil Aviation Organization (ICAO) regulations.

Claudio Cesaroni also presented, on behalf of Jorge Namour (Universidad Nacional de Tucuman, Argentina), work addressing a comparative study on different machine learning (ML) techniques, including LSTM and GRU, implemented in an NNARX (Neural Network Autoregressive with Exogenous Input) scheme, to generate forecasting of ionospheric TEC 24 hr in advance at a global level. He presented the preliminary results, accounting for various space-weather conditions. Jaroslav Urbář, again from INGV (Italy), presented a novel technique to measure lags between nonlinear non-stationary parameters. The lags were obtained scale-wise, enabling the identification of the lag dependence on the involved spatio/temporal scales. The decomposed signal components were provided by the novel Multivariate Fast Iterative Filtering (MvFIF) technique, and are called Intrinsic Mode Functions (IMFs). They are very promising in the scale-wise lag identification on artificial signals and ionospheric-based data (electron density in-situ data from the Swarm constellation).

Rayan Iman from Politecnico di Torino (Italy) presented a bagged tree model able to detect phase scintillation on GNSS scintillation at high latitudes with 95% accuracy, 5% scintillation miss-detection, and 5% scintillation false alarm. A comparison of the performance of the model to support vector machine (SVM) models, k-nearest neighbors (k-NN) models, and also to other decision-tree models was also reported.

Anna-Marie Bals from the Embry-Riddle Aeronautical University (Germany) presented the analysis of ionospheric scintillation events at high latitude by applying a machine learning framework (unsupervised hierarchical clustering and decision-tree infrastructure) to group the events into different kinds of similar temporal and spectral signatures. In the contribution, she showed how it is possible to derive important parameters such as approximate irregularity height, horizontal drift velocity, and spectral index.

Shibaji Chakraborty from Virginia Tech (USA) reported two probabilistic anomaly detection schemes (based on statistical Z-score and on nonlinear energy operators) that have been used to detect short-wave fadeout events produced by M and X class flares in the Super Dual Auroral Radar Network (SuperDARN) observations. The two schemes were based on statistical Z-score and nonlinear energy operators. He reported the performance of the detection schemes, illustrating how they varied with flare intensity and parameters of the detection schemes. He reported a correlation coefficient of ~0.73 between flare counts per month and SWF counts per month, detected using the Z-score scheme.

Rute Rodrigues Santos, from University of Coimbra (Portugal), reported on the influence of shield wires on geomagnetically induced currents (GICs) in power systems. She reported on a model, tested in Portugal, that was able to extend the results from previous studies that considered the effect of the resistances of shield wires by also including the induced geoelectric field.

Day two of the workshop was dedicated to the three invited talks and to the panel discussion. Those talks were proposed to give an overview in three different domains of space weather: the forecasting of the main features of interplanetary coronal mass ejections as support to the modeling and prediction of the magnetosphere-ionosphere-thermosphere coupled system; the space-weather effects on navigation, communication and remote sensing; and on the international efforts to establish a space-weather service for civil aviation.

Specifically, Mateja Dumbovic from the Hvar Observatory, University of Zagreb (Croatia), presented a detailed review addressing recent findings in forecasting the arrival time and speed of coronal mass ejections (CME), this being one of the key aspects of space-weather research. She presented the large diversity of coronal mass ejection models available today, by focusing on the propagation of the coronal mass ejection magnetic structure itself and on the propagation of the shock. The models reviewed ranged from empirical and simple analytical models to machine-learning and numerical three-dimensional magneto-hydrodynamical models.

Jens Berdermann, from the German Aerospace Center (DLR, Germany), surveyed the space-weather impact on navigation, communication, and remote sensing based on results from current and historical space-weather data. He aimed at stressing the importance of the awareness for space-weather-related threads, and reported about the current forecast capabilities and possible mitigation strategies.

Robert A. Steenburgh from the Space Weather Prediction Center of the National Oceanic and Atmospheric Administration (USA) reported about the international efforts for the provision of a space weather service to ICAO. The service would be aimed at developing a suite of advisories addressing space-weather degradation to High-Frequency (HF) communications and Global Navigation Satellite Systems (GNSS), and space-weather-induced radiation exposure increases. He reported how such service is ensured by four global centers (ACFJ, PECASUS, SWPC, and CRC), about the internal challenges faced by SWPC forecasters, researchers, developers, and technical support personnel, and about the external challenges faced by all the centers and the aviation industry. These latter include the ensuring of the consistency among centers; the issuing of space-weather advisories when no mechanism for collecting, reporting, or attributing impacts exists; and the education of the aviation community (pilots, dispatchers, air traffic controllers) about the service.

