INTERNATIONAL
UNION OF
RADIO SCIENCE

UNION
RADIO-SCIENTIFIQUE
INTERNATIONALE

INFORMATION BULLETIN D'INFORMATION

No 270
September 1994

Publié avec l'aide financière de l'UNESCO

URSI, c/o University of Gent (INTEC)
St.-Pietersnieuwstraat 41, B-9000 Gent (Belgium)

INFORMATION BULLETIN D'INFORMATION

Contents

75th anniversary of URSI 3
News from the Member Committees 5
 the United Kingdom 5
UTC Time Step 5
News from the Commissions 6
 Commission G 6
Reports on URSI-sponsored meetings 7
 International Symposium on Radio Propagation 7
 ESGAP - Electromagnetic Scattering in Gases and Plasmas 7
 EMC'94 Sendai 8
 CLIMPARA'94 8
 BEMS Report of 1994 Annual Meeting 10
Announcements of URSI-sponsored Meetings 10
 The Third Asian-Pacific Radio Telescope Consortium Meeting and Workshop on the Compatibility of VLBI System 10
 URSI and STEP/GASP Workshop on Theory and Observations of Nonlinear Processes in the Near-Earth Environment 11
 1995 Asia-Pacific Microwave Conference - APMC '95 12
 1995 Com. F International Triennial Open Symposium on Wave Propagation and Remote Sensing 13
Other meetings brought to our attention 14
 3ème Colloque International sur L'Intelligence dans les Resaux 14
 3rd International Conference on Intelligence in Networks 14
 4th CEPT Radio Conference 15
Courses and Lectures 15
 Fourth ICTP-URSI-ITU(BDT) College on Radiopropagation: Propagation, Informatics and Radiocommunication System Planning 15
IUCAF Annual Report for 1993 16
Administrative information 17

URSI was created in 1919 in Brussels, Belgium, during the constitutive Assembly of the International Research Council, the predecessor of ICSU, and it is thus one of the oldest member Unions of the Council, together with the Unions dealing with Astronomy, with Chemistry, and with Geodesy and Geophysics. The principal motivation was "to coordinate international activity in different branches of science and their applications". Whereas international cooperation is certainly desirable in all fields of science, it may be said that it is indispensable in some particular areas if reliable conclusions are to be drawn from scientific work and observations.

In URSI, many researches must be carried out on a worldwide basis and require international cooperation in the actual conduct of research. Some others, however, require no such collaboration, but penetrating papers and discussions at URSI meetings were often the precursors of new research as well as of renewed interest in a classical field.

At first sight, the scientific interests of the URSI Commissions differ considerably from each other. However, all the Commissions have a common interest in research relating to the propagation of electromagnetic radiation and associated questions. It is generally agreed also that this community of interests acts as a cohesive force which holds together the radio scientists in URSI.

Since some misinterpretations of URSI's scientific objectives and its role in ICSU have arisen on some occasions in the past, it is perhaps important to reiterate the fact that URSI, like the other Unions, has always been and is still concerned with its own branch of science, namely research on the scientific aspects of radio communications. However, the many practical applications of radio techniques in astronomy, geophysics, telecommunications, meteorology, etc. have led many people to the erroneous conclusion that these techniques were developed, by radio scientists associated with URSI, in order to satisfy the needs of the various users. It is not generally appreciated that most of the radio techniques in use are merely by-products of much earlier research in the basic science of radio communications, and that URSI, as the Union responsible for this branch of science, is not itself concerned with the exploitation of radio techniques in other branches of science or in telecommunications systems.

Radio communication science originated with studies of the phenomenon of radio wave propagation , and of the scientific aspects of the transmission of information from a radio transmitter at one point to a receiver at a distant point. However, the term radio communications may now be used in a wider sense ; in particular it covers several specialised radio methods, used by astronomers, space scientists and geophysicists, for the acquisition of information about distant objects or regions. When radio waves are emitted from, or reflected, refracted scattered or attenuated by, a distant object or region, they carry information about the characteristics of the emitter, or of the region through which they pass on their way to the receiver. In some cases, the waves are specially emitted and controlled by the scientist ; in other cases, the scientist receives waves emitted by distant astronomical objects and uses them to study the characteristics either of the regions through which they have passed, or of the emitting objects themselves. These applications of earlier research on radio communications have had important consequences in astronomy and geophysics.

Rapid progress has been made during the last decades in the techniques for the exploitation of space vehicles capable of making in situ observations which complement those performed at ground stations. As a result, geophysicists and astronomers might have placed less emphasis on radio techniques. It appears in fact, that a new impulse arose from the advancement of space research. Indeed new low frequency radio windows have been opened in this way in astronomical and planetary observations, while at the same time extremely precise radio measurements from space of distances in the Earth system became available, with large implications on the day to day life as well as on the monitoring of the Earth environment.

As it appears from the above, the propagation of radio waves, and hence the interaction of radio waves with the Earth's atmosphere have in the early days figured prominently in the activities of URSI. There are still within URSI structure Commissions dealing with Ionospheric radio and propagation, Waves in plasmas, and Radio astronomy, but discussions tend to concentrate on technical projects and developments of instruments, leaving the interpretation of the results to the appropriate Unions.

As illustrated above, URSI although primarily concerned with radio communications science, has often facilitated contacts between, on the one hand, radio scientists and, on the other, groups of workers in other branches of science wishing to exploit radio techniques.

One more recent example of URSI's pioneering role in the development of tools in other fields of science was the formal creation in 1990 of a Commission dealing with Electromagnetism in Medicine and Biology. This Commission met for the first time last year in Kyoto with an extremely successful scientific programme.

In the opinion of URSI, the formation of Inter-Union Commissions, or of less formal Inter-Union Working Groups, can bridge boundary areas between two or more Unions, and their existence tends to increase the cohesion of the various bodies within ICSU. At present, URSI is participating in three Inter-Union bodies : the Inter-Union Commission on Frequency Allocation to Radio Astronomy and Space Science (IUCAF), the Inter-Union Working Group on Adverse Environmental Impacts on Astronomy and the Inter-Union Working Group on VLF/ELF Remote Sensing of the Ionosphere and the Magnetosphere.

URSI is also represented in a number of ICSU Scientific Committees : COSPAR, SC-IGBP, SCAR, SCOR, SCOSTEP, FAGS, etc.

Radio physics, including time and frequency measurements, have always played a major role in the activities of URSI. Especially in the era after World War II, new fields of activity emerged as a result of research on the more fundamental aspects of radio science, and these were progressively covered by URSI Commissions, the primary objective of which remains to stimulate and coordinate, on an international basis, studies in the field of radio, telecommunication and electronic sciences. New knowledge arising from these studies often lead to engineering efforts, the consequences of which are far-reaching for our society.

The proper role of URSI within the scientific community has been the object of a long-continuing debate over the years. In 1987, a special conference grouping together URSI officers and outside personalities agreed that it would be appropriate to put greater emphasis on telecommunications. A series of international symposia on Signals, System and Electronics (ISSSE) was launched in 1989, with the aim of covering the whole range of topics in the area, and of promoting the exchange of experience and results between scientists and engineers working in these multidisciplinary areas. The Union organizes also at regular intervals major symposia on Electromagnetic Theory, including the scientific basis of the design of antennas and waveguides ; on Electromagnetic noise of natural and manmade origin and its effects on communication systems, and on Wave propagation and remote sensing.

It seems worth mentioning here the close collaboration which has been maintained almost since the creation of URSI with the International Telecommunications Union (ITU), which is responsible for the central coordination of the world telecommunication systems. Thanks to the URSI Scientific Committee on Telecommunications, formed en 1990, the scientific expertise of the Union in the field of telecommunications has been strongly reinforced.

As may be seen from the above, many of the scientists associated with URSI are involved with other international organizations. However in URSI they find a unique forum, a place where they are able to meet other scientists with completely different backgrounds, but sharing the same or similar scientific interests.

The particular subjects with which URSI is concerned at any given time vary in accordance with current progress in the whole field of radio science. At the last General Assembly in 1993, the URSI Council and Commissions adopted a number of recommendations on various subjects : Scientific uses of the Global Positioning System ; Time domain waveform measurements ; Environmental consequences of nuclear war ; Use of the frequency spectrum ; the Terrestrial ionosphere/magnetosphere system as a plasma laboratory; Electromagnetic effects associated with earthquakes and volcanic eruptions ; Optical frequency generation and measurement ; Low frequency wind measurements, Large mm and submm array ; Potential impact on human health of electromagnetic fields from wireless communications, to mention only a few.

Two long-term activities of URSI are concerned with its Young Scientists Programme and with Developing Countries.

The Young Scientists Programme, which was initiated in 1969, has developed in one of the most successful ventures of the Union. The objective is twofold : bring to the Union fresh ideas and idealism of young people, and help advance science in developing countries by making it possible for young scientists from these regions to participate in URSI meetings. At the last General Assembly held in Kyoto in 1993, the number of young scientists attending under that scheme was : 53 from developed countries, and 61 from developing countries.

URSI established a Standing Committee on Developing Countries in 1981 to consider ways in which it could make a useful contribution to the advance of radio science in these countries. In the past years, this Committee was instrumental in organizing major training courses, bi-regional Latin American-African Conferences on Radio Propagation and Spectrum Management, and in publishing a series of publications as, for example, "The Handbook of Propagation in Tropical Countries" and "The Directory of Radio Scientists in Developing Countries".

For both of these activities, URSI received generous support and assistance from ICSU, UNESCO, the International Center for Theoretical Physics, the Third World Academy of Sciences and some other institutions.

This year, URSI is celebrating its 75th anniversary. In order to mark this event, it is organizing a 2-day Symposium on "Radio Science in the Space Era" which will be held in the prestigious Royal Academy of Sciences of Belgium.

Indeed, it appears that many areas in radio science imply the use of space techniques. A non exhaustive list of topics includes :

- Atomic clocks in microgravity and clock synchronization in space
- Use of Global positioning systems (GPS) from geodesy to sailing
- Antennas in Space
- Mobile communication systems and low Earth orbit satellites
- Fractals and radio science
- Direct Digital High Definition Television

- All weather mapping, with Synthetic Aperture Radar (SAR), of the Earth and planets
- Radar altimetry mapping and monitoring of the ocean
- Synthetic Aperture Radar Interferometry and the monitoring of the Earth surface at the centimetre level
- Interactions between electromagnetic and plasma environment and spacecraft
- Waves in space plasmas of the solar system
- Very long Baseline Interferometry (VLBI) in space
- Cosmology after the discovery of the radio noise
- Bioelectromagnetic effects on users of mobile radio communication systems

Lectures on these topics, given by environment scientists representing a wide range of scientific fields, should be illuminating and should reflect the scientific health of URSI.

URSI is confident in its future. Its unique character allows it to play a twofold role : first, it has the capability of providing a vast scientific experience as, for example, in the field of telecommunications ; second, it provides a forum for interdisciplinary work. While pursuing its effort in current research, it is also endeavouring to find areas of promising new lines of research and cross-connections between the different branches of radio science.

P. Bauer, President of URSI

NEWS FROM THE MEMBER COMMITTEES

The United Kingdom

(The U.K. National Panel for URSI)

A national Radio Science Colloquium, held under the auspices of the U.K. National Panel for URSI (Chairman : Professor T.B. Jones), is an established feature of the national radio science and engineering calendar in the U.K. The 11th Colloquium in an unbroken sequence was held at a University of Liverpool Hall of Residence on July 12th and 13th, 1994. Excellent local organization was provided by Dr. Brian Austin.

Some 65 participants attended and 36 contributed papers were presented, many by young researchers. The interests of Commissions B (8 papers), C (6 papers), D (4 papers), E (1 paper), F (7 papers), G (4 papers) and H (3 papers) were represented. In a somewhat lighter vein there were 3 papers of a historical nature - Brian Austin presented a talk entitled "Sir Oliver Lodge : his place in Radio Science" and a beautifully illustrated talk on " Coherers : the appropriate solid-state devices for 1894" was given by P.T. Andrews. The last presentation was by Peter Excell of Bradford University who, with others, is hoping to establish an interactive museum of radio, radar and the ionosphere linked to the life of Sir Edward Appleton who was born in Bradford in 1892.

Papers were presented in single sessions and the venue gave adequate opportunities for discussions outside the formal programme. Two business meetings of the National Panel were also held during lunch breaks.

The URSI colloquium followed a University of Liverpool celebration of the life and works of Sir Oliver Lodge who transmitted the first radio message in 1894 while he was Professor of Experimental Physics at University College, Liverpool. Colloquium participants had the opportunity to purchase a new well-produced book concerned with the achievements of Lodge and the early days of radio.

D. Llanwyn Jones

UTC TIME STEP

No positive leap second will be introduced at the end of December 1994.
The difference between UTC and the International Atomic Time TAI is:

from 1993 July 1, 0h UTC, until further notice : UTC-TAI = -29 s

Leap seconds can be introduced in UTC at the end of the months of December or June, depending on the evolution of UT1-TAI. Bulletin C is mailed every six months, either to announce a time step in UTC or to confirm that there will be no time step at the next possible date.

Martine FEISSEL
Director, Central Bureau of IERS

Commission G

Excerpts from the Commission G Newsletter

1. Inquiry about future General Assemblies

(Comment from URSI Secretariat : a report on the decisions taken concerning the future General Assemblies will be published in one of the next issues of the Radioscientist & Bulletin)

2. URSI Working—Groups

You probably know that several working groups (WG) exist within URSI. For our commission we have

G.1 Ionosonde Network Advisory Group (INAG)
G.2 Studies of the Ionosphere Using Beacon Satellites
G.3 Incoherent Scatter
G.4 Ionospheric Informatics

in addition joint working groups

GH.1 Active Experiments in Plasmas
GH.2 Computer Experiments, Simulation and Analysis of Wave Plasma Processes
CGH.1 Wave and Turbulence Analysis
EGH.1 Electromagnetic Effects Associated with Seismic Activity
FG.1 The Middle Atmosphere
AFG.1 The Scientific Uses of GPS Signals

and an Inter Union working group

URSI/IAGA & VLF/ELF Remote Sensing of the Ionosphere and Magnetosphere (VERSIM)

These WGs are certainly not exclusive clubs. They are meant to be an informational forum were knowledge and experience on the relevant topic is available but also wanted. Most WG issue their own newsletters, organize conferences or workshops (see item 5) and maintain a list of their WG members. All the WGs usually have business meetings at the URSI General Assemblies. Any colleague who is interested in a working group can get information or can become a member. Just contact the chairman in question.

The above list of WGs is not static. At each General Assembly it is decided whether a WG should continue its work or if it has become obsolete. This also means that new WGs can be established (as EGH.1, FG.1 and AFG.1 at the past GA in Kyoto). If you have ideas about new WGs, please let me know early enough. We can then start a discussion procedure and put the matter on the agenda of our next business meeting at the 1996—GA in Lille.

G.1: Dr. P.J. Wilkinson
G.2: Prof. Dr. R. Leitinger
G.3: Dr. J.M. Holt
G.4: Dr. D. Anderson
GH.1: Dr. Sa. Basu
GH.2: Dr. H. Thiemann
AFG.1: Dr. P. Hoeg
CGH.1: Prof. Dr. A.W. Wernik
FG.1: Prof. Dr. S. Fukao
EGH.1: Here we have a problem, nobody has so far be named from Com. G as a co-chairman for this WG. Any suggestions are welcome! Co-Chairman of Com. E is: Prof. Dr. T. Yoshino
URSI/IAGA - Inter Union WG: Dr. A.J. Smith

3. URSI—News

Several of you probably already receive the URSI—News on E-Mail. Prof. Dick Dowden from University of Otago in New Zealand is doing a marvellous job in editing and cirulating this newsletter. It contains information about all commissions, meetings, etc. anything which is related to URSI. Currently there are about 300 subscriber from 33 countries. You can obtain it regularly free of charge if you just email "ADD ME" to ursi@physics.otago.ac.nz

4. Use of Ionospheric Data

I still received only a few answers on the questions about the use of ionospheric data. May I remind everybody? (See last newsletter 210—G, Dec. 93).

5. Future meetings

The URS/COSPAR Task Force on the International Reference Ionosphere (IRI) is holding a workshop on "Low and Equatorial Latitudes in IRI" in New Delhi, India, from 9—13 January 1995. Within this workshop the Ionospheric Informatics WG (G.4) organizes a one-day workshop on "Low Latitude Ionospheric Models and Model Validation".

For further information, please contact
Dr. D. Bilitza, HSTX, NSSDC
7701 Greenbelt Road
Greenbelt, MD 20770, USA
Fax: +1-301 441-9486
E-mail: bilitza@nssdca.gsfc.nasa.gov

The 9th International Symposium on "Equatorial Aeronomy" will be held in Bali, Indonesia, from 20—24 March 1995.

For further information, please contact
Dr. S. Fukao.
Radio Atmospheric Science Centre
Kyoto University, Uji, Kyoto 611, Japan
Tel: +81-774 33 5343
Fax: + 81-774 31 8463
e-mail: fukao@kurasc.kyoto-u.ac.jp

A workshop on "Theory and Observations of Nonlinear Processes in the Near-Earth "Environment" will be organized by WG CGH.1 in Zakopane, Poland in May or June 1995 (about 5 days).

For further information about this conference, please turn to Page 11 of this issue of The Radioscientist & Bulletin.

KRISTIAN SCHLEGEL

International Symposium on Radio Propagation

Beijing, 18-21 August 1993

The ISRP-93 meeting was a very informative and enjoyable one, held in delightful surroundings in the Western Hills of Beijing. It was hosted by the Radio Propagation Society of the Chinese Institute of Electronics, by the China Research Institute of Radiowave Propagation and by Wuhan University, and led by Professor Lu Baowei, Professor Sha Zong and Professor Wu Mingyi.

A total of 132 people attended, from 19 territories, of whom 55 were not from mainland China. 118 papers were presented, and the proceedings from the meeting occupy 743 pages. The 177 papers in the proceedings (including the three mentioned below) were divided between 11 topic areas as follows : Electromagnetic Wave Theory (13), Tropospheric Propagation (26), Earth-Space Radio Propagation (15), Waves in Plasmas (8), Ionospheric Physics (32), Ionospheric Propagation (14), LF, VLF and ELF Propagation (14), Scattering and Inverse Scattering (29), Radio Sounding of the Earth Environment (9), Antennas (11) and Digital Ionospheric Sounding (3).

The meeting covered 3 days with four parallel sessions after starting with a review of "The Advance of Radiowave Propagation Research in China since ISRP-88" by Professor Lu Baowei followed by a review of "Radiowave Propagation Studies for Future Radiocommunication" by Mr. R.C. Kirby and Dr. K.A. Hughes, and a review of "International Collaboration in Radiowave Propagation Studies" by Mr. M.PM. Hall. It was very worthwhile.

Martin P.M. Hall & Wang Shen
Scientific Programme Committee Co-Chairmen

ESGAP - Electromagnetic Scattering in Gases and Plasmas

Aussois, France, 21-24 March 1994

This Symposium, co-sponsored by URSI Commissions F, G and H, was held at the CNRS Paul Langevin Centre in Aussois, in the French Alps. The meeting attracted more than 40 people from 11 countries (Denmark, Finland, France, Germany, Greece, Japan, Russia, Sweden, the United Kingdom, the Ukraine and the USA). The members of the Scientific Committee were J.P. Bonnet (France), S. Fukao (Japan), E. Holzauer (Germany), J. Röttger (Sweden), K. Schlegel (Germany), A.G. Sitenko (Ukraine) and R.N. Sudan (USA). The Local Organizing Committee was chaired by J.P. Villain. Other sponsors for the meeting were CNRS, DGA/DRET and the French Ministry of Research.

Coherent diffusion of an electromagnetic wave is one of the main tools for remotely studying fluctuations in a transparent medium. Such methods are presently used or developed by various scientific communities. For example, some scientific domains where it applies are aerodynamics, meteorology, space or laboratory plasma physics. Techniques, as well as interpretations, differ from one domain to the other. They vary according to parameters such as wavelength, particle mean free path, length and correlation time of turbulence..., and to scientific objectives, such as macroscopic motions, energy transport, instability mechanisms ..

This first interdisciplinary symposium on the subject was aimed at meeting specialists from the various fields concerned by coherent scattering as a tool of diagnostics in a gas or a plasma.

The program was arranged around one invited talk and several contributed talks for each scientific subject. A total number of 36 contributions were presented. The various scientific sessions were:

- Coherent Scattering in Space Plasmas (ionosphere, magnetosphere). Review by K. Schlegel.
- Coherent Scattering in fusion plasmas (inertial and magnetic confinement). Review by F. Holzauer.
- Collective Scattering by aerodynamic flows. Review by J.P. Bonnet.
- Bragg Scattering by atmospheric turbulence. Review by J. Röttger.
- Theory of scattering by turbulent media. review by A.G. Sitenko.

This first interdisciplinary workshop has achieved his goal of comparing the various techniques, results and interpretations in terms of physical parameters. A general feeling was expressed on the interest on holding another similar conference in a couple of years. Several suggestions were made for the future:

- Include new scientific fields, as Lidar observations of neutral atmosphere, and scatter by precipitations or ice particles for meteorological radars;

- Develop collective scattering as a diagnostic tool in wind tunnels;
- Interpret ionospheric observations in terms of parameters of the turbulence.
- Extend collective scattering to magnetic fluctuations.

It was finally proposed to create a small group of experts who could be asked to prepare a synthesis describing similarities and differences of electromagnetic scattering in the various scientific domains and, more specifically to clarify the various terminologies.

The proceedings of the conference will be edited in a Special Issue of Journal of Atmospheric and Terrestrial Physics.

CHRISTIAN HANUISE

LSEET/CNRS, Université de Toulon
BP 132, F-83957 La Garde Cedex (France)
Phone : (33) 94 14 24 53, Fax : (33) 94 14 24 17
e-mail: ch@lseet.univ-tln.fr

EMC'94 SENDAI

Sendai, Japan, 16 - 20 May 1994

The EMC'94 Sendai was held at Sendai Plaza Hotel, Sendai, Japan from 16 to 20 May, 1994. The first EMC Symposium in Japan was held in Tokyo in 1984, the second one in Nagoya in 1989 and this was the third EMC Symposium in Japan, with Professor T. Takagi as Chairman.

This symposium was sponsored by the Technical Group on EMC of the Institute of Electronics, Information and Communication Engineers and the Technical Group on EMC of the Institute of Electrical Engineers of Japan, and was co-sponsored by the IEEE EMC Society, EMC-S Tokyo Chapter, Association for Promotion of Electrical, Electronic and Information Engineering and the International Union of Radio Science (URSI). There were 528 participants from 23 countries, and 187 scientific papers in the regular sessions and 37 papers in APTS (Advanced Products and Technology Session) were presented, and the symposium was a big success.

The scientific subjects covered by this symposium were nearly the same as other EMC symposia, and I will list the titles of regular sessions so that you will understand what kind of topics were discussed in Sendai; (1) EM field and lines/coupling and crosstalk, (2) printed circuit board, (3) lightning surge, EMP and ESD, (4) shielding and grounding / technique and material, (5) spectrum economy and management, non-sinusoidal signal, (6) EM environments, (7) filter, transformer and isolator, EMC in amateur radio, (8) spread spectrum techniques, remote sensing, seismogenic EM phenomena, (9) biological effects, (10) EMC in application area, (11) noise and EM field, measurement and analysis, (12) scattering TV ghost problem and radar false echoes, (13) EMI/EMC test, (14) EM energy absorber, anechoic chamber, (15) noise, including spurious and harmonics, contacts and gap discharge phenomena, (16) EMC standards and regularizations, (17) immunity susceptibility, and (18) EM sensor, probe and antenna. Latest results in every session were presented, and we enjoyed hot discussions.

A new attempt called APTS was carried out in this symposium, which was a kind a combination of exhibition and poster session. 37 papers were presented in this APTS, and it attracted a lot of attention of the participants. Furthermore, a booklet entitled "Advanced knowledge on EMC" was published, which included the advanced EMC technologies by different leading companies. It seems to be very useful for the participants.

If you would like to have a copy of the Proceedings of this symposium, please contact : Professor Y. Kami, The University of Electro-Communications, 1-5-& Chofugaoka, Chofu, Tokyo 182, Japan.

M. HAYAKAWA

CLIMPARA'94

Moscow, Russia, 31 May - 3 June 1994

Climpara'94 was an URSI-Commission-F-sponsored symposium on Climatic Parameters in Radiowave Propagation Prediction, held in Moscow on 31 May to 3 June 1994. 69 people participated from 17 countries, 25 people being from Russia. The meeting was hosted by the Radio Research and Development Institute (NIIR), arrangements being made by Dr. V.N. Troitsky. Co-Chairmen of the Scientific Programme Committee were Mr. M.P.M. Hall and Mr. J.P.V. Poiares Baptista.

The purpose of the symposium was to examine what radiometeorological parameters may best be used to predict radiowave propagation characteristics, how they vary with climate and how best they may be mapped on a world scale. The meeting sought interaction of those in studies relating to radiowave propagation prediction with those involved in remote sensing, in climatic studies and in hydrology; it benefitted considerably from co-sponsorship from the WMO's World Climate Research Programme (with a lead being taken at Climpara'94 by Dr. B. Rudolf and Dr. K. Arpe). The symposium was organised in three main areas; Precipitation (led by Prof. P.A. Watson and Dr. M. Thurai), Clear air (led by Mr. T. Tjelta and Dr. K.H. Craig) and Mapping (led by Mr. J.P.V. Poiares Baptista). There were 40 papers presented in 9 sessions and a further 22 posters on display (organised by Dr. F. Dintelmann). Discussion was lively, especially in specific workshop sessions in the three areas and in a concluding session. Posters received considerable attention, being immediately before the excellent symposium dinner held in an adjacent room. The meeting benefitted from hotel accommodation and sessions being in the same building.

The radio-science and radio-engineering communities around the world have expended much energy, ingenuity and expertise in developing methods for the prediction of various characteristics of the propagation of radiowaves in non-ionised media. However, the extent to which these characteristics may be expected to vary fom one region of the world to another is still far from clear.

In the field of meteorology, the development of sophisticated numerical mesoscale models that increase the resolution of current operational numerical forecast algorithms may in the near future supply very powerful tools also for the area of radiometeorology or wave propagation. Early attempts with resolutions around 100 km (and locally 15km) have already yielded very encouraging results for forecasting propagation losses. On the other hand, the high-time-resolution meteorological data observed for long periods by the wave propagation community may be of interest in the climatology scientific community in projects like the Global Precipitation Climatology Project. New spacecraft instruments like the joint NASA/NASDA

TRMM or EAS's MIMR will offer new opportunities to measure globally meteorological and

climatological parameters that are also of interest to wave propagation.

Most of the electromagnetic effects due to atmospheric phenomena are well understood; however, most of the models used are either empirical or physico-empirical, i.e. they are based on relevant physical parameters (some of which are radiometeorological) but made to fit propagation data, for areas where data are available, through the use of suitable coefficients.

Suitable choices of physical parameters and coefficients should enable good predictions to be made of a radio variable on a given path if the related radiometeorological data are available for that path. The radiometeorological variables vary with climate and may be called "Climatic Parameters".

Progress and understanding in examining effects of Climatic Parameters may be most advanced on attenuation due to rain, and a number of new measurements in low latitude regions were the basis for an URSI Commission F Special Open Symposium on "Regional Factors in Predicting Radiowave Attenuation due to Rain" which was held in Rio de Janeiro in December 1990 (see M.P.M. Hall, URSI Bulletin No. 257, pp 23-26, June 1991). It was arranged that the symposium was followed immediately by two concurrent meetings of those closely concerned with these issues in two Working Parties of ITU-R. This enhanced the exchange of ideas and information on this topic between the two communities.

Very comparable considerations have now become apparent for the use of world maps of radio refractive index Climatic Parameters for steering the prediction of line-of-sight multipath and of signal levels likely to cause transhorizon co-channel interference.

A Workshop held immediately following on the Commission F Triennial Symposium at Ravenscar in the UK in June 1992 (see M.P.M. Hall, URSI Bulletin No. 263, pp 17-20, December 1992) considered the use of Climatic Parameters in the prediction of rain effects (attenuation and off-beam scatter) and clear-air effects (ducting and multipath). This led to the much fuller meeting at Climpara'94.

The symposium gave a forum to compare experiences and exchange points of view between different scientific communities and with colleagues in Central and Eastern Europe. Specific new collaborations were established, notably between those in tropical and temperate areas. One outcome of the symposium was a proposal to set up an informal Climpara Correspondents Newsletter operating by E-mail. This cannot be a high profile activity, but is intended to encourage the exchange of relevant information between those interested in this topic area. Offers of contributions would be much appreciated.

To ensure that prediction of radiowave propagation is reliable throughout the world involves radio-scientists (e.g. from URSI) and radio-engineers (e.g. from ITU-R) in a co-ordinated campaign, though often the individuals involved span both camps. Before long, it may be that self-contained prediction packages for use world wide will contain maps of terrain height and coverage, and maps of appropriate Climatic Parameters - both areas are progressing well.

M.P.M. Hall and J.P.V. Poiares Baptista
Co-Chairmen

REPORTS ON URSI-SPONSORED MEETINGS

BEMS Report of 1994 Annual Meeting

Copenhagen, Denmark, June 12-17, 1994

The 16th Annual Technical Meeting of the Bioelectromagnetics Society was held June 12-17, 1994, at the Sheraton Hotel, Copenhagen, Denmark.

Over 400 abstracts were received from 16 countries: 192 were assigned as platform reports and 200 as poster reports. There were two mini-symposia - Clinical Symposium on Bioelectromagnetics in Medicine jointly organized with the Society for Physical Regulation in Biology and Medicine and the Symposium on Epidemiological Studies of Power Line Fields in Northern Europe - and a workshop on Safety of Mobile Communications. In addition, there were sessions jointly organized with the Bioelectromagnetics Association and URSI Commission K in Electromagnetics in Biology and Medicine.

There were 30 reports designated as Student Contributions. The Curtis L. Johnson Student Award for best poster report was presented to Adam Lacy-Hulbert, University of Cambridge, UK and the Award for best platform report was presented to Jeffrey Carson, St. Joseph's Health Center, London, Ontario, Canada.

Copies of the book of Abstracts for the 1994 Annual Technical Meeting may be ordered from the Bioelectromagnetics Society, 120 West Church Street, MD 21701 USA, Tel: 301-663-4252, Fax: 301-663-0043

Cost is $10.00 plus $2.00 shipping outside of the United States.

The following is a summary of the participants by country:

Argentina:	1	Japan:	41
Australia:	8	Latvia:	1
Austria:	4	Netherlands:	3
Belgium:	4	Norway:	10
Canada:	15	Poland:	2
China:	1	Russia:	2
Croatia:	2	Slovenia:	4
Czech. Republic:	8	South Africa:	3
Denmark:	25	Spain:	9
Finland:	16	Sweden:	47
France:	18	Switzerland:	11
Germany:	41	Taiwan:	3
Greece:	1	UK:	35
Hungary:	6	Ukraine:	3
Israel:	2	US:	179
Italy:	26	Yugoslavia:	2
		Total:	**507**

The 1995 Annual Technical Meeting of the Bioelectromagnetics Society is 18-22 June at the Park Plaza Hotel, Boston, MA, USA. Call-for-papers will be mailed in early November. Interested persons should contact the Society, at the above address, to be sure they are included in the database for mailings.

William G. Wisecup, DVM
Executive Director

ANNOUNCEMENTS OF URSI-SPONSORED MEETINGS

The Third Asian-Pacific Radio Telescope Consortium Meeting and Workshop on the Compatibility of VLBI System

Urumqi, China, October 10 - 14, 1994

The third APT (Asian-Pacific Radio Telescope Consortium) Meeting is aimed at promoting the cooperation of scientific research in this area and a discussion on the compatibility of VLBI system is essential

During this meeting, there will be a formal opening of the newly established Urumqi VLBI station.

Scientific Organizing Committee:
R. Ekers (Australia, ATNF, Chair)
Ye Shu-hua (China, Shanghai Observatory, Chair)
D. Jauncey (Australia, ATNF)
Wang Shou-guan (China, Beijing Observatory)
T. Yoshino (Japan, CRL)
M. Inoue (Japan, NAO)

Local Organizing Committee:
Jiang Dong-rong (Shanghai Observatory, Chair)
Qian Zhi-han (Shanghai Observatory)
Zhang Fu-jun (Shanghai Observatory)
Zhang Jin (Urumqi Station, Chair)
He Xiao-yun (Urumqi Station)
Liu Pei (Urumqi Station)

Preliminary Programme:

Oct. 9 (Sun)	Registration, Sight seeing, reception.
Oct. 10 (Mon)	Opening, Space VLBI, VLBA, Status and Progress.
Oct. 11 (Tue)	EVN, IRIS, APT status and progress, Observatory Reports.
Oct. 12 (Wed)	Tour to Urumqi VLBI station.
Oct. 13 (Thu)	New Results of Research and Progress in Technology.
Oct. 14 (Fri)	System Compatibility, Summary.
Registration Fee:	120 USD
Accommodation:	Single room à 30 USD/night Double room à 35 USD/night

The Venue
Urumqi is a big city in North-Western China with an average temperature in October around 4°C. Weather is usually sunny and cool, but the first snow may occur in mid-October.

Transportation:
Airflights to Urumqi:

From	Time (hours)	Frequency
Alma-Ata	1.5	1,2,5,6
Beijing	3.5	Daily
Guangzhou	4.5	Daily
Shanghai	4.5	1,3,4,6

Rail to Urumqi:

From	Time (hours)	Frequency
Beijing	3 days	Daily
Shanghai	4 days	Daily

Visit of Dunhuang
Dunhuang is famous for its ancient temples with wall painting. Pre- or Post-meeting visits to Dunhuang can be arranged by the travel agency via air or rail and car as there are flights between Urumqi and Dunhuang (Thursday only).

For further information, please contact:
Prof. Jiang Dong-rong, Shanghai Observatory
80 Nandan Rd, Shanghai, 200030, P.R. China
Fax: 86-21-4384618, Telex: 33164 SHAO CN
E-mail:bmasao@ica.beijing.canet.cn

URSI and STEP/GASP Workshop on Theory and Observations of Nonlinear Processes in the Near-Earth Environment

24-28 April, 1995, Zakopane, Poland

The initiative to organize a Workshop was undertaken by the URSI Commissions G (Ionospheric Radio and Propagation) and H (Waves in Plasmas) at the XXIVth General Assembly of URSI in Kyoto (Japan). The idea of the Workshop is to bring together specialists working on nonlinear processes such as turbulence, chaos, wave interactions in the near-Earth environment and laboratories, and exchange ideas on the theory, instrumentation, and methods of data analysis. To stimulate a discussion a number of invited, review papers will be presented. Contributed papers are also welcomed.

Scientific Programme
The range of topics will cover :

- ionospheric and atmospheric turbulence (natural and artificial)
- non-linear dynamical systems methods
- wave-wave interactions
- solitons in plasma and neutral atmosphere
- mode conversion in natural and artificial plasma
- wavelet transform as a tool for studying turbulence

Venue, accommodation and social programme
The Workshop will be held in a comfortable Pensione Zgorzelisko, about 17 km from Zakopane (approximately 400 km from Warsaw, 120 km from Cracow), in the heart of Tatra Mountains (Tatra Mountains National Park) in southern Poland. It can provide accommodation for 100 persons in 40 double rooms (each with private bath) and 10 double apartments. The conference room can accommodate 120 persons. The cost including full board, per night, per person is 19 USD in double-bedded rooms and 28 USD in double apartments (for a single occupancy : add 20%). There is also a possibility to accommodate a certain number of participants in the nearby private houses (rooms with up to 8 persons without private bath) at lower cost (13-14 USD with full board) (prices as in May 1994 and may increase by 10-15% in 1995).

Social programme may include guided hiking, mountain canoeing, folklore dancing, etc. An informal reception is also planned.

Detailed information will follow to the pre-registered participants.

The number of Workshop participants is limited to 120 persons and contingent upon their willingness to share accommodation with colleagues. The participation is granted on a first-come, first-serve basis.

Transportation

Warsaw may be directly reached by plane from many cities in Europe, North America and Asia. Cracow has direct international flight connections with Frankfurt, London, Paris and Rome. There is also a direct coach line between London and Zakopane. Please consult your travel agent. Coaches will be provided to transport participants from Warsaw and Cracow to Zgorzelisko and back on 23 April and 29 April, respectively.

Registration fee

The registration fee will be 80 USD. Included in the registration fee is the cost of the conference materials, proceedings, coffee or tea, and snacks during the coffee breaks.

Deadlines for submission

- of pre-registration form : 20 November 1994
- of abstracts : 28 February 1995

Information

For more information, please contact :
Professor A.W. WERNIK
Space Research Center
Polish Academy of Sciences
ul. Bartycka 18a
00-716 Warsaw, Poland
Fax/phone : +48 39-121273
E-mail : workshop@chopin.cbk.waw.pl

A.W. WERNIK

1995 Asia-Pacific Microwave Conference - APMC '95

October 10-13, 1995, Taejon, Korea

The 1995 Asia-Pacific Microwave Conference (APMC '95) will be held at Taejon, Korea on October 10-13, 1995. This conference is sponsored by the Korean Institute of Telematics and Electronics, the Korean Institute of Communication Sciences, the IEEE MTT Society, the IEEE Korea Council and MTT Chapter and the Korea EMC/EMI Society.

Scope of the conference: contributed papers are solicited describing original work in the microwave field. The technical subject categories for the conference are as follows:

1. Active Devices and Circuits
2. MMIC and GaAs Technology
3. High-Power Devices and Techniques
4. Measurement and Instrumentation
5. Microwave-Optical Interactions
6. High-Speed Optical Devices and Systems
7. Passive Components and Circuits
8. Guided Waves
9. CAD Procedures, Techniques and Modelling
10. Microwave Superconductivity
11. Electromagnetic Field Theory
12. Ferrite Devices
13. Microwave Acoustics
14. Millimeter Wave and Submillimeter Wave Techniques
15. EMC/EMI
16. Scattering and Propagation
17. Antennas
18. Microwave Terrestrial, Satellite and Mobile Communication Systems
19. Microwave Industrial, Scientific and Medical Applications
20. Phased and Active Array Techniques
21. Radar
22. Radio Astronomy
23. Remote Sensing

Submission guidelines:

Authors are required to submit

1. Five copies of a 30-50 word abstract on a single separate sheet. This sheet should indicate the title and author(s) of the paper.
2. Five copies of a 500-1000 word summary with supporting illustrations. the title of the paper and the author's name(s) should be on the front page of each copy.
3. A separate sheet with the complete mailing address (and FAX number, as appropriate) of the author and a statement specifying the most appropriate topic from the preceding list.

Time table:
Paper submission deadline : March 10, 1995
Accepted paper notification : May 31, 1995
Camera-Ready manuscript deadline : August 10, 1995

General Information

Conference	October 11-13, 1995
Workshops	October 10, 1995
Exhibition	October 10-13, 1995

Venue
The conference will be held at Taedok Science Town in Taejon, Korea

Official Language
The official language of the conference is English, which will be used for all printed materials, presentations and discussions.

Exhibition
Exhibits of commercial products related to microwave will be held during the conference. We are expecting enthusiastic collection of vendors and conference registrants.

Registration and Hotel Accommodation
Information on the registration and hotel accommodation will be given out in later announcements.

Social Programme
Reception, Banquet and coffee breaks will provide chances for the participants to mingle and communicate with their colleagues. Also conference tours are planned for participants during and after the conference.

Taejon
Taejon is the sixth largest city in Korea with a population of 1.19 million. It is located in the central part of the country about two-hour (154 km) south of Seoul, and is rapidly becoming a major scientific center in Korea. On the outskirts of the city lies the Taedok Science Town, which hosted Taejon Expo'93. Yusong Hot Spring Resort is located near by the Conference Site. Taejon is the commercial, industrial and educational center of the province.

For further information please contact:
Prof. Noh-Hoon Myung
Conference Secretary, APMC '95
Dept. of EE, KAIST
373-1 Kusong-dong, Yusong-gu
Taejon 305-701, Korea
Tel: + 82 42 869 5417
Fax: + 82 42 869 8010
e-mail: nhmyung@eekaist.kaist.ac.kr

1995 URSI Commission F
International Triennial Open Symposium on
Wave Propagation and Remote Sensing

20-24 November, 1995, Ahmedabad, India

The seventh Commission F Triennial Open Symposium will be held from 20-24 November 1995 at Ahmedabad, India. Ahmedabad is the sixth largest city of India, its airport flights connecting with Delhi and Bombay. It has ancient architectural features and Lake Kankaria is situated in the city.

The triennial meetings are primary events of Commission F. Papers on any topic of interest to Commission F are welcome; however, these are particularly encouraged in the following areas:

a. Application of radiowave propagation studies to telecommunications and remote sensing.
b. Remote sensing of the lower and middle atmospheres.
c. Studies of scattering from the Earth's surface, oceans, land and ice.
d. Characterisation of radio propagation for terrestrial and satellite communications systems.
e. Radiowave propagation studies for mobile communications.
f. Radar meteorology.
g. Climatic parameters in radiowave propagation

Synopses should cover no more than one sheet of A4 paper, or E-mail equivalent, but give sufficient information to enable an objective assessment to be made by referees. Synopses should (in a compact form) include a title, the authors, the topic area letter from the list above, the contact address, phone, facsimile and E-mail numbers.

Synopses should be received by 20 February 1995 by :
Mr M.P.M. Hall
Rutherford Appleton Laboratory
Chilton, Didcot, Oxon. OX11 OXQ, UK.
Fax: +44 235 446140
E-Mail: martin.hall@rutherford.ac.uk.

Details of arrangements may be obtained from :
Prof. O P N Calla
SATCOM Area Space Applications Centre
Ahmedabad, India
Fax: +91 79 404563
E.Mail: calla@sac.ernet.in

3ÈME COLLOQUE INTERNATIONAL SUR L'INTELLIGENCE DANS LES RESAUX
3RD INTERNATIONAL CONFERENCE ON INTELLIGENCE IN NETWORKS

11 - 14 October 1994, Bordeaux, France

The third edition of ICIN (International Conference on INTELLIGENCE in NETWORKS) will take place in Bordeaux, France from 11 to 13 October 1994.

This event is sponsored by the ITU (International Telecommunication Union). ICIN is organised by SEE (Société des Electriciens et des Electroniciens), IREST (Institut de Recherches Economiques et Sociales sur les Télécommunications) and ADERA (Association pour le Développement et l'Enseignement et des Recherches auprès des Universités, des centres de recherche et des entreprises d'Aquitaine) in cooperation with 12 scientific societies including IEEE/COMSOC.

The International Steering Committee, is chaired by K. Hoffman of Stentor Resource Center Inc (Canada), Chairman of the Programme Committee Forum Telecom 95 (ITU Geneva).

Senior representatives from NTT, Bellcore, Euroscom and France Telecom will take part in the Opening Session.

The very high quality of the papers selected has led the organizers to propose a "tutorial" day. this day of initiation for newcomers, which has been prepared by Eurocom (Sofia Antipolis, France) will take place in Bordeaux on 10 October.

Conference Programme

Communication networks are undergoing dramatic changes. trends in society are creating a demand for new services, such as tele-working, personal mobility, home entertainment and global communications. Deregulation and competition are stimulating an environment for rapid growth of services.

The continuing development of network intelligence, which would build on advances in distributed computing and broadband communications, will be a key factor for success. Future services will require effective cooperation of network intelligence across network operator, service provider and user domains. Research and development organisations are intensifying their efforts on providing these intelligent network capabilities.

ICIN 94 will contribute to this discussion.

The Programme Committee which has drawn up the scientific programme of this conference is composed in such a way that its members represent different components in the field of intelligent networks : telecommunications operators, telecommunications and data processing equipment manufacturers, university researchers and teachers and network users. Many eminent foreign speakers have agreed to participate, thereby adding a representative international dimension to the conference.

The delegates have been invited to speak on 5 main themes outlined by the Programme Committee:
- Applications and Services
- Architecture
- Networks and System Implementations
- Service Specification, Creation and Management
- Non technical aspects of IN

The organizers are proud to have received 143 propositions in reply to the call for papers. 19 propositions came from France and 124 others came from 16 different countries.

Seeing that the quality of the papers submitted is very high, the Programme Committee has organised a "tutorial" day which aims to introduce the topics to newcomers so that they might fully benefit from the Conference.

Eurecom (Sofia Antipolis, France) is responsible for the organisation of this special day.

The Programme Committee has preferred to limit the number of parallel sessions in order that delegates might participate in a more concentrated fashion. That is why only 66 papers were finally selected. Among these, 56 come from foreign speakers from 12 different countries. In order to avoid eliminating too many interesting presentations, 28 have been proposed as "poster sessions".

They have been divided into 12 sessions. the main themes are the architecture of intelligent networks with 2 sessions, the administration with 2 sessions of which one will be devoted to aspects of mobility, the creation of services with 2 sessions, management of the intelligent network (1 session), aspects of marketing and international strategies with 2 sessions, the long-term architecture (1 session). The intelligent peripheral (1 session), aspects of engineering and implementation and service interaction aspects will also be dealt with.

In order to give a certain prestige to the conference the Programme Committee has invited certain highly acclaimed speakers to participate at this Opening Session.

The conference will therefore be opened with speeches by:
- Y. Inoue, Executive Manager at NTT Telecommunications Networks Labs,
- G.J. Handler, Corporate Vice President Technology Resources (Bellcore)
- M. Antal, Professor, Director of Eurescom.

This programme brings together all the ingredients that are likely to make it a great international success.

For further information, please contact:
ADERA - ICIN 94
Tel. (+33) 56 15 11 51
Fax (+33) 56 15 11 60

OTHER MEETINGS BROUGHT TO OUR ATTENTION

4th CEPT Radio Conference

Prague, Czech Republic, 21-23 November 1994

European Radiocommunications Office announces this conference, which will take place in the Hotel Inter-Continental, Nám. Curieovych 43/5, CZ-110 00 Prague 1, Czech Republic.

The CEPT, the regulatory organisation for telecommunications in Europe, invites you to its fourth Radio Conference. Mobility is the theme of this year's conference which will highlight and discuss the following main subjects:

* working to facilitate mobile communications within the ERC and ECTRA
* the mobile Green Paper of the EC
* views of mobile users
* DSI Phase II Seminar (one full day)
* European mobile systems
* national issues concerning mobility

The objectives of the conference are:

* to provide a forum for open discussions and consultation on all subjects included in the programme
* to provide updated information and obtain feed back on ERC activities and developments
* to concentrate on today's key mobility issues

This full three day conference will be of interest and value to everyone involved in radiocommunications, i.e. manufacturers, network operators, service providers, users and administrations. It is intended to be both informative and to provide a forum for consultation.

An exhibition, arranged by the ERO, will be in the vicinity of the auditorium on all 3 days of the conference.

The conference is organized by:
European Radiocommunications Office
Holsteingade 63
DK-2100 Copenhagen, Denmark
Tel: + 45 35 43 24 42
Fax: + 45 35 43 35 14

For further information, registration and hotel accommodation, please contact :
Vindrose Rejser APS
Vester Voldgade 90
DK-1552 Copenhagen V, Denmark
Tel: + 45 33 13 52 23
Fax: + 45 33 14 29 09

COURSES AND LECTURES

Fourth ICTP-URSI-ITU(BDT) College on Radiopropagation: Propagation, Informatics and Radiocommunication System Planning

ICTP, Trieste, Italy, 30 January - 3 March 1995

Directors:
Prof. S.M. Radicella, (ICTP, Trieste, Italy).
Prof. J. Van Bladel (University of Gent, Belgium)

Lecturers and lecture titles:

1. Introductory Course
   1 a.- Electromagnetics (J. Van Bladel)
   1 b.- Computer Techniques (ICTP expert)
   1 c.- Informatics for Radiocommunications (F. Gardiol)
2. Propagation information for modern HF systems planning (P. Bradley)
3. Propagation information for VHF-UHF systems planning (L. Barclay)
4. Climatic information for satellite communication planning (G.O. Ajayi)
5. Noise, interference and EMC in modern radiocommunication system planning (P. Degauque)
6. Digital signal processing in radiocommunications (J.G. Lucas)
7. Mobile and personal communications system planning (J. Shapira)
8. Biological effects of electromagnetic waves from radiocommunication systems (P. Bernardi)
9. Radio spectrum management for system planning (R. Struzak)
10. Laboratory on Informatics for Radiocommunications (K. Hughes, J.G. Lucas, P. Degauque and R. Struzak)
    10 a.- Signal processing
    10 b.- Noise, Interference and EMC
    10 c.- Propagation predictions
    10 d.- Spectrum management
    10 e.- Mobile communication network planning

Time distribution:
1. 30 January - 8 February
2.- 9. 9 February - 17 February
10. 20 February - 3 March

S. M. Radicella

IUCAF ANNUAL REPORT FOR 1993

Excerpts of the Annual Report for 1993 of the Inter-Union Commission on Frequency Allocations for Radio Astronomy and Space Science (URSI-IAU-COSPAR), by Chairman Dr. B.J. Robinson

Introduction:
IUCAF, the Inter-Union Commission on Frequency Allocations for Radio Astronomy and Space Science, was set up in 1960 by URSI, IAU and COSPAR. Its brief is to study and coordinate the requirements for radio frequency allocations for radio astronomy, space science and remote sensing in order to make these requirements known to the national and international bodies responsible for frequency allocations. IUCAF also takes action aimed at ensuring that harmful interference is not caused to radio astronomy, space science or remote sensing (operating within the allocated bands) by other radio services. It has to be particularly vigilant about radio transmissions from aircraft or space vehicles.

Membership:
The present composition of IUCAF is:

URSI	W.A. Baan (USA)
	R.J. Cohen (UK)
	H.C. Kahlmann (The Netherlands)
	B.J. Robinson(Australia)
IAU	G. Swarup (India)
	A.R. Thompson (USA)
	M. Ishiguro (Japan)
	B.A. Doubinsky (Russia)
COSPAR	D. Breton (France)
	A. Gasiewski (USA)

ex officio advisers:
Director, ITU Radio Bureau : R.C. Kirby (Switzerland)
Chairman, ITU Radio Board : M. Miura (Japan)

IUCAF acknowledges the considerable efforts made by the retiring members, and welcomes the new members and the contributions they offer. The XXIVth General Assembly of URSI in Kyoto appointed Dr. Baan and Dr. Cohen to replace retiring members Dr. Grahl and Dr. Price. The COSPAR representatives Dr. Breton and Dr. Gasiewski were appointed at the end of 1993 after consultation with the new Secretary General, Professor S. Gredzielski. They replace Dr. Hieber and Dr. Horner. Dr. Breton and Dr. Gasiewski both have expertise in Passive Remote Sensing of the Earth, an area where frequency allocations are under threat from many active radio services.

IUCAF has maintained it network of Correspondents in 35 countries to interact with national authorities responsible for radio frequency allocations.

Dr. J.W. Findlay, who had been Chairman of IUCAF until 1987, died on 22nd March 1994. We keenly remember his many contributions to the work of IUCAF, particularly his efforts at WARC-79.

Scientific Meetings :

During the period November 1992 to November 1993 IUCAF members took part in several meetings and conferences.

IUCAF also provided input papers to ITU Radiocommunication Bureau meetings of Study Group 7 (Scientific Services) and Study Group 8 (Mobile Satellite Communications).