A panel discussion was held at the end of the day, addressing unsolved issues from the talks and addressing the importance of the cross-fertilization among the different space-weather domains. A particular focus was given to the importance of the growing interest in using machine-learning-based techniques for the modeling and prediction of space environments. In the workshop, five contributed talks out of 11 were dedicated to the exploitation of such techniques. What was underlined was that the need arose, especially from the ionospheric community, to exploit solar forecasting (coronal mass ejection propagation and consequent impact at the magnetospheric level) to feed machine-learning-based techniques for ionosphere prediction. In view of machine-learning-based ionospheric prediction, the session, "G05: Machine Learning Methods for Ionospheric Modeling: State of the Art and Future Actions" in the next URSI AT-AP-RASC is being advertised.

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Report on VERSIM 2020

1. General Information

The 9th VLF/ELF Remote Sensing of Ionospheres and Magnetospheres Workshop (VERSIM 2020) was successfully held as a virtual meeting during the week of 16-20 November 2020. The meeting had been rescheduled from the original meeting (23-27 March 2020 at the Uji Campus, Kyoto University, Japan), cancelled due to the COVID-19 pandemic. The VERSIM workshop aims to bring together scientists from all across the globe to present and discuss topics related to the excitation, propagation, and effects of electromagnetic waves in the ELF/VLF (300 Hz - 30 kHz) range. The VERSIM group was established as a joint URSI/IAGA work group in 1975. It has been the main scientific body to specifically focus on whistlers in the Earth's ionosphere and magnetosphere (whistler waves were one of the first electromagnetic signals detected by ground instruments, and gave important clues about the Earth's active space environment). The scope of this group has grown substantially over the years. It has grown particularly in recent years with the recognition that whistler-mode chorus and hiss waves play a particularly important role in shaping the dynamics of the Earth's high-energy radiation belts (particularly topical in light of the continuing successful operation of the Van Allen Probes and the Arase (ERG) spacecraft). Whistler waves are also known to be intimately involved in the magnetic reconnection process (which is currently very topical due to the launch of the MMS satellite) and solar flaring. In addition to the traditional VERSIM topics, results of recent space missions, such as Arase, MMS, and the Van Allen Probes, were presented.

The scientific program committee for the workshop consisted of Jacob Bortnik (UCLA, USA); Mark A. Clilverd (British Antarctic Survey, UK); Craig Rodger (University of Otago, New Zealand); Janos Lichtenberger (Eotvos Lorand University, Hungary); Jyrki Manninen (University of Oulu, Finland); Andrei G. Demekhov (Polar Geophysical Institute, Russia); Rajesh Singh (Indian Institute of Geomagnetism, India); Binbin Ni (Wuhan University, China); and Yoshiharu Omura (Kyoto University, Japan).

The local organizing committee consisted of Yoshiharu Omura (Kyoto University), Hirotsugu Kojima (Kyoto University), Kiyofumi Hirahara (Nagoya University), Yoshifumi Saito (ISAS/JAXA), Takanobu Amano (The University of Tokyo), Iku Shinohara (ISAS/JAXA), Yusuke Ebihara (Kyoto University), Seiji Zenitani (Kobe University), Masafumi Shoji (Nagoya University), Satoshi Kurita (Kyoto University), Naritoshi Kitamura (The University of Tokyo), Claudia Martinez (Nagoya University), Etsuko Kawasaki (Kyoto University), Hiroko Nitto (Kyoto University), Yikai Hsieh (Kyoto University), Satoko Nakamura (Nagoya University), and Takeshi Nogi (Kyoto University).

2. Participants

We had 59 invited oral papers and 83 poster papers presented during 10 sessions. These consisted of morning sessions (9 am - 12 am JST) and evening sessions (9 pm - 12 pm JST). There were 174 registered participants, which included seven special guests, from 20 countries. The maximum numbers of online participants were 108 in the oral sessions, and 113 in the parallel poster sessions A and B.