Major questions dealt with at the meetings listed above concerned :

a) Impact of the ITU World Administrative Radio Conference 1992
b) GLONASS Navigation Satellite System
c) ITU Radiocommunication Bureau meetings
d) Adverse Environmental Impacts on Astronomy
e) Space Frequency Coordination Group
f) World Radiocommunication Conference WRC-93 (Geneva)
g) Resolutions on the Preservation of Passive Bands

Education/Training Activities :

a) Participation in the work of the ICSU Working Group on Adverse Environmental Impacts on Astronomy is a broad educational effort directed at government representatives, science writers and the public.
b) Dr. J. Ponsonby has proposed an alternative to the Spread Spectrum modulation commonly used by space and mobile services. Spread spectrum produces a high level of spurious sidebands. At the 1993 URSI General Assembly Dr. Ponsonby gave an invited paper describing a Continuous Phase Modulation which produces far lower spurious sidebands. He has built a prototype modulator which he plans to demonstrate to engineers responsible for space and mobile systems.

Activities involving Developing Countries

There has been continuing contact with the IUCAF Correspondents in Argentina, Brazil, Chile, China, Egypt, India, Indonesia, Iraq, Malaysia and Mexico. There has still been no success in establishing IUCAF contacts in African countries.

Publications and Reports

The following reports have been distributed up to March 1994 :

- IUCAF 395 — IUCAF Report for 1992-93 to ICSU
- IUCAF 396 — Report on Contact with INMARSAT re Spurious Emissions at 1.6 GHz.
- IUCAF 397 — Report on CEPT input to WRC-93 proposing sharing by active services of existing exclusively passive bands.
- IUCAF 398 — Report on Article 14 Agreements for GLONASS and Radio Astronomy.

IUCAF ANNUAL REPORT FOR 1993

- IUCAF 399	Report on IUCAF meeting in Kyoto (August 1993)
- IUCAF 400	List of IUCAF Documents
- IUCAF 401	Report on the Third GLONASS - IUCAF Meeting on the Use of the Band 1610.6 - 1613.8 MHz
- IUCAF 402	Report on WRC-93 (Geneva)

Future Plans :

1. Continuation of efforts to reduce interference to Radio Astronomy from GLONASS navigation satellites in the frequency band 1610.6 - 1613.8 MHz.
2. Continuing pressure on INMARSAT to reduce potential interference from mobile systems using aircraft and communication satellites. This involves both in-bad interference at 1660-1660.5 MHz and adjacent band interference into the passive band 1660.5 - 1670 MHz.
3. Continuation of studies on the unwanted out-of-band emissions produced by wide-band digital modulation and the technique of spread-spectrum modulation (commonly used in transmissions from satellites and aircraft relating to wide-band sound broadcasting, high-definition TV broadcasting, navigation, mobile satellite telecommunications and covert communications).
4. Involvement in COMMSPHERE 94, an URSI International Symposium on Future Telecommunications and the Electromagnetic Environment. This is scheduled for December 1994 in Eilat, Israel.
5. Continuing interaction with the ICSU Working Group on Adverse Environment Impacts on Astronomy.

Conclusion :

IUCAF is well represented in the America, Asia, Europe and the Middle East by its Members and the network of Correspondents. Representation in African countries is still lacking, and continues to be a major problem.

Vigilance is required to ensure that the outstanding successes achieved at WARC-92 in the international status of space research, earth exploration and radio astronomy will benefit these scientific activities well into the 21st century. At WRC-95 and WRC-97 the status of passive remote sensing will need to be improved.

Specific problems caused by harmful interference radiated from spacecraft and aircraft will occupy the attention of IUCAF as the regulatory decisions of the ITU take effect in the areas of satellite communications, navigation and broadcasting. A good working relationship has been established with the operators of proposed low-earth-orbit communication satellites and with the administration of the GLONASS navigation satellites.

Vital statistics :

Number of Members :	10
Number of Correspondents :	35
Number of meetings organized :	3
Number of meetings attended :	5
Number of documents distributed :	8

B.J. Robinson

ADMINISTRATIVE INFORMATION

The URSI Board of Officers :

President :	Dr. P. Bauer (France)
Past President :	Prof. E.V. Jull (Canada)
Vice-Presidents :	Prof. J.B. Andersen (Denmark)
	Prof. P.J.B. Clarricoats (U.K.)
	Prof. T. Okoshi (Japan)
	Prof. T.B.A. Senior (U.S.A.)
Secretary General :	Prof. P. Lagasse (Belgium)

The URSI Secretariat :

Secretary General :	Prof. P. Lagasse
Assistant Secretary Gen. :	Prof. P. Van Daele
Administrative Secretary :	Mrs. I. Heleu

For further information about URSI, please contact :

The URSI Secretariat, c/o University of Gent (INTEC)
Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium
Tel. (32) 264.33.20, Fax (32) 264.42.88
E-mail heleu@intec.rug.ac.be

For contributions to The Radioscientist & Bulletin :

E-mail rsb@intec.rug.ac.be

The object of the International Union of Radio Science (Union Radio-Scientifique Internationale) is to stimulate and to coordinate, on an international basis, studies in the field of radio, telecommunication and electronic sciences and, within these fields:

a) to promote and organize research requiring international cooperation, and the discussion and dissemination of the results of this research ;
b) to encourage the adoption of common methods of measurement, and the intercomparison and standardisation of the measuring instruments used in scientific work ;
c) to stimulate and coordinate studies of :
   - the scientific aspects of telecommunications using electromagnetic waves, guided and unguided.
   - the generation and detection of these waves, and the processing of the signals embedded in them.

The Radioscientist

Vol 5 No 3 **September 1994**

Feature Articles

Fessenden and the Early History of Radio-Science
John S Belrose 94
Physical Optics and Terrain Diffraction
Jim Whitteker 111

Reviews

MicroMath Scientist. 116
ed Lakhtakia: *Essays on the Formal Aspects of Electromagnetic Theory* 118
Zhdanov and Keller: *Geoelectrical Methods in Geophysical Exploration* 118

New Products and Services

DSP-II and its applications 120
A DSP system for the Macintosh computer . 123
GRAFT: A graphical VLF frequency analysis program for the Macintosh 125
The Alaska SAR Facility: What it is. What it does. 127

An early prototype table of contents found its way into the previous issue (*Radioscientist, 5,* p 47) which showed incorrect page numbering and the wrong publication date (June 1993!). The editors regret the mistake.

NEWS

Review references now available online

The National Space Science Data Center (NSSDC) is happy to announce that the references from the 1990-1992 Review of Radio Science is online and available for anonymous FTP transfer from the data system at NSSDC. Permission to place the references online was granted by Ross Stone, Editor.

The Commission letter designator, Commission Name, the file for the references in the Commissions and the file sizes in bytes are given below:

Commission	File_name	Size
A Electromagnetic Metrology	A_REF.TXT	212k
B Fields and Waves	B_REF.TXT	800k
C Signals and Systems	C_REF.TXT	328k
D Electronics and Photonics	D_REF.TXT	531k
E Electromagnetic Noise and Interference	E_REF.TXT	122k
F Wave Propagation and Remote Sensing	F_REF.TXT	415k
G Ionospheric Radio and Propagation	G_REF.TXT	392k
H Waves in Plasmas	H_REF.TXT	376k
J Radio Astronomy	J_REF.TXT	634k
K Electromagnetics in Biology and Medicine	K_REF.TXT	186k

The URL for use with World Wide Web is:

`http://nssdca.gsfc.nasa.gov/htbin/htdir/anon_dir/multidis/`

To use anonymous FTP:
To log in to the ANONYMOUS FTP account at NSSDC:
`FTP NSSDCA`
`LOGIN ANONYMOUS`
`PASSWORD my_full_email_address`
To change to the URSI references directory
`CD multidis`
To list the directory
`DIR`
To change to the Commission H directory, for example
`CD ursi_h`

To go back up a directory level

```
CD ..
```

To copy the Commission H references file, for example

```
GET ursi_h file_name_on_your_computer
```

To quit

```
QUIT
```

README files, which describe the reference lists, are also online.

The access was arranged and the files were organized and uploaded by William W L Taylor, Nichols Research Corporation, Arlington, VA, USA, who was also the USA Editor for the Commission H references. His email address is:

wtaylor@nhqvax.hq.nasa.gov

N Y Times recalls lives of two top USA scientists

Julius Adams Stratton, well known to the URSI community, has died in Boston, *The New York Times* reported recently. Stratton was President of the Massachusetts Institute of Technology 1959-1966 where "...major innovations in teaching and curriculum development changed the environment of scientific education at MIT."

These changes included the formation of interdisciplinary centres (in space research, earth sciences, life sciences, materials science, engineering and advanced engineering study) and planning of the Institute's first women's dormitory. The work of Stratton and his predecessor "marked MIT's transformation from a technical institution into what has been called 'a university polarised around science.'"

William Wilson Morgan (88), who discovered the spiral structure of the Milky Way galaxy, died in June in Wisconsin. In an obituary, *The New York Times* reported that Morgan, a specialist in astronomical morphology, "devised classification systems for the brightness of stars, developed a system to determine distances to remote stars more accurately and demonstrated the existence of super-giant galaxies.

"His investigations of starlight and the distances and arrangement of stars led to the discovery that gained him wide recognition in science. After years of observations and analysis, he discovered the broad pattern in which the interstellar gas and billions of stars in the Milky Way are arranged Because the solar system is part of the Milky Way, astronomers cannot view it from outside and are unable to get a clear understanding of its shape." The *Times* noted the unusual standing ovation Morgan received when he announced his findings in 1951.

Letters

I thought I'd let you have a few lines with my views on the new style of *The Radioscientist & Bulletin.* As the first issue was structured it could've been called The "Bulletin & Radioscientist" because all the really interesting stuff came second! I'd really prefer to see the undoubtedly important, but less stimulating Committee news and so on relegated to the back end of the new style journal/magazine.

As always the content is very good (thanks to your efforts and those of your associate editors) and hopefully you'll see people responding to the invitation to become URSI Correspondents. Incidentally, the very attractive rates and the opportunity to subscribe to relevant journals much more cheaply, were given a good plug by Tudor Jones (UK President) at the National Radio Science Colloquium here in Liverpool last week.

Brian Austin

Department of Electrical Engineering & Electronics, University of Liverpool

Not being one myself, I couldn't help noticing that you radioscientists seem to lack agreement on just who was, in fact, the inventor of Radio. In my youth, they said it was Marconi, now it seems Fleming helped a great deal, we have a major input by Reginald Fessenden, and Hertz had started it all off in the first place.

In the past weeks, when not rushing to meet *Radioscientist & Bulletin* deadlines, I have been reading a book [Adrian Vaughan's *Isambard Kingdom Brunel: Engineering Knight-Errant,* J Murray, London 1991] about I K Brunel, the engineer of Britain's Great Western Railway. Like myself, he was no scientist either. In 1850 he wrote to an organiser of Prince Albert's Great Exhibition at Hyde Park, "I think in an English exhibition you should seek to secure that characteristic of which we are most proud... that for which we are most distinguished, usefulness... for that reason I should omit any mention of electric machines which as yet can only be considered as mere toys". Such prejudice led to an unfortunate condemnation of a handy invention [Vaughan writes]: "In 1853 he was asked to join in a company being formed to exploit a discovery of one Mr Wilkins who had found a way to transmit messages by electricity without wires — wireless." Brunel, who worked for the telegraph monopoly that existed at the time, turned it down: I'd love to know what became of Mr Wilkins and his invention, which would have happened four years before Hertz's birth.

Peter Dowden

Production Editor

THE EDITOR'S PAGE

Science for the sake of Science — Gone forever? All around the world funding for pure research is being cut. This is partly because the need for Defence research is perceived to be greatly reduced in these Cold Warless times and partly because of the world wide spread of the monetarist philosophy or "market economy". Both of these arise from the public concept of research as solely for the advance of technology, and perhaps Defence technology in particular. We scientists as far back as Archimedes, and radioscientists in particular, must bear some responsibility for these views because we have had to make our research appear Defence-related to get funding.

In New Zealand and maybe many other countries elsewhere, virtually all funding is for "Public Good" research. Individual scientists have to bid for research contracts of, typically, 3 years, to get their own salaries, expenses and overheads, and that of their technicians. These bids are taken annually. If one doesn't get one's bid accepted one is out of a job, so one is most careful to keep one's research "relevant".

In USA and Canada, it seems that whole institutes or laboratories are simply closed down. I have received email circulars from both countries requesting scientists to write to their Congressman (or whoever) to protest such closures. In the FSU where inflation has been galloping, such institutes and the scientists in them have had to survive on substantially reduced domestic funding and scarce foreign grants. As a result, the majority of individual scientists have survived only by "moonlighting" (taking on additional employment) or by changing their vocation completely. Only a handful of the most brilliant are able to find a tenured or even visiting position in research abroad. So we are all in the same boat or yellow submarine, "Earth", as the Beatles had it. Maybe it won't last forever — the President of the NZ Royal Society sees "that time when we move out of the monetarist culture of the period." Can we radioscientists bring this time closer?

Scanning the issue. If this gets to you in September, it will the third issue in three months — which is not bad for a quarterly! This has taken its toll of the 80–page target. We have more "copy" but not the time to lay it out and meet the printing deadline.

Early radio is again the cover article, and there is more in this vein being polished up for the December issue. If you don't like this dominating the *RS&B*, or even if you do, write a Letter. There are many claims for radio firsts, so write a letter if you have contrary evidence against claims made in the last three articles (Lodge, Fleming and Marconi, and now Fessenden). A Letter in this issue suggests wireless began before Hertz was even born!

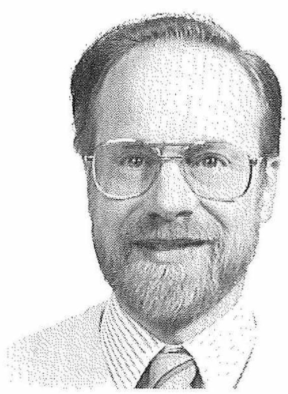
The tutorial by James Whitteker (who has just joined our team as Associate Editor) is one of three in the last year or so on scattering or diffraction ranging from VLF to microwave. All research papers, including tutorials and historical articles like those above, are (or will be from now on) prefaced by an abstract and we acknowledge the help of the referees. Each issue of the *RS&B* is now scanned by INSPEC for abstracting such papers.

There are four articles in the department *New Products and Services*. Products described in this department range from the purely commercial, so that sales have to cover the development costs and overheads (eg the IPS-71 ionosonde in the March issue), through primarily research instruments which were not developed with eventual sales in mind (eg the first three in this issue), to free services or access to research data (eg the Alaska SAR Facility). Contributions to this department are welcome. These are not peer refereed so the author(s) must be in a position to bear some responsibility for the product or service described. Thus claims for products must be based on first-hand knowledge and authors must have authority to offer services. All products and services should be appropriate to radio science and use by readers should be attainable in principle (eg, though a joint research project) if these are not commercially available.

Richard L Dowden

Editor

Whitteker joins *The Radioscientist*



James Whitteker, whose article "Physical Optics and Terrain Diffraction" appears in this issue, has joined the *Radioscientist* editorial team as Associate Editor.

James H (Jim) Whitteker received the BSc degree from Carleton University, Ottawa, in 1962, and the PhD degree in physics from the University of British Columbia in 1967. He was a postdoctoral fellow at University College London in 1967-1969, working in atomic collisions. He has worked at the Communications Research Centre since 1969. For the first ten years, his work was on ionospheric physics, particularly the structure and dynamics of the polar topside ionosphere. Since 1980, he has worked on VHF and UHF terrestrial radio-wave propagation. He has put into practical application a computer program for predicting path loss at these frequencies, and compiled a topographic data base for use in these predictions. His particular interest is the use of physical-optics techniques for calculating diffraction attenuation due to terrain obstructions.

Fessenden and the Early History of Radio Science

John S Belrose

17 Tadoussac Drive, Aylmer, QC J9J 1G1, Québec, Canada

Many scientists and engineers have contributed to the development of electromagnetic theory, the invention of wireless signalling by radio and the development of electromagnetic antennas needed to transmit and receive the signals.

Concerning the history of wireless communications, several names stand out above the others. The very possibility of wireless communications is founded on the researches of Clerk-Maxwell into the mathematics of electro-magnetism, researches so "pure" and abstruse that it took mathematicians several years to appreciate their significance.

Today Maxwell's equations form the basis of computational electromagnetics. In the experimental verification of the results foretold by Maxwell's theory, use was made of the results of experiments in pure physics which Lord Kelvin had made forty years previously. Kelvin had set himself the task of investigating the way in which a Leyden Jar discharged, and found that, under certain conditions, the discharge gave rise to alternating currents of very high frequency.

At the Brant Rock transmitter

Forty years later, Hertz was able to utilise these high frequency currents to produce the first wireless waves, thus validating the theory of Maxwell.

Marconi was the first to describe and the first to achieve the transmission of definite intelligible signals by means of Hertzian waves. History has accredited him with the invention of an early form of radio telegraphy. His contributions to the history of radio communications are well known, and celebrated; but other experimenters took a hand, very early.

Do you know:

(1) Who first used the word and the method of continuous waves?

(2) Who was first to transmit voice over radio?

(3) Who devised a detector for continuous waves?

(4) Who first used the method, and the word heterodyne?

(5) Who was first to send two-way wireless telegraphy messages across the Atlantic ocean?

(6) Who was first to send wireless telephony (voice) across the Atlantic ocean?

(7) Who made the world's first wireless broadcast (voice and music)?

The answer to all seven questions is Reginald Aubrey Fessenden, a Canadian-born radio pioneer, working in the United States. Fessenden must clearly be the pioneer of radio communications as we know it today. I wonder how many of you have heard of him?

It is perhaps appropriate that an Alexander Graham Bell Lecture should remember the contributions of Prof Fessenden to the early history of radio science, since the work of Bell had a profound influence on his life. Bell developed a method of sending words over wires (the telephone). The idea of transmitting the human voice by wireless dominated the early radio experiments of Fessenden.

Reggie, during his boyhood in Fergus, Ontario, followed the work of Alex Bell in nearby Brantford with great fascination. But his inquisitive mind was well ahead of Bell's experiments.

The year was 1876, Reggie was 10 years old. His Uncle Cortez Fessenden, who played an important role in the development of Reggie's inquiring mind, had been invited to see a demonstration of the telephone at the Bell homestead on 4th August. Bell's first long distance call, between Brantford and Paris, via Toronto, a distance of 113 kilometres, was made a few days later on the 10 August 1876. [1]

Reggie could hardly wait to meet his uncle after the demonstration to find out how it worked. In a conversation with his Uncle Cortez on the following day, which took place during a thunderstorm, Reggie was seeking an understanding about the transmission of sound over wires (the telephone).

"Uncle, how far do you think the roar of thunder can be heard? And have you noticed it comes booming down without a single wire to help it?"

"The thunder doesn't need a wire because it travels to us on a sound wave; with lightning it is an electric wave."

[This is a modified version of the 15th Annual Alexander Graham Bell Lecture, 12 November 1992, organised by the Communications Research Laboratory, McMaster University, Ontario, which was published in Proceedings of the Radio Society of America *November 1993]*

"Then why doesn't Bell shout on a wave?"

"He does. Bell gets his electric waves from a storage battery and those waves shuttle back and forth on the wire thus carrying his voice."

"But why is the wave on the wire. It strikes me that those wires are a crazy nuisance, the thunder doesn't need a wire, so why does Bell need one?"

"Heaven knows what direction his words would take without something to guide them," his uncle replied. "Is it not plain to you, lad, that the thunder is only a sound wave? Why, it wouldn't travel any distance at all unless you loaded the whack on a wave of electricity."

Cortez was not entirely satisfied with his answers to "Why a wire?" Being a good physics teacher, he was up on mathematics, and it appeared to him that there should be some way of using mathematics to explain the working of electricity and words and wires, but he had to admit to himself that it was simply beyond his ken.

"Words without wires," Uncle Cortez mused to himself. "I have never heard of such a nonsensical thing." But his Uncle Cortez and the world would, when Reggie grew up.

Years later, in 1897, Reginald, now 31 years old, was again having a discussion with his uncle. "Look," he said. He threw a rock into Chemung Lake, near Peterborough, Ontario.

"See how the waves circle out where the rock hit? If they are going to carry the whole range of voice sounds, the Hertzian waves must radiate like that from the antenna at the transmitting end, and they must keep going in a steady stream until they encircle the antenna at the receiving station. They must never let up even for a split second."

"I see," said his uncle. "In Marconi's scheme, they stop and go, stop and go."

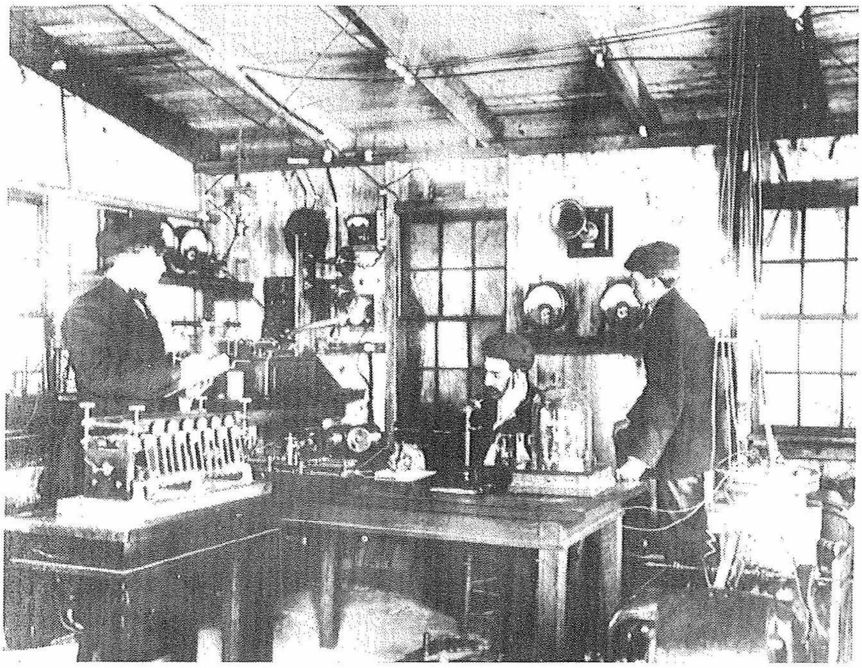
Suddenly, after minutes of silence, Reg said, "Continuous. That's the word that describes them, 'Continuous Waves'." [paraphrased from *Raby*, 4]

And so our present continuous wave approach to radio communications was born. But generating CW, modulating the waves, and receiving them was yet to be accomplished.

Pre-radio science career

Reginald Fessenden may well be the greatest Canadian-born scientist, inventor and engineer. As a scientist he should be considered the intellect, peer of Lord Rutherford, Sir J J Thompson and Lord Kelvin. Oliver Heaviside and, particularly, A E Kennelly (co-discoverers of the Kennelly-Heaviside ionospheric layer) were his contemporary colleagues.

As an inventor, he held some 230 patents. As an engineer, he did not confine his expertise to one discipline but worked with equal facility in the chemical, electrical, radio, metallurgical and mechanical fields. Yet in spite of his brilliance, the number, and the continuing usefulness of his contributions, he is now virtually forgotten, except by a few. [2, 3, 4, 5, 6, 7, 8] In *Susskind's* [9] comprehensive review of the early history of electronics and wireless, no mention was made of him.



Inside the Brant Rock Radio Shack: Operators in transmitting position.

Reginald Aubrey Fessenden was born in Knowlton, Brome County, Canada East (now Québec) on 6. October, 1866. The family resided at East Bolton (now Austin) at that time. In 1871 the family moved to Fergus, Ontario, and in 1875 to Niagara Falls, Ontario.

Educationally, the young Fessenden was a prodigy. He attended De Veaux Military Academy, Niagara Falls, New York, for one year at the age of nine. He went to Trinity College School, Port Hope, Ontario, where he won prizes and the praise of the headmaster as one of the best students that he had ever had. At the age of 16, he accepted a mathematics mastership at Bishop's College, Lennoxville, Québec, where he became interested in science through private reading of the periodicals *Nature* and *Scientific American*.

The Brant Rock staff and operators. Fessenden is seated in the middle and to his right is his son (Reginald Kennelly), holding Mikums, his cat. Mr Pannill is on the far left. Standing next to him is Jessie Bent, the secretary. Mr Stein is on the far right.

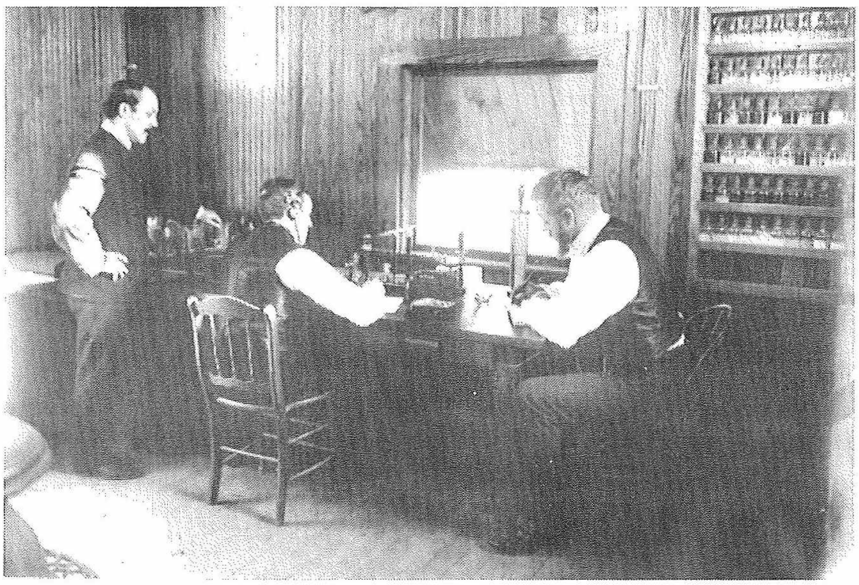
In 1886, he accepted the principalship of Whitney Institute, Bermuda. Although he never lived in Canada again, he considered himself a Canadian, and he spent vacations at his uncle's cottage near Peterborough, Ontario.

Fessenden worked at Thomas Edison's laboratory, East Orange, New Jersey, from 1887-1890. When Edison gave him the task of producing a non-flammable insulation for electrical wires, Fessenden set out to learn all he could about elasticity. The recognised authorities on the subject were Sutherland and Lord Kelvin, who held the view that both elasticity and cohesion were due to a gravitational attraction between the atoms. Fessenden was sceptical, and began a research study for a better explanation. Using mathematics as a basis for his study, Fessenden concluded that atoms had to be spherical in shape, with a positive charge at their centres and a negative charge on their surfaces. He considered atoms as electrostatic doublets.

In a series of technical notes Fessenden proposed his electrostatic doublet theory of cohesion, and used it to calculate the physical and electrical properties of metals, reportedly showing that the cohesion, rigidity and Young's modulus came out right. [*Squires*, 10; *Vosper*, 11] His paper entitled "The Law and Nature of Cohesion," published in 1892, was deemed preposterous by contemporary scientists, including Sir J J Thompson, Cavendish Laboratory, Cambridge, on the grounds that since metals were conductors, the individual atoms must also be conductors and could not contain internal charges! Ironically it was Sir J J Thompson who, five years later, demonstrated that atoms were electromagnetically constituted.

In 1890, Edison encountered financial difficulties, and Fessenden was laid off. He went to work for Westinghouse. Here he tackled different problems. The method of using platinum connecting wires for an electric lamp made light bulbs expensive, and was covered by a patent. Fessenden found ways of fusing wires of iron or nickel alloys to the glass, greatly reducing the price. This breakthrough was a significant early step in the transition of electric light from a novelty to an everyday necessity.

He later developed silicon steel. Early transformers and electric motors were lossy due to hysteresis loss in the iron cores of the transformer and iron pole pieces in motors. Fessenden reasoned that replacement of the large carbon atoms in the steel by smaller silicon atoms would reduce the hysteresis loss, and in almost a century, no better method has been found than his silicon steel.



Inside Brant Rock: Fessenden is seated at right

In 1892, he accepted the chair of electrical engineering at Purdue University, and although he stayed there for only one year, he was responsible for establishing the Electrical Engineering Department at the university, and his influence is perhaps still felt today. [*Geddes*, 2]

In 1893, the University of Pittsburgh persuaded him to accept the same chair in that city, largely because George Westinghouse was anxious to have Fessenden nearby and helped with a substantial honorarium.

In 1899, Fessenden attempted to return to Canada, but McGill returned his application for the chair of electrical engineering. The position was filled by a "professor" from Nebraska.

Fessenden never did graduate formally from a university, but because of the positions he held with Purdue University and the University of Pittsburgh he was hereafter referred to as Professor Fessenden. One can only speculate what might have happened if he had worked at McGill with Rutherford and Soddy.

Fessenden's inventive mind was already in evidence. By 1901, he already held nine patents with respect to incandescent lamps. His hobby of photography led him to the invention of what he called microphotography, an early form of microfilm. He also began experimenting with radio waves, and it is in the field of radio science that Fessenden made his greatest contributions.

Wireless telegraphy

Fessenden closely followed the work and research methodology of Heinrich Hertz, Thomas Edison and Alexander Graham Bell.

In 1900, he joined the US Weather Bureau, which sought a system for transmitting weather forecasts. Unfortunately, he soon fell out with his superior at the bureau and resigned in August 1902.

In September, he secured the financial support of two Pittsburgh millionaires, T H Given and Hay Walker; and together they formed the National Electric Signalling Company (NESCO). While the partnership eventually collapsed (in 1912), Fessenden's greatest achievements occurred under its aegis.

It is interesting to note that Fessenden, in 1905, established the Fessenden Wireless Telegraph Company of Canada. Unfortunately, this venture never went anywhere. The Canadian Company never received support from his American partners. It acquired a transatlantic license from the British government, but not from Canada. Only Marconi was licensed to erect towers in Canada and install radio equipment in Canada — a senseless government regularity ruling that held back the competitive development of radio in Canada for more than two decades.

Marconi, for his transatlantic experiment in December 1901, employed a Braun type of antenna system, see below, and a spark transmitter designed and constructed by Fleming.

Marconi knew very little about his transmitter. It is interesting to speculate on whether Marconi drew the hand-drawn sketch of "his" transmitter, labelled Marconi's transmitter, published in a 50th anniversary publication of the IEEE on the early history of wireless. This "transmitter" simply would not work.

Ratcliffe [13] has discussed scientists' reaction to Marconi's transatlantic experiment. The author has also pursued this subject. He modelled Marconi's Poldhu antenna system to determine its frequency of oscillation. But that is another story.

The technology of the era as exemplified by Marconi systems was based on the generation of radio waves by creating a spark, which can be likened to a whiplash effect. Let us digress for the moment and speak about spark transmitters.

Spark transmitters

The simplest method of producing high-frequency oscillations is to give an electrical shock [*] to an oscillatory circuit consisting of an inductance and a capacitance in series. (See Figure 1a.) This principle is used in the so-called spark transmitter.

Hertz's transmitter, in 1888, placed the spark gap across the terminals of the antenna, which was an endloaded dipole. (See Figure 1b.) The equivalent circuit of an antenna at frequencies near its self-resonant frequency is a series-

[The capacitor is charged to a high voltage by (say) a Winshurst machine. Eventually the spark gap breaks down and the resulting spark acts as a closed switch to complete the L-C oscillatory circuit. —Ed]*

Oscillation (Tank) and Antenna Circuitry

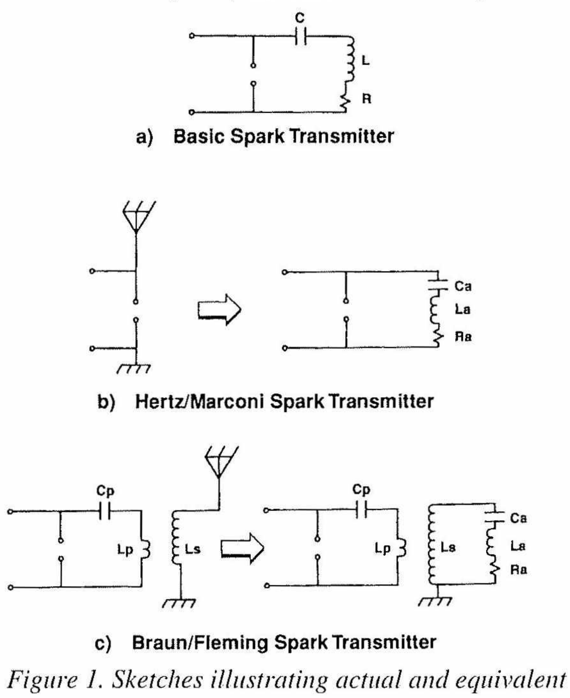


Figure 1. Sketches illustrating actual and equivalent circuits for spark transmitters.

resonant circuit (L_a - C_a - R_a)

Marconi, following the lead of Hertz, employed such a spark transmitter, but his antenna was a monopole type, a wire fed against ground. Since the only conducting path for the transmitting antenna to ground was by way of a spark across the gap, the oscillations on the antenna were in very short bursts. (See Figure 3a.)

The natural L-C-R response of the antenna system was interrupted when the spark discharge ceased. The only connection to ground was through the low impedance of the spark discharge. But this gap was considered to be an essential element of the radiating system. Indeed, some contemporary mathematicians concluded on the basis of their "theoretical" studies that no antenna could radiate without a gap!

This not-wanted gap was eliminated by Braun, a German physicist, who in 1898 patented a circuit in which the spark gap was in a separate primary circuit in series with an appropriate coil and condenser.

But the contribution of the Braun patent is perhaps as controversial as is the subject of who was the first to devise electromagnetic antennas. The German patent has been questioned. Nothing original was said about tuning, and the oscillating circuit was said to be much "slower," tuned to a lower frequency, than the antenna circuit.

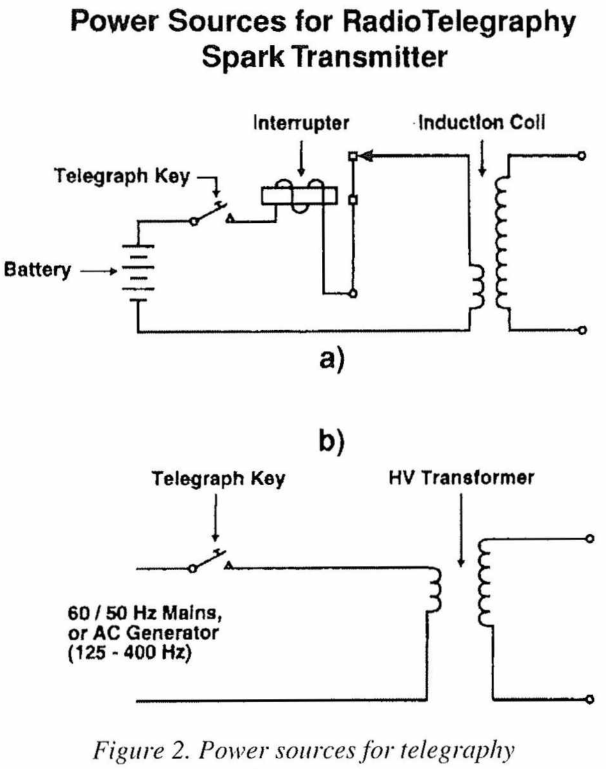


Figure 2. Power sources for telegraphy spark transmitters.

If the coupling between the oscillating and antenna circuits is high, a double peaked amplitude frequency response will result, and while such a response is not wanted, both circuits should certainly be tuned to the same frequency. I say "not wanted," because this double-hump response in effect made the transmitter transmit a "double wave."

In fact, early radio regulations were introduced encouraging "single-wave" or "sharp" emissions, by limiting the amplitude of the second wave to say one-tenth the amplitude of the stronger, desired wave. Notwithstanding, Braun's "tank circuit" was coupled inductively to a secondary consisting of the antenna in series with a coupling coil in which the driving electromotive force was induced and which provided a continuous conducting path from the antenna to ground. Except for the later insertion of a transmission line between the antenna and the coupling coil, the Braun antenna arrangement provided the complete electrical equivalent of the present-day base-driven monopole antenna.

A Braun-type spark transmitter was a considerable improvement over the "simple" or "Marconi type transmitter." It consisted of a condenser and an inductor in series with a spark gap, across which is connected an induction coil. (See Figure 1c.)

The induction coil had a low-voltage primary winding and a high-voltage secondary winding (See Figure 2a).

The low-voltage primary winding was driven by a battery and an interrupter, which made and broke the connection of the primary winding to the battery at some low audio

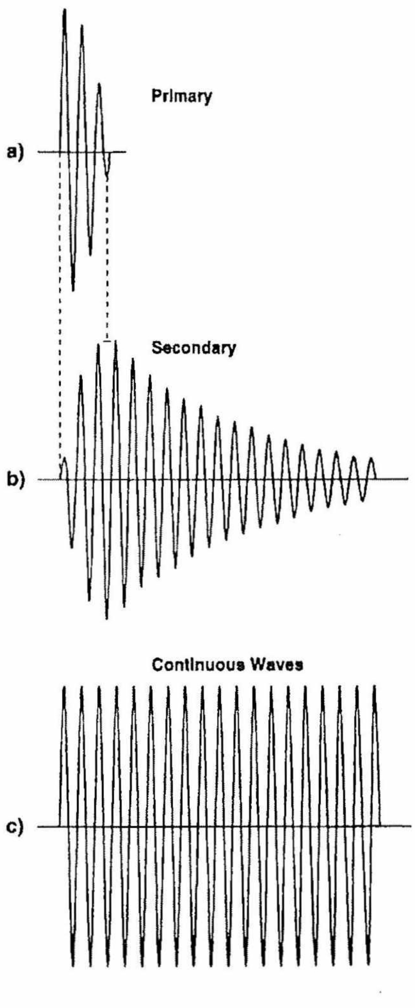


Figure 3. Idealised waveforms in the oscillation circuit (a) and the antenna circuit (b). Damped waves are much more noisy, broad, and capable of severe inter-station interference compared with (c) undamped or continuous waves ("CW").

frequency rate.

When the induction coil was working properly the condenser was charged up, and when the potential across it was sufficiently high to break down the insulation of air in the gap, a spark then passed. Since this spark has a comparatively low resistance, the spark discharge was equivalent to closing of the oscillatory L-C-R circuit.

The condenser now discharged through the conducting spark, and the discharge current took the form of a damped oscillation, at a frequency determined by the resonant frequency of the spark transmitter. The RF energy flowing in the inductor was inductively coupled to an antenna, which was tuned to the same frequency as that of the spark transmitter.

The induced oscillation in the antenna circuit was also a damped wave, but the period of oscillation was significantly longer than the oscillation in the primary (See Figure 3b). In effect, the primary is the "tank circuit" and the secondary the "antenna circuit".

Marconi's early telegraphy experiments were made using such a spark transmitter. However, it was with the simple form of transmitter, spark gap across the antenna terminals, that he obtained his first successful results and demonstrated the possibility of wireless telegraphy by means of electromagnetic waves propagated over great distances.

The interrupter was a mechanical device, operating at rate corresponding to a low audio frequency. Thus, each time the key was pressed the receiver would "hear" a buzz (ignoring for the present that a suitable detector so that the operator could actually "hear" the sound of the transmitted signal had not been devised). The audio sound to be "heard" was the interrupter frequency accompanied by the ragged and irregular noise of the spark-generated signal.

Most early radio experimenters followed or improved upon the Marconi method of signalling, because in their view a spark was essential to wireless. But later experimenters employed an AC generator and a high-voltage step-up transformer, rather than an induction coil and battery, for the power source. (See Figure 2b)

Fessenden's work in radio was important, not only for the results he secured, but because of its originality. From the outset he sought methods to generate and receive continuous waves, not damped waves which started with a bang and then died away quickly. However, his early experiments had to make do with spark transmitters, the only means known at that time for generating appreciable power.

So he set his mind to make this type of transmitter more CW-like. This led to his development of the synchronous rotary spark-gap transmitter. An AC generator was used, which as well as providing the energy for the spark transmitter, was directly coupled to a rotary spark-gap so that sparks occurred at precise points on the input wave. The spark was between a fixed terminal on the stator and a terminal on the rotor, in effect the rotor was a spoked wheel, rotating in synchronism with the AC generator (See Photo 1).

Thus, a higher spark rate was achieved, high compared with the frequency of the AC generator. But another advantage was realised, since in effect a rotary spark gap was a kind of mechanically quenched spark gap transmitter.

The oscillations of the primary circuit ceased after a few cycles, since when the rotating gap opened the spark ceased, and the antenna circuit continued to oscillate with its own damping. The quenched spark gap was more efficient, probably a less noisy, narrower-band signal compared with the unquenched gap, since any of the spark methods of excitation inherently involve consumption of energy in the spark, in addition to the energy losses occurring in the antenna circuit.

Many forms of quenched spark gap transmitters were devised, described as Wein transmitters, but the Fessenden synchronous rotary spark-gap transmitter was perhaps the best. With a synchronous spark-gap phased to fire on both positive and negative peaks of a 3-phase waveform, precisely on the peak for maximum efficiency, a 125 Hz AC generator would produce a spark rate of 750 times a second. These rotating gaps produced clear almost musical signals, very distinctive and easily distinguished from any signal at

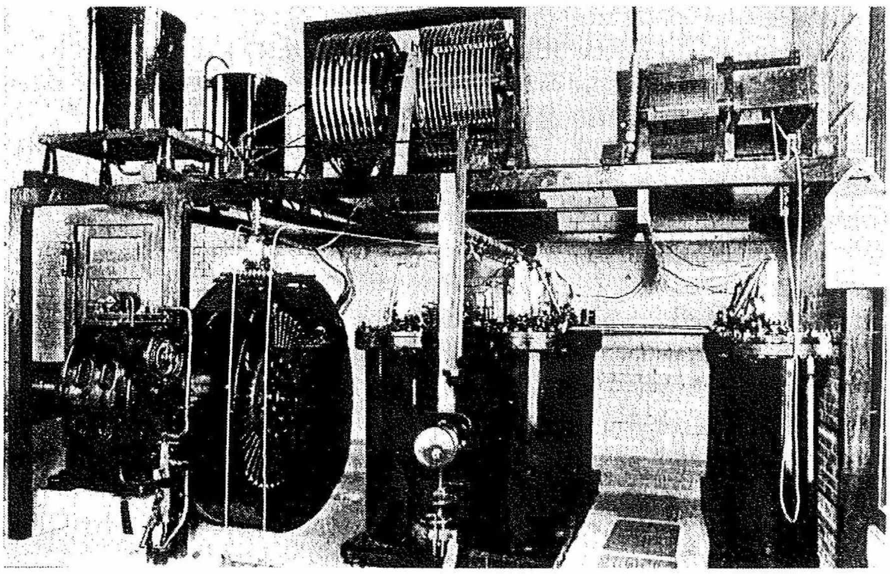


Photo 1. An early version of Fessenden's synchronous rotary spark gap transmitter.

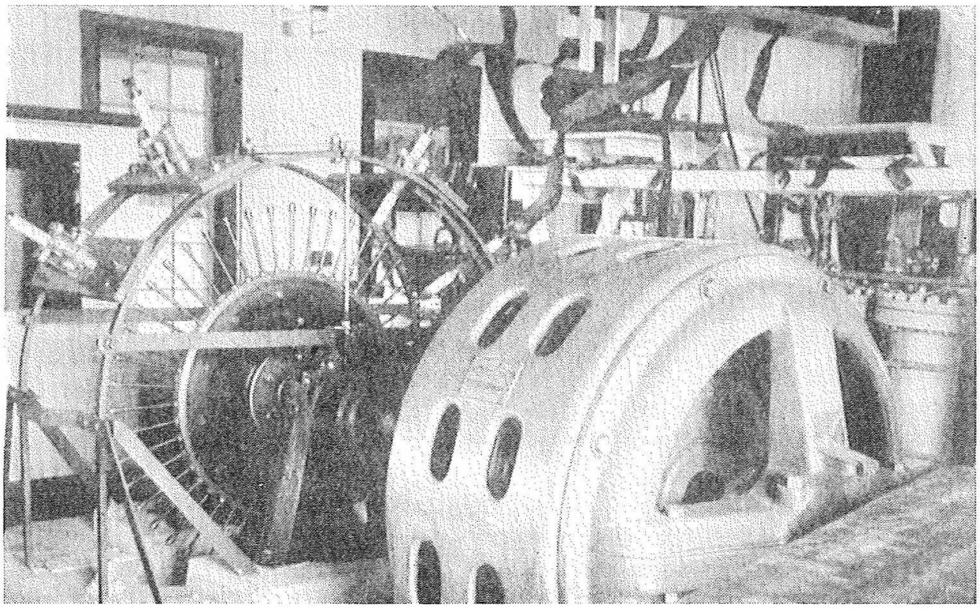


Photo 2. The Brant Rock synchronous rotary spark gap transmitter.

the time. It was not true CW, but it came as close as possible to that, and the musical tone was easily read through atmospheric noise and interference from other transmitters. (See Appendix A)

His Brant Rock station employed a synchronous rotary spark gap transmitter, the largest one built to date (See Photo 2). It was completed on 28th December 1905. The rotary gap measured 6 feet in diameter at the stator and 5 feet in diameter at the rotor. Its rotor had 50 electrodes (poles), and its stator had four. Coupled to this rotary gap was a 125 Hz, 3-phase, 35 kVA alternator.

HF alternator for CW

Spectacular as was the Brant Rock transmitter, Fessenden, after achieving initial success (to be described) soon turned his attention to other directions, devoting his efforts to newer and better developments: the HF alternator.[*]

Fessenden realised, as we have already noted above, that this stop-and-go system, the spark transmitter, was incapable of transmitting satisfactorily voice and music. A means of sending and receiving continuous waves was required.

The idea came to him during discussions with his uncle Cortez Fessenden, as I have already told you, while visiting with him at his cottage on Chemong Lake near Peterborough in 1897, and is described in his US Patent No 706 737, dated August 12, 1902.

But it was not before the fall of 1906, when Fessenden's HF alternator was developed to a point where it could be used practically (frequencies up to 100 kHz were possible), that continuous-wave transmission became feasible.

Marconi and others working in this new field of wireless ridiculed Fessenden's suggestion that a wireless signal could be produced by applying an HF alternating current to an antenna. All were unanimous in their view that a spark was essential to wireless, an error in reasoning that delayed the development of radio by a decade.

Fessenden was right, but alone in his belief. "The whip-lash theory however passed gradually from the minds of men and was replaced by the continuous wave one with all too little credit to the man who had been right." [*New York Herald Tribune*, 14]

To document the reaction of his colleagues to this departure from conventional transmission methods, spark or damped wave transmissions, we can note that J A Fleming in his book *Electromagnetic Waves*, published in 1906, said, in reference to Patent No 706 737, that "there was no HF alternator of the kind described by Fessenden, and it is doubtful if any appreciable radiation would result if such a machine were available and were used as Fessenden proposes."

Fleming was totally wrong, since 1906, the year in which his book was published, was the year of Fessenden's greatest achievements using continuous waves generated by an HF alternator, with one terminal of the alternator connected to ground and the other terminal to the tuned antenna. Certainly, the referenced statement did not appear in subsequent editions of Fleming's book.

Judge Mayer, in his opinion upholding Fessenden's patent on this invention, said, "in effect it has been established that the prior art practiced, spark or damped wave transmission, from which Fessenden departed and introduced a new or continuous-wave transmission, for the practice of which he provided a suitable mechanism — which has since come into extensive use." [*Kintner*, 15]

Initially, Fessenden employed various forms of arc transmitters and rotating spark gap transmitters with varying degrees of success. When he had perfected his HF alternator in 1906, Fessenden had achieved his goal, viz a continuous wave transmitter, the frequency of which was not determined by

["HF" (High Frequency) refers not to the decade 3 MHz-30 MHz but to frequencies above only a few kilohertz. Thus "HF" was initially only VLF in today's parlance. —Ed]*

aerial tuning but by the speed of the HF alternator. The aerial tuning only determined the power transfer from his transmitter to the aerial. Subsequently, the HF alternator was replaced by vacuum-tube transmitters, and nowadays by solid-state transmitters, but the basic principle of operation of the Fessenden transmitter is the same as that today.

As early as 1890, Tesla built high-frequency alternating current (AC) generators. One, which had 384 poles, produced a 10 kHz output. He later produced frequencies as high as 20 kHz. [*Quinby*, 16] There is no fundamental reason that such frequencies could not have been used for worldwide wireless communications; in fact, in 1919, the first continuously reliable transatlantic radio service, with a transmitter installed in Brunswick, New Jersey, used a 200 kW HF alternator operating at a frequency of 21.8 kHz. However, practical antennas used in the early days of radio were not large enough to radiate efficiently at such a low frequency, so LF rather than VLF had to used. [For a description of the New Brunswick antenna, see *Watt*, 17]

Fessenden contracted the GE Company to build an HF alternator operating at speeds of 50-100 kHz. Alexanderson struggled for two years to develop such a machine, and in September 1906, GE delivered his best effort — which in Fessenden's view was a "useless machine."

The *Alexanderson alternator* did not meet Fessenden's specifications. The GE alternator was returned with a letter stating that in the opinion of its engineers it "could never be made to operate above 10,000 cycles" [21]. It is not clear what had been improved over the Tesla alternator.

So Fessenden took upon himself to rebuild the machine. He must have persevered, day and night, in the usual way he attacked a problem, since by November 1906, he had a machine that would operate at frequencies in the 50-90 kHz band.

The Fessenden high frequency alternator was a small machine of the Mordey type, having a fixed armature in the form of a thin disc, or ring, and a revolving field magnet with 360 teeth, or projections (see below). At a speed of 139 revolutions per second, an alternating current of 50,000 Hz and a terminal EMF of 65 volts was generated. The maximum output of the alternator at the above speed was about 300 watts [*Ruhmer* (20)].

Very little difficulty seems to have been obtained in running the machine at so high a speed. A simple flat belt drive was used, powered by the steam engine at Brant Rock, and a thin self-centring shaft which entirely eliminated excessive vibration and pressure on the bearing. (See Photo 3). The belt and the step-up gear box can be seen on the far right of the photograph, the alternator is on the left. The frequency of the alternator was determined by the speed of the steam engine, which had to be well regulated.

Fessenden later developed a high frequency alternator that had an output of 50 kW. This machine was scaled up to 200 kW by the GE company, and put on the market as the *Alexanderson alternator*, named after the man who supervised the job. History forgot that Fessenden developed the prototype.