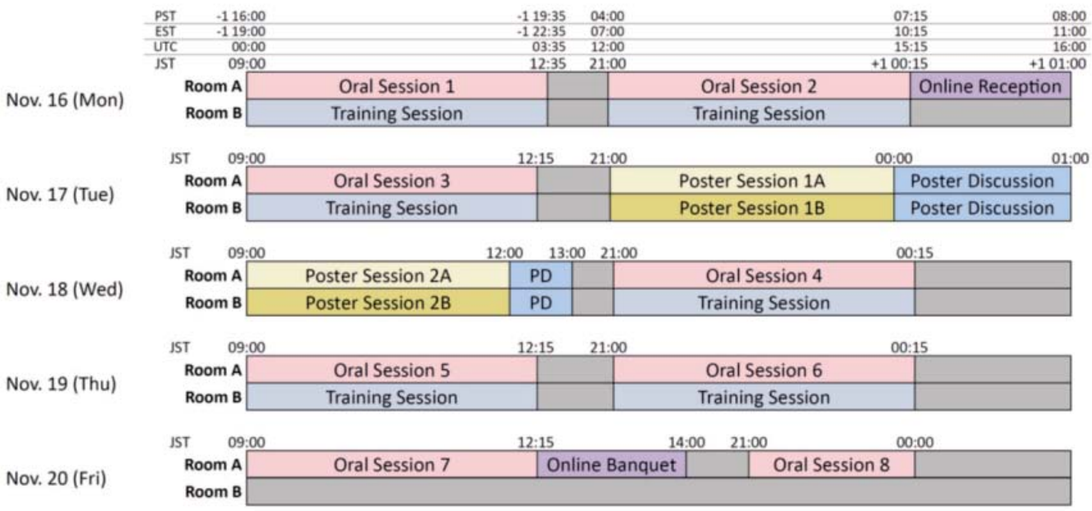

Figure 1. An overview of the VERSIM 2020 program.

Figure 2. At the beginning of the first oral session after the opening ceremony.

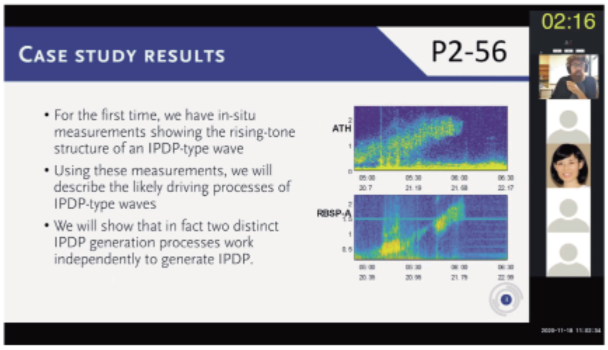

Figure 3. The Q&A time of the final poster paper presented at Poster Session 2B.

3. Session Program

We organized the session program by separating one day's program into a morning session (9 am – 12 am JST) and a late-evening session (9 pm – 12 pm JST), so that at least one session per day would be held at a convenient time for all participants in the world. An overview of the program is given in Figure 1. Oral papers were presented with the Zoom system, and all participants could ask questions directly or through the chat function. In each talk presented through the Zoom system, a timer appeared, showing "0:00 - 18:00 for talk and 18:00 - 21:00 for Q&A," and the speaker's video was highlighted next to the shared PowerPoint. Figure 2 shows a moment at the beginning of the first oral session, chaired by Craig Rodger, just after the opening ceremony. Poster papers were presented in the two parallel sessions of Zoom and Poster Gallery on the conference Web site, and free discussions were made in a virtual poster room of the Spatial Chat system. In each Zoom poster session, a series of speeches consisting of short oral presentations were given with a timer showing "00:00 - 02:00 for talk and 02:00 - 05:00 for Q&A." Figure 3 shows a moment in the Q&A time of the final poster paper presented in Poster Session 2B. All sessions were recorded, and the videos were available online until 20 October 2021.

4. Poster Paper Competition

We selected two Outstanding Poster Awards (OPA) out of 16 papers by early career scientists (within seven years after the PhD), and three Excellent Poster Presentation Awards (EPPA) out of 23 student papers. The Outstanding Poster Awards were given to Claudia Martinez-Calderon and Dedong Wang, and the Excellent Poster Presentation Awards were given to Man Hua, Miroslav Hanzelka, and Ruoxian Zhou. We also nominated Man Hua as a candidate for the IAGA YS award.