Zennick [22] has detailed the early efforts to develop this high frequency alternator, and described the principle of its operation. Figure 4 is from Zennick's book. Figure 4a is a diagrammatic cross-section of one of these alternators. The excitation is obtained by means of a single large field coil, S, which is wound around the entire machine and supplied with direct current. The magnetic flux lines, M, of this coil pass

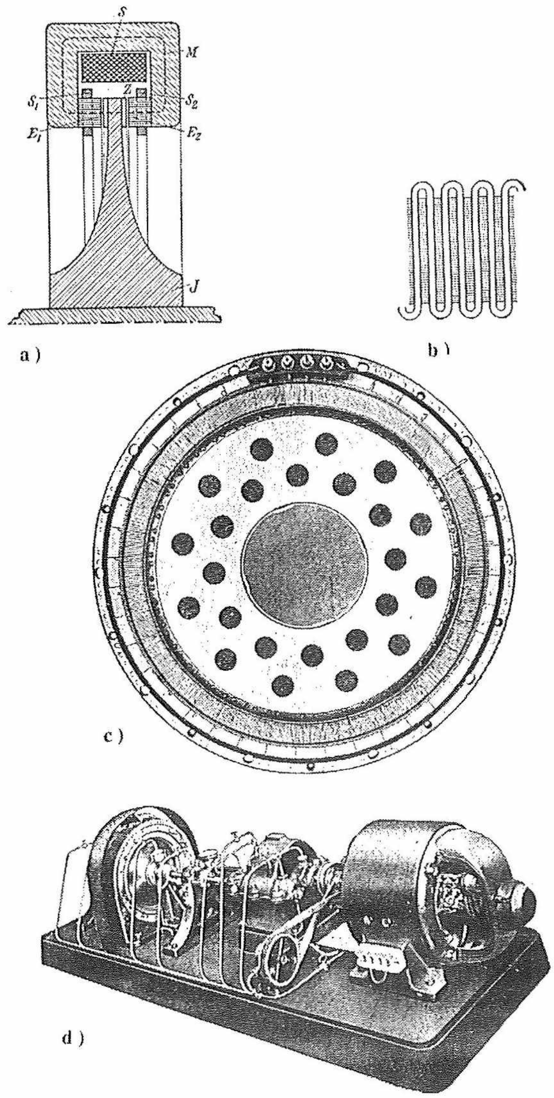


Figure 4. The Fessenden-Alexanderson HF alternator: (a) diagrammatic cross-section of one of these alternators; (b) the armature winding in which the EMF was induced; and (c) one half of the completed armature. [after Zennick, 21]

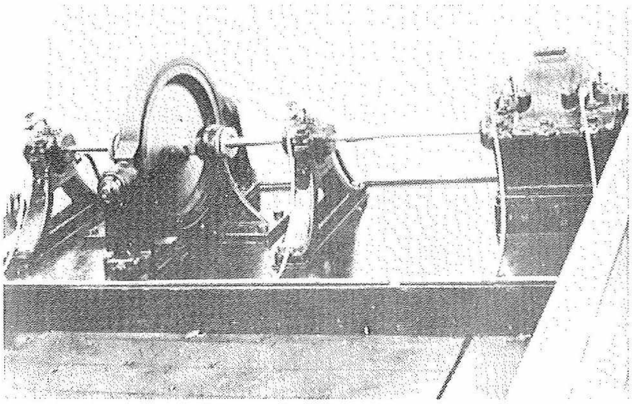


Photo 3: Fessenden's HF alternator

through the iron cores, E1 and E2, of the armature coils, S1 and S2. The only moveable part, J, has teeth or projections, Z, of iron, at its periphery. When one of these teeth is just between the armature coils, S1 and S2, the magnetic flux, M, has a path almost entirely through iron, excepting for the very small air gaps between the teeth, Z, and the cores, E1 and E2. In this position then, the magnetic reluctance is a minimum, and the magnetic flux passing through cores E1 and E2 a maximum.

When now a space instead of a tooth lies between the armature coils, the air gap, and hence the reluctance are much larger, so the amount of flux through the armature windings is very small. Hence as the moveable part J rotates, the magnetic flux varies periodically between a maximum and a minimum value, so an oscillatory emf is generated, whose frequency = the product of speed in revolution/second x number of teeth, is induced in the armature windings. The rotor of the Fessenden-Alexanderson machine is shaped like the cross-section J, in Figure 4a. The rotor of the machine shown in Figure 4d with its DC motor had 300 teeth. The space between the teeth was filled with non-magnetic material (phosphor-bronze) so the surface of the rotor, J, was quite smooth, thereby preventing any loss due to air friction (windage). The armature windings S1 and S2, in which the oscillatory emf was induced did not properly consist of coils, but a single wire wound in a wave shape form. (See Figure 4b).

Any two consecutive U-formed wires could be considered as a pair of coils of one turn each, joined in series but so as to oppose each other. Figure 4c shows one half of the completed armature.

One of these early machines is shown in Figure 4d. Here the drive is an electric motor. The photograph shows three main parts to the whole set up, from right to left, the electric motor, a step up gear box (which Fessenden refers to as a de Laval gear in connection with his alternators) and the alternator on the far left. Clearly the alternator shaft and the motor shaft are not in the same line, the difference being taken up by the gear box. The small object in front (and driven by a flat belt) is an oil pump to ensure lubrication of all high speed bearings. The capacity of the alternator increases as the air gap between armature and rotor is decreased. It was 2.1 kW in one machine having an air gap of 0.37 mm

Receiving continuous waves

The use of CW created problems for Fessenden, not only in regard to the generation of continuous waves but for reception. First, at a distant station where the received signal was weak, and if it were receivable at all, one had to find and tune the receiver to this narrowband signal in the expanse of unused radio spectrum. The broadband spark signal was more easily found. Second, the coherer-type detector used for reception of spark transmission was useless for detecting CW. Fessenden was convinced that the successful detector for wireless signals must be constantly receptive, instead of requiring resetting as was characteristic of the coherer. But this was more easily said than done. He first devised a hot-wire barretter, similar in nature to a miniature lamp of which the filament was made of Wollaston wire. From it he produced, as a result of an accident during the process of making his hotwire barretter, a liquid barretter.

The hot-wire barretter needed to have the silver coating removed from a very short length of the wire by a nitric-acid treatment. It was during such treatment that Fessenden observed that one of several such barretters, in this silver-dissolving part of the process, was giving indications on a meter attached to the circuit of signals received from an automatic test sender sending "D"s.

An examination revealed that this one had a broken filament, while the others were complete. A brief investigation disclosed the fact that this Wollaston wire dipping into the 20% nitric-acid solution was far more sensitive and reliable than any other known type.

The word *barretter* was coined by Fessenden from his classical language background. The term is a derivation from the French word *exchanger*, implying the change from AC to DC. For proper operation, the platinum-coated Wollaston wire needed to make point contact, lightly touching the acid solution (refer US Patent No 727 331, 5 May 1903 for the basic detector; and No 793 684, December 1904 for a sealed detector for shipboard use).

This detector was the standard of sensitivity for many years, until it was replaced by the galena crystal detector, and by the vacuum tube in about 1913. This detector, when used with a telephone receiver in a local shunt circuit, gave such accurate reproductions that radio operators could identify several wireless telegraphy stations in the passband of the receiver by the different characteristics of the spark transmissions, just as a friend's voice is recognised by its peculiarities of tonal quality. And it made possible subsequently the reception of radio telephony (voice).

It is interesting to read a paper by Leslie A *Geddes*, Purdue University, entitled "The Rectification Properties of an Electrode-Electrolyte Interface Operated at High Sinusoidal Current Density" [18] for a modern analysis of the Fessenden barretter type of detector. The authors became aware of Fessenden's pioneering work only after acceptance of their paper by the Journal. (See Addendum to the referenced paper).

Fessenden's telegraphy transmissions employed a synchronous rotary spark-gap transmitter, which was in effect a modulated quasi-CW method of signaling, well suited to detection by rectification. But this rectifier-detector was useless for the reception of unmodulated continuous waves. All that would be heard would be clicks, as the Morse key was closed and opened.

Again Fessenden's fertile mind worked around this problem. He devised the methodology of combining two frequencies to derive their sum and difference frequencies, and coined the word heterodyne, derived from the joining of two Greek words hetero, meaning difference, with dyne, meaning force. Today, heterodyning is fundamental to the technology of radio communications. Some radio historians consider that his heterodyne principle is Fessenden's greatest contribution to radio science. His initial heterodyne circuit is described in US Pat No 706 740, dated 12 August 1902 and his advanced heterodyne circuit, Pat No 1 050 441 and 1 050 728, is dated 14 January 1913.

Armstrong's super-heterodyne receiver is based on the heterodyne principle. Except for method improvement, Armstrong's superheterodyne receiver remains the standard radio receiving method today.

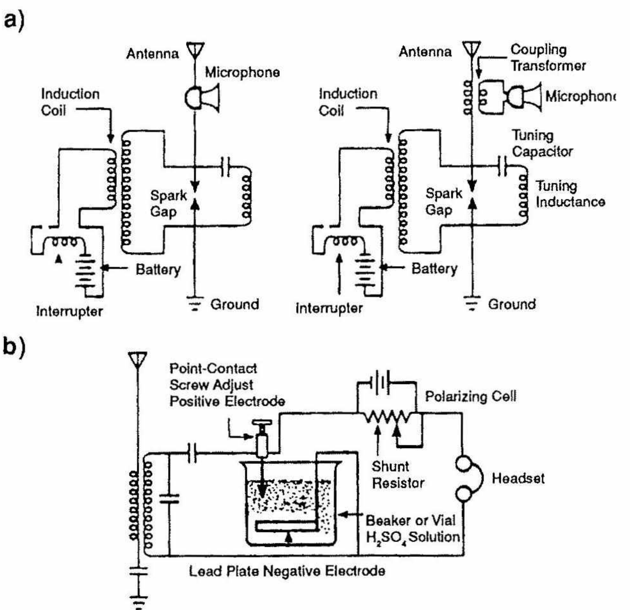


Figure 5. Two early versions of Fessenden's spark gap telephony transmitter (a) and receiver (b), which employed an electrolytic rectifier (needle point in a beaker of sulfuric acid] [after Geddes, 7, from a sketch courtesy George Elliott].

Spark telephony

Fessenden's one desire was to transmit voice without wires. In 1899, while experimenting with spark transmission employing a Wehnelt interrupter operating the Ruhmkorff induction coils, Fessenden noted that, when the telegraphy key was held down for a long dash, the peculiar wailing sound of the Wehnelt interrupter was reproduced with good clarity in the receiving telephone. This at once suggested that by using a spark rate above the voice band, wireless telephony could be achieved.

Professor Kintner, who was working for Fessenden at that time, designed an interrupter to give 10,000 breaks a second, and this interrupter was built by Brashear, an optician. The interrupter was delivered in January or February 1900, but experiments were not conducted until the fall of that year. To modulate his transmitter, he inserted a carbon microphone directly in series with the antenna lead (See Figure 5). After many unsuccessful tries, transmission of speech over a distance of 1.5 km was finally achieved on 23 December 1900, between 15-metre masts located at Cobb Island, Maryland. (See Photo 4).

The received telephony transmission was reported to be perfectly intelligible, but the speech was accompanied by an extremely loud disagreeable noise due to the irregularity of the spark (See Appendix A). The first voice over radio was that of Reginald Aubrey Fessenden on 23 December 1900, and this is what he said:

"Hello", he undoubtedly shouted into his microphone, "one, two, three, four. Is it snowing where you are, Mr. Thiessen? If it is, telegraph back and let me know."

Barely had he finished and put on the headphones, when he heard the crackle of the return telegraphy message. Intelligible speech by electromagnetic waves had been transmitted for the first time in the history of radio.

Continuous-Wave telephony

By the end of 1903, fairly satisfactory speech had been obtained by the arc method, but it was still accompanied by a disagreeable hissing noise. In 1904 and 1905, both the arc method and HF alternator method were employed (The alternator at this stage of development operated at a maximum frequency of 10 kHz). The transmission was however still not quite "perfect." [*Fessenden,* 19] In the fall of 1906, as we have already noted, the HF alternator had been brought to a practical shape. It could operate at speeds that produced frequencies as high as 100 kHz and was initially used for radiotelephony transmission from Brant Rock to Plymouth,

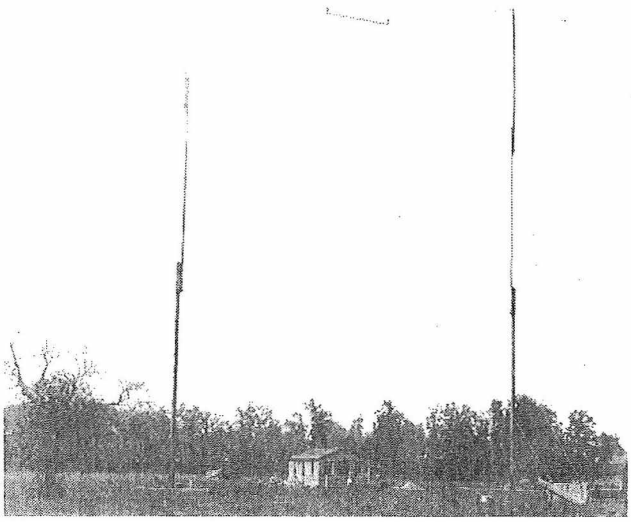


Photo 4. Twin radio towers at Cobb Island.

a distance of 17 km, and to a small fishing schooner. But the transmission distance extended far beyond this range (See below).

The method of modulation was in a like manner to that used for his telephony spark transmitter experiment, viz a carbon microphone in series with the antenna lead. The quality of the transmission was good, reported to be better than over wire lines at that time. [20]

Fessenden's communications successes

Fessenden's greatest radio communications successes happened in 1906. On 10 January, two-way transatlantic telegraphic communication was achieved — another first — between Brant Rock, Massachusetts, and Macrihanish, Scotland. James C Armor, Fessenden's chief assistant, was the operator at Macrihanish, and Fessenden himself was the operator at Brant Rock.

During January, February and on into March 1906, two-way telegraphy communication was established on a regular basis, exchanging messages about the workings of the machines, and each day improvements were made. Fessenden and his team had beaten Marconi [see Box] at transmitting telegraphy messages both ways accross the Atlantic. The frequency used was about 88 kHz.

Fessenden's sending apparatus consisted of a 40 horsepower steam engine driving a 35 kVA 125 cycle alternator, which in turn supplied current to transformers in which the voltage was raised to a value required to operate the spark. This was a rotating spark-gap driven from the generator and arranged to give sparks at predetermined points on the voltage wave.

These synchronous rotating spark gaps produced clear, almost musical signals, very distinctive and easily distinguished from any signal at the time. They were superior to other signals commonly used at the time which by compari-

Fessenden and Marconi

Marconi, who had succeeded in signalling, so he said, rather uncertainly across the Atlantic one-way on 12 December 1901 between Poldhu, Cornwall, and Signal Hill, Newfoundland, and on 15 December, 1902, between Glace Bay, Nova Scotia and Poldhu, Cornwall, had not yet succeeded in sending messages reliably over this distance even by one-way transmission.

Marconi, in this time period, was using frequencies about 10 times higher (820 kHz), which is the reason for his difficulty if not impossibility to receive the daytime signal radiated at the fundamental oscillation frequency of his antenna system.

Frequency trend as their work progressed is another contrast between Fessenden and Marconi. Marconi's initial experiments in 1885 were made at centimetre wavelengths. To achieve communications over greater and greater distances, Marconi built bigger and bigger antenna systems which resulted in a decrease of the antenna's fundamental oscillation frequency.

By 1904, his English antenna had become a pyramidal monopole with umbrella wires, and the frequency was 70 kHz.In 1905, his Canadian antenna was a capacitive structure with a very large top-hat, and the frequency was 82 kHz.

Fessenden, on the other hand, was attempting to move up in frequency. His initial experiments using HF alternators were made at VLF (10 kHz), since this was the upper frequency of the early machines. However he realised that for practical long-distance communications with realisable antennas he had to use higher frequencies (50-100 kHz), besides which he wanted to modulate his transmitter for telephony and therefore had to use frequencies well above voice band.

He knew [reference Patent No 706 737 filed 29 May 1901] that when the frequency of the alternator was very much less than the self-resonant frequency of the antenna system, that the principle fields would be electrostatic and magnetic (induction fields), which fall off as a high power of distance, and that the radiation field would be small. He knew that the "ether wave" had a wavelength that was greater than four times the monopole height. Clearly he had a good understanding of the fundamental principles of antennas and radiation.

son, were very rough and ragged.

Employing 420-foot umbrella top-loaded masts at each end of the link (See Photo 5), three different frequencies were employed in the communications between Brant Rock and Macrihanish. The results were carefully recorded and compared at various times of day and night and as a function of day of the month. (See, for example, the records for the month of January, 1906, in Figure 6) These records were perhaps the first field strength recordings ever made. Atmospheric conditions were also included in the records.

The encouraging results of these tests and the reaction of those listening in, far and wide, precipitated requests for Fessenden equipment. But Given and Walker refused to permit sales of the equipment, on the assumption that such sales would jeopardise their ultimate chances of selling the whole system in a package deal.

Then, at the height of excitement over the success in spanning the Atlantic with two-way communications, devastating news reached Brant Rock by cable. The Macrihanish tower had crashed to the ground in a winter storm on 5 December 1906. The station was never rebuilt.

New HF alternator

In November 1906, Fessenden and colleagues were conducting experimental transmissions using his newly-developed HF alternator between stations at Brant Rock and Plymouth, Massachusetts. The station at Brant Rock was modulated by a carbon microphone connected in series with the antenna lead.

About midnight, on an evening early in November, Mr Stein was telling the operator at Plymouth how to run the dynamo. His voice was heard by Mr Armor at the Macrihanish, Scotland station with such clarity that there was no doubt about the speaker, and the station log book confirmed the report.

Fessenden's greatest triumph was soon to come. On 24 December, 1906, Fessenden and his assistants presented the world's first radio broadcast. The transmission included a speech by Fessenden and selected music for Christmas. Fessenden played Handel's Largo on the violin. That first broadcast, from his transmitter at Brant Rock, MA, was heard by radio operators on board US Navy and United Fruit Company ships equipped with Fessenden's radio receivers at various distances over the South and North Atlantic, as far away as the West Indies. The wireless broadcast was repeated on New Year's Eve.

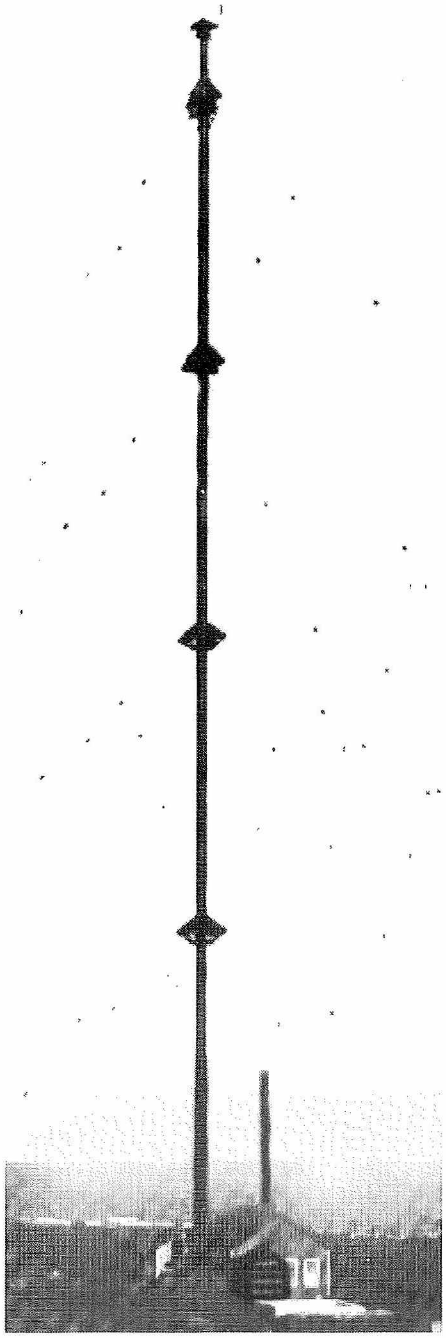


Photo 5. The Brant Rock, Massachusetts, tower, with the radio shack at the bottom. The tall pipe extending above the transmitter building is the smoke-stack for the steam engine, which was used (belt drive) to drive the AC generator for Fessenden's synchronous, rotary spark gap telegraphy transmitter and, later, his HF alternator for telegraphy and telephony.

The final days of King Spark

As CW systems were later developed (1905-1915), Marconi sought to use his spark expertise to achieve a semi-continuous timed spark that approximated to a continuous wave. In a sense this was the ultimate Marconi spark transmitter and was used as the international transmitter at Caernarfon, Wales, for a few years. It was noisy, and a Poulsen arc was held in standby.

Eventually, the Marconi spark transmitter was replaced by a General Electric Co (Alexanderson) HF alternator. The Fessenden-Marconi competing radio technologies battle was over. Fessenden had won. His CW technology was the way to the future.

The US Navy installed a high-power Fessenden rotary spark transmitter at Arlington, Virginia, in 1913, call sign NAA. This transmitter was subsequently replaced by an HF alternator, which was used for their VLF Fleet Broadcast at 33 kHz until the mid 1950s, but over the years the HF alternator was gradually replaced by vacuum tube transmitters, as are today's transmitters being replaced by solid state transmitters.

The three-element vacuum tube was well-known by 1915 to be capable of regeneration and oscillation. It could therefore generate CW. World War I spurred transmitting-tube development. The rise of CW followed in post-war years.

Radio amateurs contributed to the demise of spark. Using spark and CW superpower, commercial and government

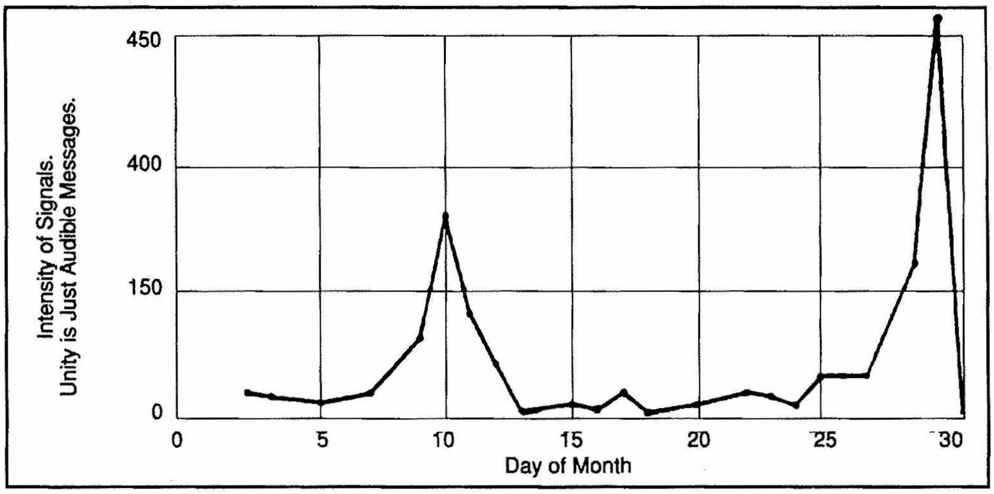


Figure 6. Curve showing variation of the intensity of transatlantic signals for the month of January 1906. Unity corresponds to a just audible message. Such a curve is certainly one of the first recordings of LF propagation data. [after Fessenden, 19]

stations were working intercontinental distances, yet, as 1921 began, no radio amateur signal from this side of the Atlantic had ever been reported heard in Europe.

The ARRL sponsored one-way transatlantic tests in December 1921, and sent Paul Godley, a well-known amateur and engineer, to England with the latest receiving apparatus. Godley set up a tent on a windswept Scottish beach and, using a Beverage wave antenna and frequencies near 200 metres, he copied nearly 30 American radio amateur signals.

CW stations outnumbered spark stations by almost two to one. CW had won the race. By 1924, spark was forbidden on the new 80, 40, 20, and 5-metre radio amateur bands.

Concluding remarks

Fessenden, a genius and mathematician, was the inventor of radio as we know it today. Marconi finally had to admit that Fessenden was right, when in 1914 the Marconi Company purchased a license to Fessenden's patents from the National Electric Signalling Company (NESCO), which later became the Radio Company of America (RCA).

Fessenden was at home in his laboratory, but out of his element when dealing with the business and political aspects of inventing. He never reaped until late in life any financial reward for his radio inventions, and was compelled to spend much time and energy in litigation.

Disagreement with his partners Given and Walker came to a head at the end of December 1910. While Fessenden was detained at a meeting in Pittsburgh, an attempt was made to shut down operations at Brant Rock and to remove his papers, but the quick-wittedness of his wife and the loyalty of most of his staff circumvented this manoeuvre, but only delayed his ouster from NESCO, which occurred on 8 January 1911.

Fessenden immediately launched litigation, first with NESCO and, subsequently, with GE, Westinghouse and, finally, with RCA, which was only settled fifteen years later when he received an out-of-court settlement for a half-million dollars from the Radio Corporation of America (RCA), which had long since acquired Fessenden's patents. The Queen's University Library Archives holds a Fessenden declaration to the IRS in Washington in which he certifies that he received $500,000, with $200,000 of this sum going to his lawyers.

He certainly never reaped the financial rewards that were due him for his radio inventions, but he had the satisfaction of being proven right. He was indeed the greatest wireless inventor of the age.

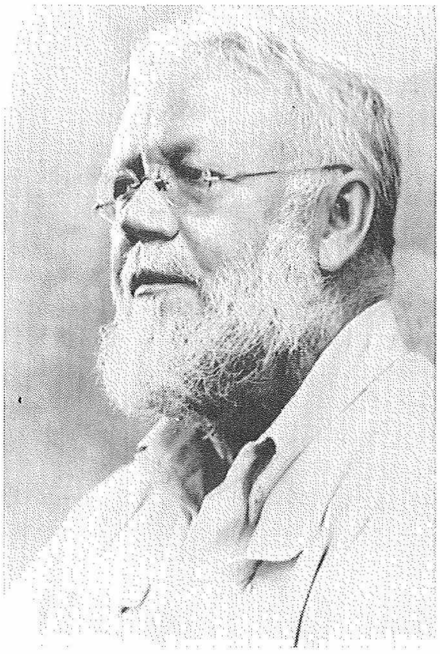
To conclude, let me continue briefly in the vein in which I began, viz Fessenden was an inventor who worked in many fields of science.

In addition to the inventions already mentioned, Fessenden gave us the radio pager (he called his device a beeper); he gave us sonar, which he demonstrated could detect icebergs, and his fathometer to measure the depth of water beneath the keel of a ship. He gave us turbo-electric drive to power ships; the first gyrocompass; the loop antenna; radio direction-finding; his pheroscope for submarines; a first TV receiver; ultrasonic methods for cleaning; electrical conduit; carbon tetrachloride; and tracer bullets.

Professor Fessenden was deeply disturbed by the sinking of the ocean liner Titanic on her maiden voyage to New York during the night of 14-15 April 1912. The vessel struck an iceberg just before midnight, and sank within two hours. He considered that the Titanic's iceberg avoidance procedure (clear air vision from the crow's-nest) to be very dangerous and that it should be replaced by a reliable system discovered by himself. Sonic frequency echo sounding could prevent a recurrence. He set his mind to perfecting this technology; later known as Sonar (Sound Navigation And Ranging).

The principle of such a sounder was to send a short-duration burst of sound (frequencies up to 20 kHz) from a transducer located about 3 metres below the surface of the water, of such power that it would travel as far as several kilometres through the water. When this wave came into contact with a solid object, such as an iceberg or the floor of the ocean, an echo was created. By measuring the time taken for the sound waves to travel out and the echo to return, it was possible to determine the distance to the object. During the period 1914 to 1925 Fessenden was granted over thirty patents for inventions using sonic frequencies. [Elliott, 22]

In September 1914, the USS Miami tested Fessenden's Submarine Electric Oscillator in the North Atlantic. Fessenden demonstrated that indeed he could get distinct echoes from icebergs, as far as 4 kilometres from a very large iceberg. The USS Alywin, in that same year conducting tests in the Boston Harbour, showed that Fessenden's sonic detection device could pick up the signals from a moving submarine from distances as great as 9 kilometres. In an associated test, the captain of one US submarine was able to direct the movements of another submarine several kilometres away by modulating the sonic signal by the Morse dot and dash method.


Prof R A Fessenden, 1866-1932

During US involvement in WWI years, 1917-1918, the USN fastened Fessenden's sonic listening device to the hulls of many troop carriers. By picking up the sounds of submerged submarines, the transports could often escape torpedo attacks. Submarines lying silent on the ocean floor could also be detected using his echo sounder.

In the 1920s, Fessenden's depth sounder or fathometer became a common instrument aboard vessels of all sizes from large passenger liners to small fishing boats. It was used on cable-laying vessels. Fessenden set to work to see if his echo sounder could be used as a geophysical tool to detect underground ore and oil deposits. This work led to his development of a new more efficient transducer, a piezoelectric sonar transducer. Not only was the device able to transfer more sound energy to conducting media, sea water or land, but the same device could be used for receiving. "Sound" frequencies as high as 60 kHz could be used.

His work involved with safety at sea won him the Scientific American Gold Medal in 1929. Other awards included the Medal of Honour of the Institute of Radio Engineers for his efforts in that field, and the John Scott Medal of the City of Philadelphia for his invention of continuous wave reception.

Reginald Aubrey Fessenden died in his house by the sea in Bermuda on 22 July, 1932. Burial was in St Mark's Church cemetery, and over the vault was erected a memorial with fluted columns. On the stone lintel across the top were inscribed the words:

His mind illuminated the past
And the future
And wrought greatly
For the Present

Beneath the scribed words, in the picture-writing of the ancient Egyptians was

I am yesterday and I know tomorrow.

His son summarised his greatest achievements in one sentence: "By his genius, distant lands converse and men sail unafraid upon the deep."

During his brief tenure as principalship of the Whitney Institute in Bermuda, Fessenden met his future wife, Helen May Trott, in 1885. They were married in 1890 in New York City.

Helen must certainly have provided support for her husband in his work, and she must have had a considerable knowledge about his accomplishments. After his death she wrote the book *Fessenden: Builder of Tomorrows* [22], and she must clearly have been responsible for seeing to the granting of seven patents after Fessenden's death. Helen Fessenden died in 1941, and established by her will a Fessenden-Trott Trust, administered by the Bank of Bermuda Limited, Hamilton, Bermuda. This trust, in memory of Professor Fessenden, provides funds for scholarships awarded annually to Canadian students, US students from Purdue and Pittsburgh Universities, and Bermudan students and family members studying at Canadian, UK or US universities

There are no direct descendants of Reginald from his side of the family, but the Fessenden family name is still maintained by descendants from other branches of the family. Fessenden's only son, Reginald Kennelly Fessenden, died in 1944 in a boating accident off the coast of Bermuda. The Trott name is still maintained by descendants living in Bermuda.

Most of Fessenden's inventions are taken for granted as a part of our everyday life, and few know, particularly the general public in his home country Canada, of the Canadian-born genius who provided the world with manifold benefits. History, through the effort of a few, will begin to remember Fessenden.

On 3. June, 1990, Brome County Historical Museum and Archives, Knowlton, Québec opened a small permanent exhibit and unveiled a plaque honouring Reginald Aubrey Fessenden and commemorating the 90th Anniversary of the first transmission of voice by radio on 23. December, 1900. The Wellington County Museum and Archives, Fergus, Ontario, has just recently mounted the first of a series of exhibits entitled "Marks of Distinction — Celebrating the Achievements and Skills of Wellington County Residents." This first exhibit, opened by the Minister of Communications Canada on 5. February 1993, focuses on the life and work of R A Fessenden.

The Department of Communications, in collaboration with the Department of Industry, Science and Technology and the Natural Sciences and Engineering Council of Canada, in recognition of the life and heritage of Prof Fessenden in the fields of radio sciences and communications, has just recently announced an undergraduate and postgraduate scholarship program to encourage students to continue with university studies in this field of science. The first of these scholarships will be awarded in the spring of 1993.

In the past we have lauded Marconi's successes. In the future we should also pay tribute to Reginald Aubrey Fessenden.

That concludes my lecture. Finally, I would like to tell you about a CBC-Shell Oil Company 1979 drama on Fessenden. This drama was one of a series entitled *The Winners*, and the particular drama was entitled *The Forgotten Genius*. While the chronological sequence of events is not quite right, the story is factually correct.

The Sounds of a Spark Transmitter

So far as I know, no one recorded for posterity the sounds of on-the-air spark signals.

Certainly, because of the tremendous variety of gap speeds for synchronous and non-synchronous rotary gaps, electrode shapes and number of electrodes in use, every spark station had its characteristic sound.

This characteristic of a spark transmitter was actually an advantage when there were a number of stations on the air. A spark signal was broad, and within the broad bandwidth of the simple receivers used, there could be several stations operating near the same wavelength with overlapping signals. Communications would have been more difficult if all the signals sounded the same.

Certainly, many of you who read this article will have seen, heard and smelled (the smell of ozone) an operating spark transmitter. Just the sound of an old rotary gap transmitter was good for appreciable DX.

Certainly, there are operating spark transmitters to be seen and heard, for example, the shipboard wireless transmitter at the Antique Wireless Association's Radio Museum, East Bloomfield, New York or the early radio amateur type non-synchronous rotary gap spark transmitter at Fred Hammond's Radio Museum, Guelph, Ontario.

The American Radio Relay League headquarters' Educational Activities Department, Newington, CT has available for borrowing copies of a VHS videotape in which Ed Redington assembles a working spark transmitter piece by piece while describing his boyhood adventures (and misadventures) in spark communications.

But have you heard how the received signal sounded? We had not, so we constructed a 5 MHz spark transmitter using an automotive ignition coil for the induction coil to learn how a spark transmitter worked and how it sounded. This transmitter, we admit, is only a small spark transmitter operated under laboratory conditions.

We were particularly interested to hear how Fessenden's spark telephony transmitter might have sounded. Recall that, to modulate his transmitter, he inserted a carbon microphone directly in series with the antenna lead. Our spark transmitter was like the one shown in Figure 1c, excepting that Lp and Ls were not directly coupled, but instead were link-coupled through a short length of transmission line.

The frequency and the output spectrum of the transmitter is determined by the frequency response of the antenna system. Our "antenna" was an L-C-R circuit, with components chosen to simulate a 5 MHz quarter wave monopole. The output frequency spectrum is indeed very broad, megahertz wide. (See Figure 7)

Somewhat surprising is the magnitude of what appears to be, say, a "third harmonic" of the fundamental oscillation frequency. The primary circuit of a spark system will have a wide band spectrum, but I do not see how it can accentuate, say, the third harmonic. Connected to a quarter-wave vertical, yes; but coupled to a simple series resonant circuit, no. So we measured the CW signal amplitude frequency response of our spark system. The response was like that traced out by the spectrum analyser when the generator source was a spark (not a swept-signal generator). While this does not explain the unexpected resonance, clearly a spark transmitter when connected to a real quarter-wave antenna would radiate on harmonic resonant responses of the antenna system (for a quarter-wave vertical on frequencies three, five, seven, etc times the fundamental oscillation frequency).

The signal of our spark transmitter sounds terrible on a narrowband communications receiver, but the receiver used for spark transmission reception was broadly tuned, and the recovered audio can be remarkably good, considering the source was initiated by a spark discharge.

To make recordings of the signal received, we had to relearn how to set up and "tune" a spark transmitter. The primary and secondary circuits, the "tank" and "antenna" circuits, must not be over-coupled, since this results in a double-peaked, extremely broad amplitude-frequency response.

The spark should take place between polished, hemisphere-shaped electrodes, not between pointed electrodes. And the widest gap possible consistent with regular sparking when the key is held down must be used, since otherwise the signal becomes all "mushy."

In effect, we "tuned" our transmitter by gradually narrowing the gap for the best received sound before making a recording at a particular spark rate. Thus, the signals heard and recorded using our spark transmitter were the best that could be realised. We did, however, demonstrate how the spark signal can change from a clear musical sound to a mushy unpleasant sound by using a gap too narrow.

We can attest to Fessenden's difficulty with operating, and modulating, a spark transmitter operating at 10,000 sparks per second for spark telephony. The gap adjustment is very critical.

When just the right width, the spark is sharply confined, the spark rate regular, the speech loudest, and the disagreeable noise least. Besides the problem with the disagreeable noise, the voice-induced resistance change, which modulated the antenna current via a carbon microphone inserted in series with the antenna lead, is indeed small. One had therefore to shout very loud.

However, the signal sounded like Fessenden described it: The words were perfectly clear, except that they were accompanied by an extremely loud disagreeable sound.

If you would like to have a copy of recordings made with our spark transmitter, illustrating: spark transmission using a mechanical interrupter, and simulated synchronous rotary spark gap transmissions for telegraphy; and spark transmissions for telephony, write to the author and send $10 to cover the cost of the audio-cassette and handling and mailing.

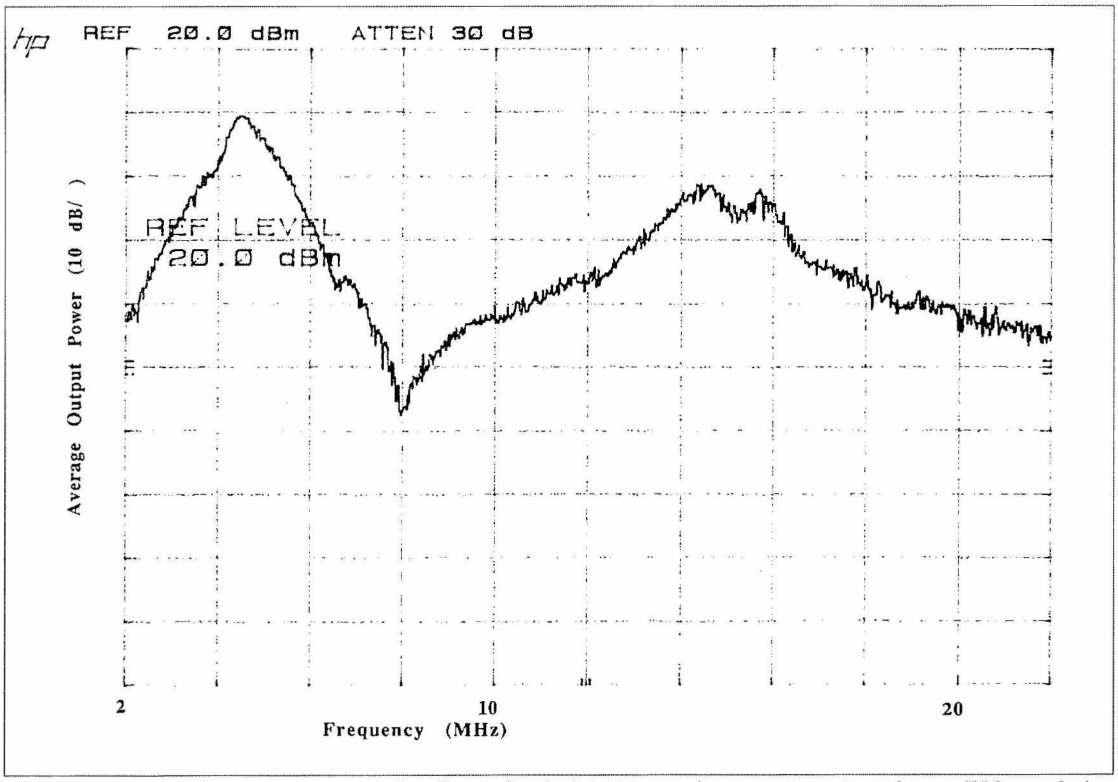


Fig 7. Relative averaged output spectrum for the author's 5 MHz spark transmitter (spark rate 750 sparks/second). Notice the response that appears to be a "hird harmonic" of the fundamental oscillation frequency (see text).

John S "Jack" Belrose received his BASc and MASc degrees in Electrical Engineering from the University of British Columbia, Vancouver, in 1950 and 1952, and his PhD degree in Radio Physics from Cambridge University, England in 1958. From 1957 to present he has been with the Communications Research Centre (formerly Defence Research Telecommunications Establishment), Ottawa, where currently he is Director of Radio Sciences.
He has written many papers, lectures and chapters in several books, published in various professional publications and journals, and radio amateur magazines on topics of interest and personal research in the field of antennas and propagation, particularly, on HF and VLF antennas by modelling and measurement, VLF and LF radio propagation, and HF propagation in the high-latitude region.
During his student and professional career he has been a member a several scientific and professional organisations. Currently he is member of The Radio Club of America; he is the Canadian National Coordinator of the AGARD (Advisory Group for Aerospace Research Development) Electromagnetic Propagation Panel; a special rapporteur on VLF and LF propagation for CCIR Study Group 6 and he is a Technical Adviser of the ARRL. He has been a licensed radio amateur since 1949. His present call sign is VE2CV, which he has held since 1961.
Jack is married to Denise, née Fenal, formerly of Paris. They have resided at their present address since 1959, have two sons, a married daughter and one grand-daughter. Camping, swimming, cross-country skiing, putting up and taking down antennas, and walking his dog everyday, 25 years of walking an Irish Setter, keeps him physically fit.

References and bibliography

1 Van Steen, M, "Alexander Graham Bell—The Journey of a Mind," *Beaver*, Jun/July 1992 42-50.
2 Raby, O, "Canada's Great Radio Pioneer, " *Electron*, July 1967 18-20.
3 Raby, O, "The Wireless Telephone," *Electron*, August 1968, 21.
4 Raby, O, *Radio's First Voice — The Story of Reginald Fessenden*, Macmillan of Canada, Toronto, 1970.
5 Quinby, E J, "Builder of Tomorrows: Part 1," *Proc IEEE*, **52**, *no 1*, October 1978.
6 Ibid, Part 2, **53**, *no 2*, March 1979.
7 Geddes, L A, "Fessenden and the Birth of Radiotelephony", *Proc of the Radio Club of America Inc*, November 1992, 2024.
8 Elliott, G, "Who was Fessenden?", *Proc of the Radio Club of America Inc*, November 1992 25-37.
9 Susskind, C, "The early history of Electronics, Pt I: Electomagnetics before Hertz," *IEEE Spectrum*, August 1968, 90-98; "Pt II: The experiments of Hertz" *Ibid*, December 1968, 57-60; "Pt III: Prehistory of radiotelegraphy," *Ibid*, April 1969, 69-74; "Pt. IV. First radiotelegraphy experiments," *Ibid*, August 1969 66-70; "Pt V: Commercial beginnings," *Ibid*, April 1970, 78-83.
10 Squires, W, "Fessenden before Radio," *ARFS Bulletin*, No 27, published by the Amateur Radio Fessenden Society, PO Box 737, Picton, ON, KOK 2T0, February 1989.
11 Vosper, G W, Private communications, 1992.
12 Geddes . L A, *The History of Electrical Engineering at Purdue (1888- 1988)*, Purdue Research Foundation, West Lafayette, Indiana 47907, 1988.
13 Ratcliffe, J A, "Scientists' reactions to Marconi's transatlantic radio experiment," *Proc IEEE*, **121**, 1033-1038, September 1974.
14 *New York Herald Tribune*, editorial at the time of Fessenden's death on 22 July, 1932.
15 Kintner, S M, "Some Recollections of Early Radio Days," *QST*, July 1932, 31-33, 90.
16 Quinby, E J, "Nikola Tesla, World's Greatest Engineer," *A History of the Radio Club of America, Inc. 1909- 1984*, **54**, *no 3*, The Radio Club of America, Fall 1984, 223-228.
17 Watt, A D, *Radio Engineering*, Pergamon Press, 1967, 130.
18 Geddes, L A, K S Foster, J Reilly, W D Voorhees, J D Bourland, T Ragheb and N E Fearnot, "The Rectification Properties of an Electrode-Electrolyte Interface Operated at High Sinusoidal Current Density", *IEEE Trans Biomed Eng*, **BME-34**, September 1987, 669 672.
19 Fessenden, R A, "Wireless Telephony," paper presented at 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, NJ, 20 June 1908.
20 Ruhmer, E, *Wireless Telephony*, translated from German by J Erskine-Murray, with an Appendix about R A Fessenden by the Translator, Crosby Lockwood and Son, Ludgate Hill, 1908. Author's Preface is dated 15 February 1907.
21 Fessenden, R A, The inventions of Reginald A Fessenden— part I, *Radio News*, January 1925 (Parts II to XII were published in the February through November issues of *Radio News*).
22 Zenneck, J., Translated from the German by A E Seelig, *Wireless Telegraphy*, McGraw Hill, New York, 1915.
23 Elliott, G., "Fessenden's Work with Sonic Frequencies," *ARFS Bulletin, no 54*. Jan/Feb 1993; and *no 55*, Mar/Apr., published by the Amateur Radio Fessenden Society, PO Box 737, Picton, ON, KOK 2T0.
24 Fessenden, Helen M, *Fessenden Builder of Tomorrows*, Coward-McCann, NY, 1940 (reprinted by Arno Press, NY, 1974)

The editors thank the referees for their assistance in evaluating this paper

Physical Optics and Terrain Diffraction

Jim Whitteker

Communications Research Centre, Ottawa, Canada

Abstract

Physical optics, or Fresnel-Kirchhoff theory, cannot be said to be modern, originating well before Maxwell's equations were introduced. It nevertheless has the virtues of being fairly easy to understand, and accurate enough to address problems of radiowave diffraction over terrain at VHF and UHF. The basis of physical optics is Huygens' principle, which states that the wave field at each point in space may be regarded as an elementary source of radiation. This statement is not exact, but is approximately true for short wavelengths. From Huygens' principle flows the familiar physical-optics solution for diffraction over a knife edge. A single-knife-edge model of terrain has often been used for path-loss estimates because of its simplicity, but in recent years this solution has been extended, first to two, then to several knife edges. When image theory is introduced, these solutions can be used also for solid terrain, in which the spaces between the knife edges are filled in with reflecting ground. Applied to terrain diffraction problems, these newer solutions find a place at frequencies that are too high for rigorous ground-wave methods, and too low for ray-optical methods.

Physical Optics

The origin of physical optics goes back more than 300 years to 1690, when Christiaan Huygens published his Traite de la Lumiere, in which he introduced his now-famous principle. (Huygens was Dutch, but he lived in Paris from 1666 to 1681, during which time this work was largely written.) Augustin Fresnel added the idea of interference in 1818. Then in 1859 and 1891 respectively, Hermann Helmholtz and Gustav Kirchhoff put the subject into the mathematical form that is used today[1].

So physical optics is old, some would say out-dated. But it has the virtue of being understandable intuitively, and is the basis of many people's informal thinking about diffraction. I was tempted to subtitle this article 'diffraction for dummies', or perhaps 'you don't need all that fancy math for terrain diffraction'. Physical optics also has the virtue of being quite accurate within its limits of validity, which includes most problems of radiowave diffraction over terrain at VHF and UHF.

Huygens' Principle

Huygens' principle states that the wave field at every point on a surface may be regarded as an elementary source of radiation. The fundamental equation from which this idea can be justified is the Helmholtz integral formula, which gives the wave field E(P) at any point P in terms of the field E and its derivative on any closed surface S that contains P but does not contain any sources:

$$E(P) = \frac{1}{4\pi}\iint_S \left(E\frac{\partial}{\partial n}\frac{e^{ikr}}{r} - \frac{e^{ikr}}{r}\frac{\partial E}{\partial n} \right) dS \qquad (1)$$

where k is the propagation constant, and the other quantities are indicated in Figure 1. The derivative $\partial / \partial n$ is taken along the inward normal of (ie perpendicular to) S.

The Helmholtz integral is exact; it can be derived from the wave equation and Green's identities [2]. However, Huygens' principle emerges from it only if the wavelength is short compared to the distances between terrain features. This condition is usually satisfied for terrestrial VHF and UHF, since the wavelength is of the order of a metre, and horizontal distances of interest are usually hundreds or thousands of metres. The field E can be written as the product of two factors. One factor is e^{iks}, where s is distance along the local wave normal, ie along the local direction of propagation, as indicated in Figure 1. The other factor can be assumed to vary slowly in space. The differentiations in (1) can now be carried out, retaining only the variation of e^{ikr} in the first term, and only the variation of e^{iks} in the second. (Specialists will notice that I am using a particular sign convention. The factors e^{-ikr} and e^{-iks} could have been used instead.) This leads to

$$E(P) = \frac{-ik}{4\pi}\iint_S (\cos\theta_1 + \cos\theta_2)\; E\frac{e^{ikr}}{r} dS \qquad (2)$$

where θ_1 and θ_2 are defined in Figure 1. This looks more like Huygens' principle. That is, the radiation from each point of

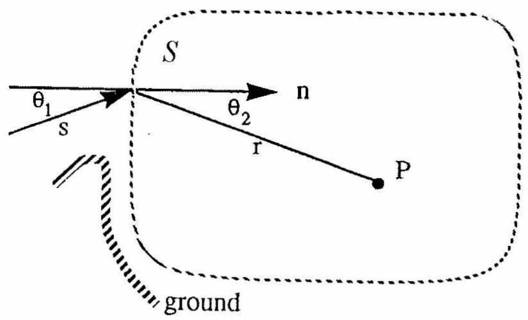


Fig 1. Narrow hill and integration surface S.

S is proportional to the surface field E, with a directional dependence, and it arrives at P modified by the free-space propagation factor e^{ikr} / r.

Approximations

This is still not a very useful equation if we have to find the field everywhere on S just to find it at some interior point. However, because the phase of Ee^{ikr} varies rapidly over most of S, and because the cosines of (2) cancel directly to the right of P, all of S can be neglected except for a limited area (the first few Fresnel zones) to the left of P. Then the Kirchhoff boundary conditions assert that the field on S above the hill is just the (known) incident field, and that the field on the shadowed side of the hill is zero. The very existence of diffraction implies that these conditions are not exact, but they are plausible and fairly accurate if the wavelength is small and the hill is steep. Finally, I will assume that the terrain is uniform perpendicular to the direction of propagation. This assumption can be made because of the limited horizontal (as well as vertical) size of the first few Fresnel zones just mentioned.

Knife Edges

Now we are ready for the classical elementary terrain diffraction problem: a single narrow hill, modelled as a knife edge. Since terrain heights and Fresnel zones are much smaller than the propagation path length, we can approximate $r = (x^2 = z^2)^{1/2}$ as $x = z^2 / (2x)$ (x horizontal, z vertical). The fact that this is quadratic in z leads to a solution in terms of the Fresnel integral

$$F(\tau) = \int_{\tau}^{\infty} e^{it^2} dt \qquad (3)$$

where the t in the integrand has appeared as a dimensionless analogue of z and the lower limit of integration represents the height of the knife edge or hill. Next suppose that the propagation path is crossed by N distinct, narrow hills. If each hill is modelled as a knife edge, Huygens' principal (eqn 2) can be used repeatedly. The field at the receiver is then proportional to the value of the multiple integral

$$I = \int_{h_1}^{\infty}\int_{h_2}^{\infty} \dots \int_{h_N}^{\infty} e^{ikr_z} dz_N \dots dz_2 dz_1 \qquad (4)$$

where r_z is the length of the zig-zag path illustrated in Figure 2.

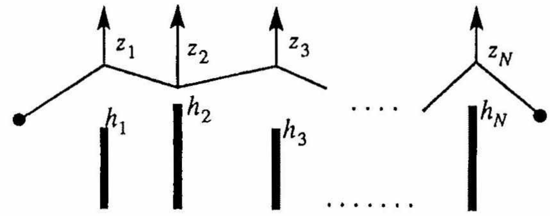


Fig 2. One possible path over N knife edges.

The integration can be considered to be a summation over all such paths. This integral can be derived in more sophisticated ways [3,4,5]. However, no matter how you formulate the problem, you wind up with this multiple integral which you somehow have to evaluate. It's tempting to think that it might be turned into a product of ordinary Fresnel integrals, but it can't be, because of the cross terms between neighbouring knife edges in the expression for r_z.

Knife-edge Solutions

For two knife edges, Millington et al [6] worked out how to evaluate the required double integral as a surface integral over part of the plane. Something similar might be done for three knife edges (triple integral) as a volume integral, but it would be exceedingly complicated, and even worse for higher dimensional spaces.

For N knife edges, Vogler [4] worked out how to evaluate the multiple integral by expanding the sum of the cross terms in the exponent of the integrand as a power series. The series is somewhat complicated, and the time required to compute it rises very rapidly as a function of the number of knife edges, but it very nicely breaks through the N = 2 barrier. The series does not converge everywhere, but the problems for which it does not converge can be transformed into problems in which it does (more on this later).

When the knife edges are evenly spaced and the same height, the multiple integral can be evaluated exactly [7]. A particularly nice result appears when the distances from the outer knife edges to the transmitter and receiver are the same as the knife-edge spacing (Figure 3):

For N = 1, it is easy to see from symmetry that the absorbing screen blocks half the radiation. But for N > 1, the $1/(N + 1)$ attenuation is not obvious at all, just one of those neat results that emerge sometimes. Xia and Bertoni [8] have made use

Fig 3. The N knife edges attenuate the field by a factor of 1/(N+1).