5. URSI Financial Support

The URSI support of 2,000 Euros was very helpful for us to prepare for the virtual meeting, when we had some debt because of the sudden cancellation of the workshop originally planned in March 2020. We lost the deposit for hotel accommodations, and had to return all the registration fees to the registered participants for the original meeting. After collection of the registration fees for the rescheduled virtual meeting (regular 10,000 JPY~126 persons, student 2,000 JPY~41 persons), and paying all the expenses and the debt, we had 2600 Euros left in out bank account. We returned the URSI support fund 2000 + 600 Euros to URSI.

6. Next Workshop

On the last day of the workshop, we had the business meeting of the VERSIM working group, and we decided unanimously to continue our activity. It was announced that the 10th VERSIM Workshop will be held in Sodankyla, Finland, September 2022.

Yoshiharu Omura,
Chair of the Local Organizing Committee
of VERSIM 2020
E-mail: oomura.yoshiharu.2a@kyoto-u.ac.jp

URSI Conference Calendar

December 2021

IEEE AP-S/URSI 2021
2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting
Marina Bay Sands, Singapore, 4-10 December 2021
Contact : Secretary: Xinyi Tang aps2021.secretary@gmail.com , https://2021apsursi.org

February 2022

URSI Benelux Forum 2022
Eindhoven, Netherlands, 3 February 2022
Contact : Prof. Mark Bentum, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands, m.j.bentum@tue.nl

RFI 2022
Radio Frequency Interference 2022
Virtual meeting, 14-18 February 2022
Contact : events@ecmwf.int, https://events.ecmwf.int/event/258/

March 2022

URSI France 2022 Workshop
Journeé scientifique 2022 d'URSI France
Paris, France, 22-23 March 2022
Contact : E-mail: ursifr-2022@sciencesconf.org, https://ursifr-2022.sciencesconf.org/

EuCAP 2022
16th European Conference on Antennas and Propagation
Madrid, Spain, 27 March - 1 April 2022
Contact : Dr. Manuel Sierra Castañer, EuCAP2022 Conference Chair, EuCAP2022 email-service@euraap.org, http://www.eucap2022.org

May 2022

AT-AP-RASC 2022
Third URSI Atlantic Radio Science Conference
Gran Canaria, Spain, 30 May - 4 June 2022
Contact: Prof. Peter Van Daele, URSI Secretariat, Ghent University – INTEC, Technologiepark-Zwijnaarde 126, B-9052 Gent, Belgium, E-mail: peter.vandaele@ugent.be, http://www.at-rasc.com

July 2022

COSPAR 2022
44th Scientific Assembly of the Committee on Space Research (COSPAR) and Associated Events
Athens, Greece, 16-24 July 2022
Contact : GREECE COSPAR 2022 Secretariat, Fax: +30 2103643511, E-mail: info@cosparathens2022.org , https://www.cospar-assembly.org/assembly.php

September 2022

EMC Europe 2022
Gothenburg, Sweden, 5-8 September 2022
Contact : EMC Europe 2022 Secretariat: info@emceurope2022.org, Conference Chair: Prof. Jan Carlsson jan.carlsson@emceurope2022.org, https://www.emceurope2022.org/

August 2023

URSI GASS 2023
XXXVth URSI General Assembly and Scientific Symposium 2023
Sapporo, Hokkaido, Japan, 19 - 26 August 2023
Contact: URSI Secretariat, c/o INTEC, Tech Lane Ghent Science Park - Campus A, Technologiepark-Zwijnaarde 126, B-9052 Gent, Belgium, E-mail info@ursi.org

August 2025

AP-RASC 2025
Asia-Pacific Radio Science Conference 2025
Sydney, Australia, August 2025
Contact: Prof. Paul Smith, Macquarie University, Australia, E- mail paul.smith@mq.edu.au

A detailed list of meetings is available on the URSI website at http://www.ursi.org/events.php

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EFGHJ RFI Mitigation and Characterization
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EGH Radio Diagnostics of Space Weather Plasma Processes
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EHG Solar Power Satellite
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FCGEH Risk and Disaster Management
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GEH Seismo-Electromagnetics (Lithosphere-Atmosphere-Ionosphere Coupling)
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GH Active experiments in Space Plasmas
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GJFEH Interdisciplinary Space Weather
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