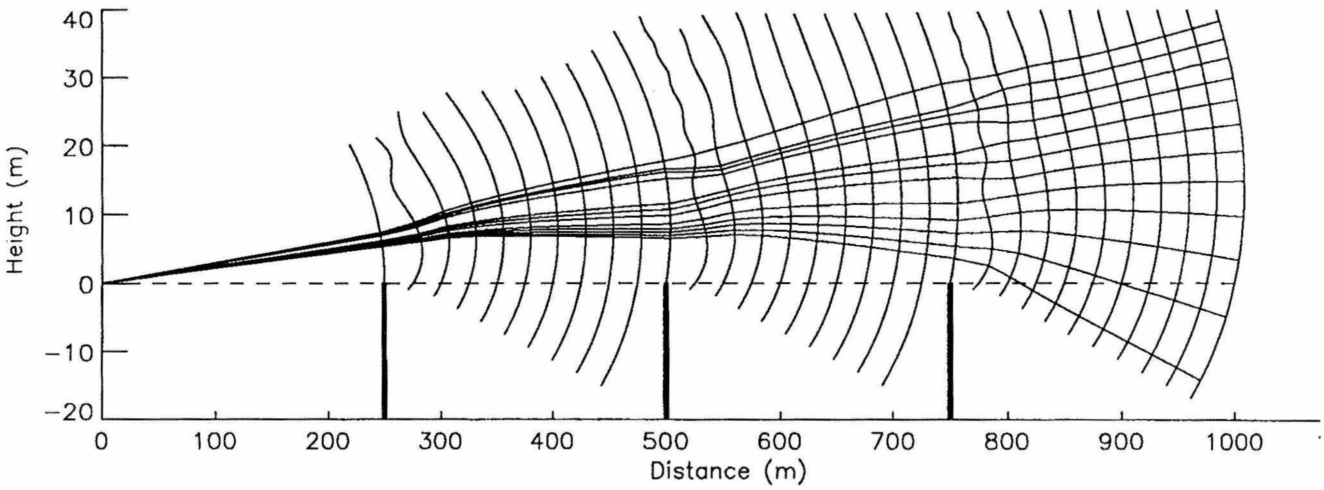


Fig 4. Wave fronts and normals at 50 MHz for three knife edges at the same height as the transmitter.

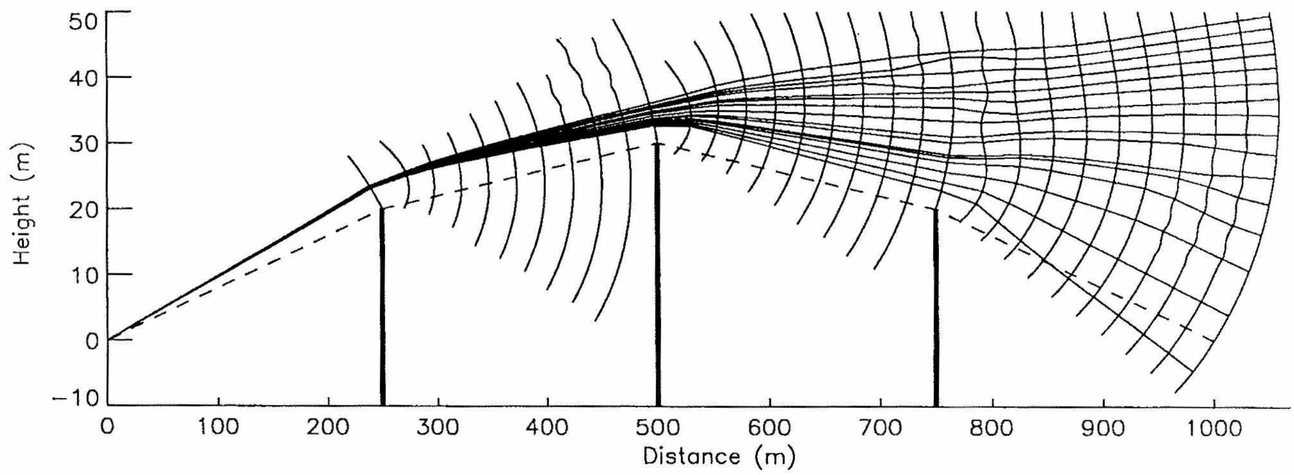


Fig 5. Wave fronts and normals at 50 MHz for three elevated knife edges.

of these results in knife-edge models of urban rows of buildings.

Although the field amplitude rather than its phase is usually of practical interest, a way of visualising diffraction, as in Figure 4, is to plot lines of constant phase (roughly vertical) and the perpendicular wave normals (roughly horizontal) that indicate the local direction of propagation.

The waves appear to flow around the obstacles, like ocean waves around a breakwater. Some of the wave fronts exhibit an interference pattern due to the wave scattered from an edge interfering with the direct wave. (Between knife edges, the shape of successive wave fronts varies continuously, although more wave fronts would have to be plotted between those shown to make this obvious.) Wave normals traced back from right to left pass well above the knife edges, and do not converge except at the point source on the far left.

However, for higher knife edges (Figure 5), wave normals traced back from the shadow have more of a tendency to converge to points close above the knife edges. This tendency increases with frequency and with the height of the knife edges. In the limit, the immediate source of the wave seems to be the knife edge. This special situation allows the use of the geometrical theory of diffraction, in which wave normals or rays go from edge to edge, like a stretched string, and the calculation is much faster than for numerical integrations over surfaces.

Solid Terrain

While it's fun to play with knife edges, gently undulating terrain is not well represented by them. The surface field cannot be neglected. Helmholtz's integral can still be used if we can find what the field actually is on the surface, and this is what is usually done in rigorous diffraction theory.

However, it is more in the spirit of physical optics to avoid the hard part of the problem. If the surface is highly reflecting, as it is likely to be at grazing incidence, then images can be used. To do this, select an area of terrain small enough that it can be considered flat. Looking at the scene from P (Figure 6), you can pretend that the ground is not there, and that the ground-reflected wave comes from an image of S, with the field contribution from each part of the image multiplied by

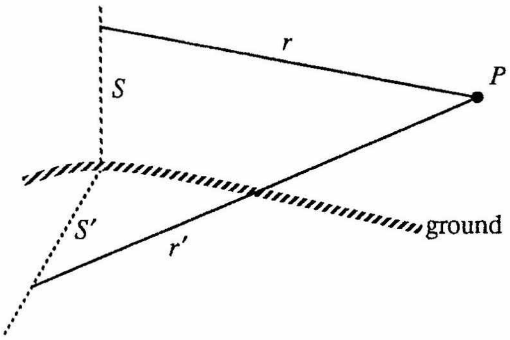


Fig 6. Broad hill, integration surface S, and its image reflected in the ground.

a reflection coefficient. That way, all you have to do is integrate over S and its image S', and the problem is not much more complicated than the knife-edge problem.

At VHF and UHF [9], using images in this way is quite accurate for horizontal polarisation. For vertical polarisation, it is accurate enough except at frequencies in the low VHF range reflecting from sea water. The difficulty here is that the Fresnel reflection coefficient really only applies to plane waves, and a rigorous approach would require treating anything else as a superposition of plane waves. For vertical polarisation, the reflection coefficient varies rapidly as a function of angle of incidence near the Brewster angle. However, sea water is usually not very hilly, and can be dealt with by smooth-earth theory. (Except for paths over ocean islands. This sounds like a pleasant topic for experimental study, if the islands happen to be tropical.)

Solid-terrain Solutions

When images are used, the calculation for solid terrain is similar to the calculation with knife edges. You must evaluate many integrals in succession, only this time there are twice as many of them, and at each step the results of the two integrations are added [9].

Curved terrain can also be considered. In early work on the subject, an approximate solution to the problem of diffraction over a cylindrical ridge [10] involved integration over a vertical plane above the summit of the ridge. The construction suggested by Figure 6 was applied to both sides of the ridge, except that the reflecting surfaces were curved rather than flat, and the more complex optical properties of curved surfaces had to be taken into account.

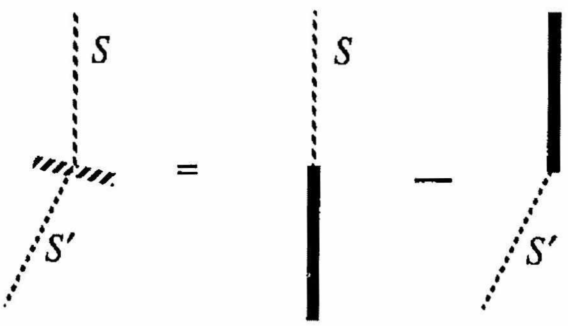


Fig 7. A solid-terrain problem as the sum of two knife-edge problems. The minus sign indicates a reflection coefficient of -1.

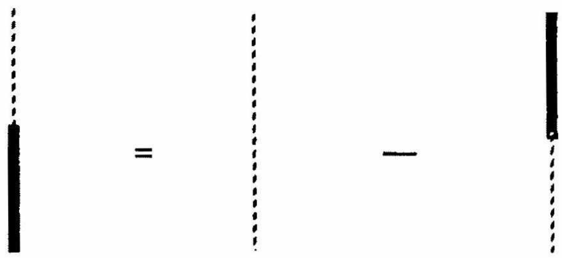


Fig 8. Babinet's principle for knife edges.

A later analysis [11] of discontinuities (knife edges or steps) added to a cylindrical hill combined physical optics at the discontinuity with more rigorous theory on the curved surface, in which the field was represented as a sum of wave modes. With the Kirchhoff boundary condition, it is possible to reinterpret the modes incident on the discontinuity as a new set of modes appropriate to continued propagation on the other side.

For terrain of arbitrary shape and electrical properties, numerical integration is required. It's not an ideal answer, because of the difficulty of assuring the accuracy of the result after many integrations, but a practical computer program has been written on this basis. Comparisons [9] with rigorous diffraction theory in the special case of a smooth earth have shown that agreement within a decibel or two can be achieved. Practical calculations on general terrain are less accurate. The limitation seems to be not so much the theory, but the numerical methods used to implement it.

However, if you can live with the fiction that the ground is perfectly reflecting (reflection coefficient of -1), numerical integration can be avoided. In this case, not only is image theory exact, but the complication of the variation of reflection coefficient with angle of incidence disappears. Then the method of Millington et al [6] for two knife edges, and Vogler's [4] method for multiple knife edges can be adapted to solid terrain [12, 13]. In the latter case, because of cancellations that occur only for perfect reflection, the resulting calculations are not much more complicated than for knife edges. The same series is used, but with some terms omitted.

Knife Edges and Solid Terrain

Solid terrain calculations are possible with knife-edge techniques because there is a close connection between segmented perfectly reflecting terrain and a series of knife edges. As we have seen, reflecting terrain can be removed and replaced by the image that it reflects. Consider Figure 6 again. The integrations over S and S' can be separated, and

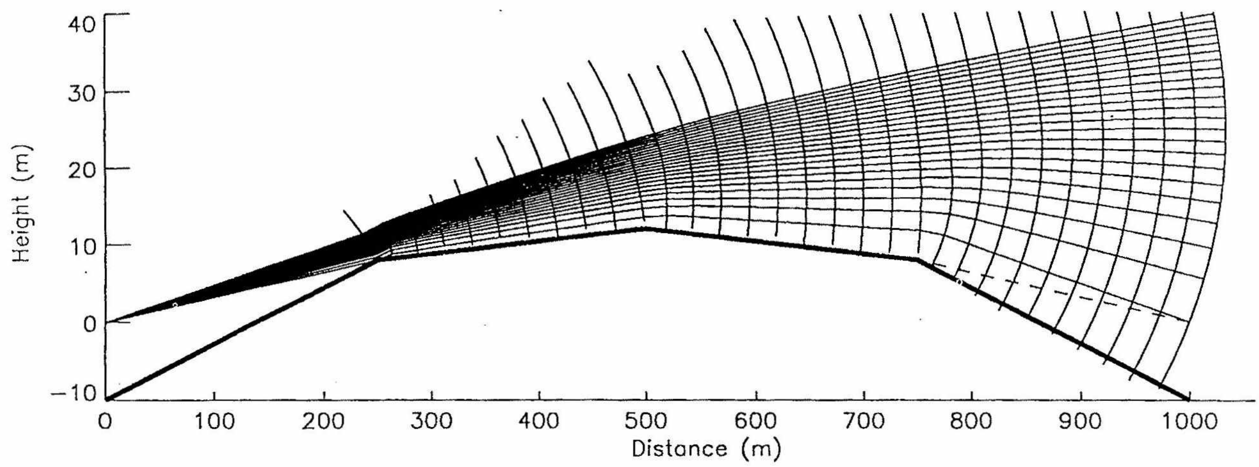


Fig 9. Wave fronts and normals at 50 MHz for solid perfectly reflecting terrain.

each one looks like a knife-edge problem, since the integration stops at the ground. The equivalence is indicated in Figure 7.

A solid-terrain problem has been transformed into two knife-edge problems, with an inverted knife edge in one of them. Another transformation that inverts knife edges is Babinet's principle [1], illustrated in Figure 8. The field in the presence of a knife edge equals the field in the absence of the knife edge minus the field in the presence of a complementary knife edge.

Now it happens that terrain profiles with valleys cause convergence problems in Vogler's series. By using Babinet's principle and image transformations, you can transform valleys into hills [13]. In these transformations, reflecting surfaces come and go. Even if you start off with knife edges only, some of the transformed problems may have reflecting surfaces in them. The addition of reflecting surfaces to knife edges seems to complete the system in a way reminiscent of how complex numbers complete the real number system.

Figure 9 shows wave fronts over some simple solid, perfectly reflecting terrain. One thing to notice is that the wave fronts are much smoother in appearance than for knife edges (Figures 4 and 5). Something that the diagram indicates only indirectly (by the distance between wave normals) is that the attenuation is greater than for knife edges. This is because the reflected wave interferes destructively with the direct wave near the reflecting surface. It is well known that a wave is attenuated much more by a broad rounded hill than by narrow ridges with the same horizon angles.

A curious feature of Figure 9 is that the wave fronts are perpendicular to the reflecting surface and the wave seems to be guided along it. To see why this should be so, think of a plane wave incident on a surface at nearly grazing incidence, and consider this wave to be the superposition of a wave travelling along the surface and a perpendicular wave directed toward the surface. The perpendicular wave will be cancelled near the surface by destructive interference with the reflected wave, leaving only the wave travelling along the surface.

Conclusion

Why do I think physical-optics methods are suitable for terrain diffraction at VHF/UHF? Since they take advantage of some simplifications available at high frequencies, they are easier to apply than the rigorous diffraction theory used for ground-wave calculations at lower frequencies. However, they do not assume that edges radiate as line sources, and are therefore suitable for more gentle terrain and lower frequencies than might be appropriate for the geometric theory of diffraction. Also, the terrain can be any shape, provided a terrain profile can be reasonably approximated as a series of straight lines, each one many wavelengths long. In these respects, physical optics occupies somewhat the same territory as the parabolic wave equation applied to terrain diffraction [14].

References

[1] Baker, B B, and Copson, E T, *The Mathematical Theory of Huygens' Principal*, Oxford University Press, London, 192 pp (1950).

[2] Beckmann, P and Spizzichino, A, *The Scattering of Electromagnetic Waves from Rough Surfaces*, Artech, Norwood MA, USA, 503 pp (1987).

[3] Lee, S W, "Path integrals for solving some electromagnetic edge diffraction problems", *J Math Phys 19(6)*, 1414-1422 (1978).

[4] Vogler, L E, "An attenuation function for multiple knife-edge diffraction", *Radio Sci 17(6)*,1541-1546 (1982).

[5] Eliades, D E, "Path integral analysis of paraxial radiowave propagation over a nonlevel plateau", *IEE Proc 138, Pt H*, 521-526 (1991).

[6] Millington, G, Hewitt, R,and Immirzi, F S, "Double

knife-edge diffraction in field-strength predictions", *IEE Proc, 109, Pt C*, 419-429 (1962).

[7] Boersma, J, "On certain multiple integrals occurring in a waveguide scattering problem", *SIAM J Math Anal, 9(2)*, 377-393 (1978).

[8] Xia, H H, and Bertoni, H L, "Diffraction of cylindrical and plane waves by an array of absorbing half-screens", *IEEE Trans Ant Prop, 40(2)*,170-177 (1992).

[9] Whitteker, J H, "Fresnel-Kirchhoff theory applied to terrain diffraction problems", *Radio Sci 25*, 837-851 (1990).

[10] Neugebauer, H E J, and Bachynski, M P, "Diffraction by smooth cylindrical mountains", *Proc IRE, 46(9)*, 1619-1627, 1958.

[11] Wait, J R, "Diffraction and scattering of the electromagnetic groundwave by terrain features", *Radio Sci, 3(10)*, 995-1003, 1968.

[12] Whitteker, J H, "Diffraction over a flat-topped terrain obstacle", *IEE Proc, 137, Pt H(2)*, 113-116 (1990).

[13] Whitteker, J H, "A series solution for diffraction over terrain modeled as multiple bridged knife edges", *Radio Sci 28(4)* pp 487-500 (1993).

[14] Levy, M F, "Parabolic equation modelling of propagation over irregular terrain", *Elec Lett 26(15)*, 1153-1155 (1990).

The editors thank the referees for their assistance in evaluating this paper

REVIEWS

MicroMath *Scientist.*

MicroMath Scientific Software, PO Box 21550, Salt Lake City, Utah 84121, USA.

Scientist is a package for mathematical modelling, solving differential equations and performing statistical calculations. Written in Turbo-Pascal, it runs in a windowed environment under DOS, with pull-down menus, on-line help, mouse compatibility, editor, and graphical support. It installs easily from a single disk, and comes with a comprehensive 223 page manual — which you'll need to get to grips with it. It requires at least MSDOS 3.3, and version 5.0 or above is recommended. At least 2 Mb of RAM and at least 2 Mb of hard disk are required. EGA, VGA, LCD and Hercules screens are supported. A floating point co-processor is recommended, but not obligatory. According to the handbook, many common hard-copy devices are supported, including dot-matrix, laser, JET and PostScript printers, and HP plotters. It also claims to write several different file formats, though we didn't check them all.

Commands are accessed via pull-down windows, also predefined hot keys.

Problems are defined in "model", "parameter" and "data" windows, and can be entered directly from the keyboard or read from files. *Scientist* knows how to read data in several standard formats, including ASCII, Lotus 1-2-3, dBase, Quattro Pro, DDIF, MS Excel. A handy feature for importing data from previous calculations.

Many sample codes, with good background descriptions, are provided for a wide range of applied problems in mechanics and chemical systems. These are composed, edited, and viewed in "model", "spreadsheet" "parameter" and "plot" windows. An interactive "quick tour" is provided to familiarise you with the way problems are defined, solved and plotted.

Built-in algorithms include those for the solution of systems of differential equations — including the standard Runge-Kutta methods and also EPISODE, for solving stiff systems. Powell's algorithm is available for least squares minimisation. Extensive statistical support is provided. As well as standard algorithms for means of various types, variances, skewness, kurtosis, you can compute correlation matrices, coefficients of determination, and even heteroscedacticity — which I had never come across before.

Where does *Scientist* fit in the range of scientific analysis software? It is not a hard-core, matrix oriented numbercruncher like MATLAB, nor a spreadsheet-like package with added scientific capability — though it includes elements of both. It is more like MATHCAD, being able, for example to interpret and solve implicit equations such as $A = B + B * A / (1 + A)$ for the variable A, if B is given. However the user interface is quite different from MATHCAD.

For a stern initial test (will it run on ageing hardware?), one of us (Gary) installed *Scientist* on his elderly 16 MHz 386 Hercules-screened home workhorse with DOS 5.0. First setback. *Scientist* came up fine, but ignored the serial port connected mouse — which is Microsoft compatible (as required) and which works fine with Windows. Changing ports, rebooting and fiddling with connections didn't help. Checking "mouse" entries in the handbook index brought to light no diagnostic information.

No matter, the manual said that I could also drive *Scientist* by accessing the menu bar and windows from the keyboard in a reasonably standard manner, so I did that to run through the "quick tour". This estimates the parameters A and K in a least-squares fit of the function C = A * EXP(–K * T) to 4 experimental data points.

This worked fine, although the manual is written assuming that you *do* have a mouse, and I had to navigate tentatively around the 8 or so screens consecutively accessed with the keyboard. I was guided through the steps of entering, compiling and saving a model (of the equation), selecting data, parameters, the least-squares fit algorithm, and finally starting the fit — which took only a few seconds, displaying its progress on the screen as it iterated. Finally, setting plot options and initiating a screen plot showed me what I had achieved. This plot, with all its set options, can be also be saved to disk for later viewing, without re-doing the computations.

I installed *Scientist* on my office 66 MHz 486DX next day. It wouldn't run in a 4DOS window under Windows 3.1 (complaint::" Not enough memory").

Mildly irritating, because I invariably work in a windows environment, and all the other DOS applications I use DO run in a 4DOS window. I backed out of windows, and *Scientist* ran OK under DOS 6.0. Now the mouse was also recognised, and I quickly ran through the quick tour again — much easier. Finally, I successfully screen dumped the plot to my elderly dot-matrix printer. The plot window also has options for saving the plot to disk in a variety of other formats (see above) and it was straightforward to write a PostScript file, which printed successfully on a Laserjet, and also showed up correctly, under Windows, in Ghostview

The quick tour demonstrated very well the wide range of options available for attacking this type of problem, but as I am a confirmed MATLAB 4.0 user, nothing was intuitive. I tried similar, but different parameter-fitting problems more or less successfully but found it necessary to refer constantly to the manual. If this is a criticism however, it's one I encounter universally with modern software, as my current attempt to master the extremely powerful but somewhat inscrutable *Excel 5.0 for Windows* involves similar head-scratching and perplexity.

Many commands have "on-line help" buttons which can be selected by mouse. However some of them merely say "no help for this item".

For a realistic differential equation solving test on a problem familiar to us, Paul set up a two-dimensional underwater acoustics raytrace in a range independent sound speed profile. This involves the numerical solution of 4 nonlinear first order differential equations, solved here using the 4th order Runge-Kutta algorithm supplied. The problem definition information he entered, shown to give some idea of what's necessary, was

```
//ray trace
IndVars:t
DepVars:x1,x2,x3,x4
params:c0,z0,a,b
x1'=x2*co*(1+a*exp(-(x3-z0)/b)+(x3-z0)/b-1))
x2'=0
x3'=x4*co*(1+a*exp(-(x3-z0)/b)+(x3-z0)/b-1))
x4'=-(c0*a/b*(-exp(x3-z0)/b+1))/
     (c0*(1+a*(exp(-x3-z0)/b+(x3-z0)b-1)))/
     (c0*(1+a*(exp(-(x3-z0)/b)+(x3-z0)/b-1)))
//initial conditions
t=0
x1=0
x2=cos(theta*3.1415926/180)/1480
x3=1200
x4=sin(-theta*3.1415926/180)/1480
//parameters
c0=1480
z0=1200
a=.006
b=520
theta=10
```

This gets saved in an ASCII file, and the format is pretty self explanatory. x1 and x3 are range and depth, x2 and x4 are ray parameters. and the 4 derivatives are x1', x2', x3' and x4', the latter two complicated because they include analytic expressions for the canonical Munk soundspeed profile and its derivative with depth.

In two separate runs, we traced the path of 2 sample rays starting at 10 and 12 degrees angle from the horizontal, departing from a source at 1200 metres depth, for 100 km horizontally. Again, we produced a PostScript file of the graph which plotted successfully, shown in fig 2. It looks as expected.

We also dumped the screen to a Deskjet printer. But on the printer page, the graticule is only 7 cm across, and there seemed to be no obvious way of magnifying it for a larger printout. This is more of an irritation than a limitation, as *Scientist* can write the output data to an ASCII file for later plotting or further manipulation by another package. The raw output can also be saved in a "spreadsheet", but the file format was not recognised by either Quattro or Excel.

We had considerable difficulty forming this plot, since it required data from two different result spreadsheets. As far as we could determine, to add additional traces to one already existing on the screen, it is necessary to repeat the whole plot setup procedure from scratch for the second trace, setting up axes, independent variables, line and symbol markers — which we just wanted to be the *same* for both traces — again. This was time consuming and messy.

When the raytrace was extended to considerably longer ranges, some odd things happened. Strange code was written to already existing files on the disk, somewhat un-nerving. Was something running off the end of an array? Also, when attempting to produce multiple plots, *Scientist* sometimes plotted variables which we thought had not been selected.

These manifestations of "flakiness", of course, may have been just peculiar to our own systems, and the scale of the problem we were attempting — certainly more suitable for MATLAB 4.0.

However *Scientist* certainly seemed to cope well with simpler, "one-off" problems of the curve-fitting, regression, and statistical analysis types. For research lab use, where a large number of similar problems of these types are routinely encountered, *Scientist* is well worth considering — as long as you don't habitually operate in Windows, as we do. It could also be of value in teaching laboratory situations.

Gary E J Bold and Paul Casey

University of Auckland, New Zealand

ed Lakhtakia: *Essays on the Formal Aspects of Electromagnetic Theory*

ed Akhlesh Lakhtakia, World Scientific, Singapore, ISBN 981-02-0854-5, 796 pages, price GBP £71, (approximately USD $105), 1993.

The Concise Oxford Dictionary's definition of an "essay" is: "Attempt (at); a literary composition (usually prose and short) on any subject". The subject, in the present instance, is fundamental electromagnetic theory. As Craig Bohren says in his fascinating foreword: "No, we are not in a state of crisis: merely in a state of reasonable doubt as to whether electromagnetic theory is in its final form". He goes on to say ".... much of the criticism in this volume will ultimately be shown to have been unfounded. But we can hope that an indissoluble residue will remain, and that this will lead to new observable phenomena and perhaps a better understanding of old ones". As indicated by the editor, the 21 "essays", written by an assembly of active researchers, do not come to a particular consensus of opinion. The editor, perhaps wisely, refrains from writing individual introductions to the various contributions.

This reviewer found many of the ideas presented very thoughtful. Just to give the flavour of the material, let me quote some of the titles: "Electromagnetic phenomena not explained by Maxwell's equations" (by T W Barrett), "Electromagnetic transients not explained by Maxwell's equations" (by H F Harmuth), "Inhomogeneous waves and Maxwell's equations" (by P Cornille), "A unified approach to classical and quantum electromagnetic interaction" (by J W G Wignall), "Universal boundary conditions and Cauchy data for the electromagnetic field" (by M Idemen), and "The Maxwell postulates and chiral worlds" (by A Lakhtakia).

Presumably, the individual essayists were invited by the editor to contribute to the volume without any preconditions. As such, the reader will find nothing in the nature of rebuttals such as might be found in the pages of refereed journals. Also there is no cross referencing of the individual contributions. However, on the plus side, I found that references to the literature, old and new, were extensive.

Taken on balance, I would recommend the purchase of this tome by university science libraries and it should be shelved beside Alfred O'Rahilly's *Electromagnetics, a Discussion of Fundamentals*, Cork University Press, 1950 and Edmund T Whittaker's *History of the Theories of Aether and Electricity*, Dublin University Press, 1910.

James R Wait

Review Editor
2210 East Waverly, Tucson, AZ 85719-3848, USA

Zhdanov and Keller: *Geoelectrical Methods in Geophysical Exploration*

The Geoelectrical Methods in Geophysical Exploration, Methods in Geochemistry and Geophysics, 31, Michael S Zhdanov and George V Keller, ISBN 0-444-89687-3, Elsevier Science BV, Amsterdam, Netherlands, 1994, 873 pages. Price US$ 211.50 (includes FORTRAN codes).

This tome is another entry in the series on Geochemistry and Geophysics. Previous titles included: Mining Geophysics (Parasnis), DC Sounding (Bhattacharya and Patra), Time-varying Geoelectric Sounding (Patra and Mallick), Magneto-Telluric Sounding (Kaufman and Keller), Frequency and Transient Sounding (Kaufman and Keller), Advanced Theory of Deep Geomagnetic Soundings (Berdichevsky and Zhdanov), Inductive Mining Prospecting (Kaufman and Keller, Induction Logging (Kaufman and Keller), Anisotropy in Geoelectromagnetism (Negi and Saraf) and Exploration with Deep Transient Electromagnetics (Strack). Although I am not completely familiar with all these volumes, there is an evident overlap with the book by Zhdanov and Keller being reviewed here. One thing they all have in common is a very high price tag. Nevertheless, the present book, the latest in the series, does make a commendable effort to integrate the many facets of the subject in a form that could be quite useful to graduate students in geophysics and researchers in allied fields such as remote sensing and radio physics. The diverse background of the two co-authors is a strong point in the selection of topics. George Keller's light touch and his cogent anecdotes nicely complement Michael's theoretical narrative. Not surprisingly the latter follows the Russian school.

In the preface it refers to two earlier books (not published by Elsevier) which are "Electrical Methods in Geophysical Prospecting" (by Keller and Frischknecht, 1966) and "Elecktrorazvedka" (by Zhdanov, 1986). I was familiar with the first book having been the commissioning editor for Pergamon Press and its founder, the late Robert Maxwell. I have not seen the second book but I have seen the presumably related text by Berdichevsky and Zhdanov mentioned above. These two books, with other sources, form the core material for the present tome. The only general problem I see, after a fairly careful reading, is that the east and the west have a slight but annoying impedance mismatch if I may be forgiven for using electrical engineering terminology. It appears that the Russian electromagnetic theory harmonic time factor, which is $\exp(-i\omega t)$, conflicts with portions of the text extracted from the western literature – including most papers and monographs published by IEE and IEEE who employ $\exp(+i\omega t)$ or $\exp(+j\omega t)$. Also there is a dichotomy on the use of k to indicate the wave number or the propagation constant (they differ by + or – i). There is the usual quota of typographical errors, eg in such places where electromagnetic mutual coupling between loops is quoted. Such errors, while minor in the mathematical context, can cause considerable annoyance to the user who has not followed the derivations. Such a situation is aggravated by the fact that most of the analytical substance of the book does not have cited references at the appropriate location in the text but, instead, one must search through the reference list at the end of each chapter. By the way, I couldn't find a reference to Lipskaya!

Some of the specific topics, treated by the authors either singly or jointly, are as follows: *Maxwell's equations* and the special case of quasi-static theory where displacement currents are neglected, (such a limit is not reconciled with induced polarisation effects which are omnipresent), *Rock properties* in both a parametric and an "existential" sense, (no mention of "complex resistivity" is given but the overall coverage is informative), *DC Resistivity Theory* (a nice readable summary of well worn topics but here it would have been useful to extend the DC expressions for potential to the usual quasi-stationary case by letting r become complex which is the usual approach in treating IP, eg see the reviewer's text, "Geoelectromagnetism† Academic 1982, for an established procedure), *Exact Analytical Models* (a good survey of what can be done with an arsenal of special functions and some good insight in formulating separable problems) and *Interpretation* (contains a clear explanation of analytical continuation and migration).

Almost 100 pages cover case histories with reference to mineral exploration, vulcanology, groundwater, tracking lost hydrocarbons, petroleum, geothermics, and crustal studies.

Some rather curious comments are made about radio waves propagating to long distances. The curves shown in figs 12.11 to 12.12, on pages 689-691, refer to ground wave transmission over an airless earth! It is well known that field strengths are much greater, at ranges of 2000 km or more, for VLF to MHz, when the omnipresent ionosphere is considered. The formula (12.2) taken from Watt (1967) bears no similarity to those in the figures. Also note that equation (12.3) is dimensionally incorrect. The statement that follows is certainly wrong. The 11 major VLF transmitters are *not* "Beverage antennas of great length". Indeed they are top-loaded vertical m9onopoles of great physical height (eg 300 m or more). The claim, that such antennas can be treated as a grounded wire using methods described in Chapter 7, is unfounded.

As I indicated above, the price is high and well beyond the means of most if not all graduate students. But industrial groups will need to have access to this book and would find it a worthwhile purchase. Current budgetary restrictions at most university libraries could make this buy or not to buy a difficult choice.

PS: Why doesn't somebody make verbatim translated copies of the (former) Soviet monographs and sell them as paperbacks for a fraction of the prices set by the Dutch publishing houses?

† Now available from the author (J R Wait) with corrections.

James R Wait

Review Editor
2210 East Waverly, Tucson, AZ 85719-3848, USA

Note from the Review Editors

If you are interested and willing to review books for *The Radioscientist*, send a complete description of the item and the name and address of the publisher. Publication dates should be 1994 or 1995. Of course, you may keep the book after you have fufilled your commitment.

Review Editors
Steven Dvorak and James R Wait
ECE Dept,
University of Arizona
Tucson AZ 85721, USA
fax: +1-602-621 8076
email: dvorak@helios.ece.arizona.edu

DSP-II and its applications

1. Introduction

The recording and analysis of VLF and ELF radio waves (0.3-30 kHz), from natural and artificial sources, received on the ground by broad-band and narrow-band receivers, have long played a crucial role in many aspects of research into the physical processes occurring in the earth's magnetosphere and ionosphere. An example is the use of whistlers to track plasmaspheric motions; the embedded field-aligned irregularities or "ducts" which guide whistlers from the lightning source to the opposite hemisphere act as tracers which can be followed by measuring how the whistler dispersion varies with time.

Since the propagation of the waves through the medium is largely determined by characteristic frequencies in the plasma (eg the electron gyrofrequency), it is usual to study the received signals (typically the horizontal magnetic and/or vertical electric field components of the wave at the aerial site) in the frequency domain, which entails spectrum analysis of the original time series in one way or another. Various ingenious ways of achieving this have been employed over the years; the Rayspan (Helliwell, 1965), in which a large bank of parallel narrow-band tuned filters was scanned rapidly in rotation, was an early example. During the last decade or so, with improvements in technology, it has become possible to approach this problem by a direct 'brute force' method, ie by digitising the analogue input wave signal at the full bandwidth, and then computing the Fourier transform in real time. This requires both high-speed analogue-digital converters and fast digital computation of the spectrum. For example to implement real-time spectral analysis of a 10 Hz broadband signal to 10 Hz resolution with a redundancy of 2 requires, as a minimum, digitisation at a rate of 20 kHz and the computation of a 2048-point spectrum in 50 ms. A solution circa 1982, used by British Antarctic Survey at both their Cambridge headquarters and their Antarctic field station Halley (76S, 27W) until 1990, was described by Smith and Yearby (1987). This was known as AVDAS Mk 1 (Advanced VLF Data Analysis System). In March 1990, a completely new version of this system (AVDAS-II) was brought into operation, based on the latest DSP (digital signal processing) technology; this has since been developed to become essentially a universal VLF instrument.

The system specifications and overall philosophy originated at BAS, driven by the research requirements for acquisition and analysis of VLF radiowave data. Detailed design and construction were carried out by High Greave Associates, Sheffield. Several systems are now in use around the world. The system is described briefly in this article; although it has been developed and primarily used to date for the processing of VLF radio-wave data, there is no reason why it should not be applicable to any real time signal-processing application in the same frequency range (eg speech analysis).

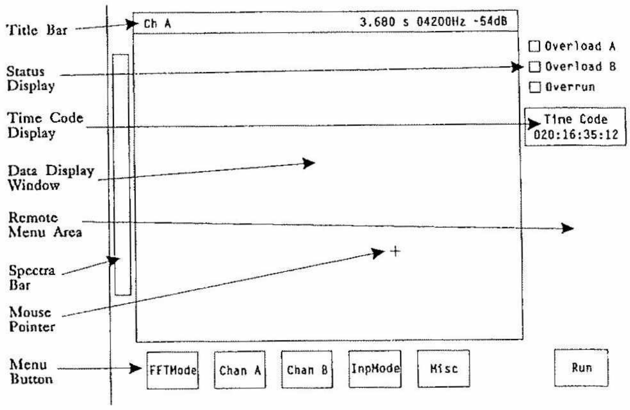


Figure 1. The screen layout for the DSP-FFT application. When the AVDAS application is running on the host computer, tape recorder control buttons (play, stop, rewind, fast forward) appear in the remote menu area. Current settings may be examined or changed by clicking the menu buttons or by issuing SHOW or SET commands on the host computer.

2. Design philosophy

The core signal-processing capability is provided by an Analog Devices ADSP 2100 DSP chip. The remainder of the hardware is built around this to form a standard hardware platform, designated by High Greave Associates as the DSP-II platform, which provides a flexible advanced real-time system. The functionality of the system is provided by application firmware which is mounted on the hardware platform. Great flexibility is achievable in that a particular system specification or upgrade may be implemented primarily by modification of the firmware alone, often with no changes whatever to the hardware. Further versatility is provided by application software which resides on a host computer, and communicates with the firmware/hardware.

3. Brief hardware description

The DSP-II euro-style rack contains a power supply and four standard circuit cards which plug into a backplane: analogue input, DSP, graphics, and control processor. There is space for other, optional, cards: time code reader, memory expansion, secondary DSP, disc drive controller, analogue output, and general input/output. Connections are provided for the input signals, VGA colour monitor, mouse, RS232 port for the host computer, digital output, and parallel printer.

3.1 Analogue input card

This provides two 12-bit analogue data acquisition channels with simultaneous sampling rates selectable up to 102.4 kHz. Each channel has a programmable anti-alias filter with a cut-off at the current sampling rate divided by 2.56, giving at least 60 dB rejection of any potential alias. Independently programmable-gain amplifiers provide for a range of signal levels between 0.1 and 10 volts peak (AC or DC coupling).

3.2 DSP card

This contains the ADSP 2100 DSP device, running at a clock speed of 32 MHz (8 Mips), with 16k words of data RAM, 16k words of program RAM and FIFOs for data interface with the control processor and digital output.

3.3 Graphics card

This provides a frame buffer of 1024 x 512 eight-bit pixels. An Inmos G300 device provides timing for 640x256 and 640x512 non-interlace screen formats and a 24-bit colour lookup table enables the display of any 256 colours from a palette of 16,777,216. A hardware accelerator can perform high-speed rectangle fills and moves.

3.4 Control processor

This controls everything except the actual signal processing. It comprises a Motorola 68010 CPU with 64k ROM, 64k RAM, a dual UART and two PIAs. The operating software is normally supplied in EPROM.

3.5 Time code reader card

BAS analogue magnetic VLF data tapes contain an IRIG-B time code (1 kHz carrier). This card, containing its own Motorola 6809 processor with associated RAM and ROM, reads the time code and outputs the day number and time to the control processor.

4. Configuration as AVDAS

In this configuration the system acts as a powerful and highly flexible real-time spectrum analyser for analogue broadband signals, either live or previously recorded on tape. BAS currently use both analogue reel-to-reel tape and DAT (digital audio tape), but other there are other possibilities (eg video tape). The DSP-FFT application, which calculates Discrete Fourier Transforms of the input signals with a real-time bandwidth up to 40 kHz using the Fast Fourier Transform algorithm, is loaded on the DSP-II hardware platform. Typically this will be in ROM on the control processor board, which loads it into RAM on power-up. Alternatively, any application code can be downloaded from the host computer as Motorola 'S28' records. Although the DSP-II platform and DSP-FFT application together can be used in stand-alone mode, it is more usual to have a host computer connected. As well storing download code, and initialisation files for commonly-used operating parameter setups, the host can record on disc any processed data files and the results of the data analysis session. In our installation at BAS HQ Cambridge, the host computer is an IBM-compatible PC running the AVDAS application (though a Macintosh could equally well be used). Since all the fast processing tasks are carried out by the DSP-II hardware platform running the DSP-FFT application, the host computer does not require a high specification (we currently use an old XT!).

The DSP-FFT application provides:

Channels A and B (typically the north-south and east-west wave magnetic field components): input sensitivities of 10V, 3V, 1V, 0.3V, 0.1V; AC or DC coupling.

FFT analysis modes: Transform sizes 256, 512, 1024; logarithmic or linear power output; Flat, Hanning or Hamming input window functions.

Other analysis modes: Broadband power over the selected frequency range.

Data capture modes: unprocessed time series data.

Display: Spectrogram or oscilloscope display of the Fourier transform output, oscilloscope display of the broadband data.

Frequency ranges: 40, 20, 10, 5, 2, 1, 0.5, 0.2, and 0.1 kHz; sampled at 2.56 times, with and without appropriate anti-alias filtering.

Redundancy: 1 (no overlap), 2 (50% overlap), or 4 (75% overlap).

Remote control: all functions via the RS232 serial interface.

Control of the system and setting of analysis parameters is achieved either by using the mouse to 'click on' pull-down menu boxes and buttons shown on the display screen, or by typing commands on the host computer running the AVDAS application.

The data are presented in large display windows on the screen. For spectrogram data, frequency and time run vertically and horizontally respectively. Colour (or grey scale if selected) indicates signal intensity. Either or both channels may be displayed, using either a single or a split display window. Besides the buttons for setting the analysis parameters (frequency range, input gain, transform size, etc) the screen also has buttons for controlling the tape recorder (play, fast forward etc), input signal overload indicators, the current data time (from the tape time-code) which is continually updated, and a colour palette (which may be changed, eg to grey scale). In logarithmic power mode, the default full-scale range is 90 dB but the top and bottom of the range may be changed as required, to give the desired contrast to the spectrogram. There is an indication of the coordinates (time, frequency and amplitude) of the current position of the mouse-driven cursor.

In the "run" mode, the incoming signal (usually from a playback tape recorder), is continuously processed and the display screen shows a continuously refreshed spectrogram (either constantly wiping across the screen from left to right, or else scrolling from right to left with the right hand side being constantly updated). Averaging may be invoked if required, ie averaging together sets of 2, 4,...or 256 consecutive spectra to provide a smoothed output with a correspondingly compressed time scale. At any time the display may be frozen on demand (the tape playback stops) and the displayed spectrogram processed in a variety of ways. The cursor may be used to measure (and log to disc) the amplitude, frequency and time of any features seen in the spectrum. The application incorporates a facility for extracting and saving the power as a function of frequency, averaged over a specified time interval (ie a power spectrum at a particular time) or the power as a function of time, averaged over a specified frequency interval (this would be the output if the input signals had been passed through a band-pass filter). An explicit capability is included for whistler scaling, which permits the L-shell of propagation and the magnetospheric equatorial electron density to be estimated from three frequency-time coordinate pairs on the whistler profile (Ho and Bernard, 1973; Park, 1982). Arrival azimuths can be estimated either if a goniometer signal (Bullough and Sagredo, 1973) is input to channel A and the azimuth reference to channel B, or else if north-south and east-west signals are separately input to channels A and B; in the latter case the signal polarisation can also be estimated (Yearby and Smith, 1994). All or part of the current screen data may be saved to disc in either spectrum or time-series format and may later be recalled on demand. Alternatively, all or part of the displayed data may be output to a printer as a hardcopy plot (colour or monochrome according to preference).

Any of these features could be easily modified, or new ones added, by rewriting or modifying the AVDAS program which runs on the host PC and remotely controls the DSP-FFT application running on the DSP-II platform. Full details are given in the manufacturer's user manual (High Greave Associates, 1993).

5. Configuration of Quick-look data plots

Often it is useful to have a summary plot of the spectra of signals on a whole data tape (Smith, 1993). We are able to achieve this using a special QLOOK application (a product of High Greave Associates, commissioned by BAS), consisting of code downloaded to the DSP-II and an associated program which runs on the host computer. In this application there is no output to the display screen. The frequency range may be selected to be 4, 8, 16, or 32 kHz, and compressed data spectrograms are produced in either continuous, sampled 1-minute-in-5, or sampled 1-minute-in-15 format. For the standard 8 kHz setting, the frequency resolution for the 40-point spectrum is 200 Hz and the time resolution is 72 spectra per minute. Graphics files containing the required plots are saved to disc for later plotting; a plotter supporting resolution of at least 180 dots per inch is required. 1h 6h or 12h of data, depending on the sampling mode, are compressed on to a single-page plot. Operation may be either synchronised or unsynchronised. In the former case, the time code on the tape is read and used to ensure the correct formatting. The latter option is invoked when no time code is available, and in this case the system is free-running from a known starting time. Fig. 5 of Smith (1995) shows an example of the output.

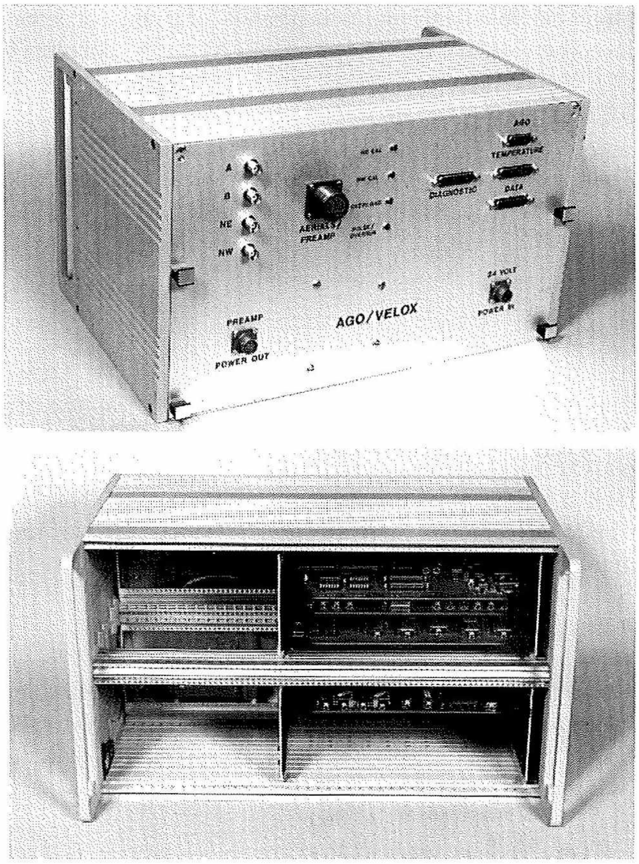


Figure 2. The AGO VELOX. (top) Exterior view showing external connections. (bottom) Interior view. The cards which are visible on the right are (from the top): Analogue input; DSP; AGO interface and calibration (a non-standard card specifically designed for the AGO-VELOX); control processor.

6. Configuration as VELOX

Since January 1992 a continuous multichannel ELF/VLF receiver has been running continuously at Halley. This is called VELOX (VLF/ELF logger experiment), and data from it form part of the BAS contribution to the Global Geospace Study (Dudeney et al, 1994). The instrument is fully described in the paper by Smith (1995). Broadband horizontal magnetic field components of the received waves are filtered into eight frequency bands in the range 0.25-10 kHz and processed to provide mean log amplitude, arrival azimuth, polarisation, and maximum/minimum levels, in each of these eight bands, at 1 s time resolution. All the filtering and other processing is achieved by a dedicated DSP-II platform (without a graphics card as none is needed here), loaded with specially-designed VELOX application firmware. The two inputs are the analogue signals from the north-south and east-west aerials, and the formatted output data files are written to disc. Control (for example of the input gains) is provided from the VELOX software which runs on the host computer. Again the application was specified at BAS in response to scientific requirements, and implemented by High Greave Associates.

There were a number of practical and financial advantages in the approach outlined above, as opposed to the development of a completely new receiver from scratch. Firstly, no new development of hardware was required, only software which was largely based on what already existed for the implementation of the AVDAS. Secondly, the provision of spare cards at Halley would be minimised since both AVDAS and VELOX used identical ones. Thirdly, the receiver characteristics can be relatively easily changed in the future, should this be required, for example to add new frequency channels or change the centre frequencies or bandwidths of existing channels.

A version of VELOX has been designed for use on the BAS AGOs (Automatic Geophysical Observatories) in Antarctica (Dudeney et al, 1994). Although the hardware is essentially compatible with the standard DSP-II platform used for the AVDAS and VELOX, the AGO-VELOX version has low temperature versions of some of the components and is specifically designed to minimise power consumption (the AGO uses batteries recharged by a wind-generator as its power source). GPS time is received from and data are sent to the AGO bus. A special card provides this interface, via PLDs and a FIFO; this card also incorporates calibration facilities (which for the Halley VELOX are provided externally). The software (all permanently written into ROM; there is no host PC in this application) is a version of VELOX, slightly modified to allow for the smaller number of channels and the longer sampling times (still 1 s for power but 10 s for all the other parameters), imposed by data rate constraints on the AGO. In addition to the "filterbank" data, the AGO-VELOX also provides a broadband "snapshot" once every 15 minutes. The first AGO-VELOX (see Figure 2) is currently under test at BAS HQ and should be installed on the A80 AGO (located at 80.8S, 20.4W) during the 1994-95 summer season.

Conclusion

Essentially the same DSP-based system, configured in several different ways to satisfy different requirements in VLF data acquisition and analysis applications, has been described. This strategy has been used very successfully in the BAS research programme. In principle the system could be programmed to implement virtually any type of VLF receiver, for example a narrow-band "trimpi" receiver designed to measure the transient phase and amplitude perturbations observed on VLF transmitter signals due to lightning-induced electron precipitation (Smith and Cotton, 1990).

For further information on HGA products, please contact Peter Hughes at his address given below.

References

Bullough K and Sagredo J L (1973) VLF goniometer observations at Halley Bay, Antarctica - I. The equipment and the measurement of signal bearing. *Planet Space Sci 21*, 899-912.

Dudeney J R , Rodger A S , Smith A J , Jarvis M J and Morrison K (1994) Satellite Experiments Simultaneous with Antarctic Measurements (SESAME). *Space Sci Rev* (in press).

Helliwell R A (1965), *Whistlers and related ionospheric phenomena* , Stanford University Press, Stanford, California.

High Greave Associates (1993) *DSP-II Digital Signal Processing System User Manuals*, Edition 3.2, January 1993, HGA Sheffield.

Ho D and Bernard L C (1973) A fast method to determine the nose frequency and minimum group delay of a whistler when the causative spheric is unknown. *J Atmos Terr Phys 35*, 881-887.

Park C G (1982) Whistlers. in *CRC Handbook of Atmospherics*, vol 2, edited by H Volland, pp 21-77.

Smith A J (1993) Quicklook plots from VLF data. *VERSIM Newsletter 5*, p 7, July 1993.

Smith A J (1995) VELOX: a new VLF/ELF receiver in Antarctica for the Global Geospace Science mission. *J Atmos Terr Phys* (in press).

Smith A J and Cotton P D (1990) The Trimpi effect in Antarctica: Observations and models. *J Atmos Terr Phys 52*, 341-355.

Smith A J and Yearby K H (1987) AVDAS - A microprocessor-based VLF signal processing and spectral analysis facility for Antarctica. *Br Antarct Surv Bull 75*, 1-15.

Yearby K H and Smith A J (1994) The polarisation of whistlers received on the ground near L=4. *J Atmos Terr Phys 56*, 1499-1512.

A J Smith[1], P Hughes[2], K H Yearby[3]

1:British Antarctic Survey, Madingley Road, Cambridge CB3 7XT
2: High Greave Associates, 247 High Greave, Sheffield S5 9GS
3: Department of Automatic Control and Systems Engineering, University of Sheffield, Sheffield S1 4DU

A DSP system for the Macintosh computer

Product Information

The Digital Signal Processing (DSP) system is a DSP computer hardware and software package designed to digitise and process real-world analog signals. The DSP computer can connect to Macintosh computers and the software includes Macintosh programs that give the user full control of the DSP computer. The system was locally designed and has found to be very useful in a number of research groups within the Physics Department.

What is DSP ?

There are many techniques which are used for the analysis of signals. These include filtering, Fourier transforms to mention only a few. Traditionally these techniques could be applied using analog devices. Usually these are capable of performing only one specific signal processing task (eg filtering at a specific frequency). Digital signal processing systems, on the other hand, are general purpose signal processing tools which can be reprogrammed to do an almost infinite variety of tasks.

As stated previously, DSP stands for digital signal processing. What does this mean? In general a signal carries some kind of information that is of interest to an observer. An example would be an audio frequency voltage as a function of time. Processing is when an operation is performed on that signal to extract some desired information. For example, a Fourier transform could be used to obtain the power spectrum of the audio signal. Digital refers to the fact that the processing is done with a digital computer or purpose-built digital hardware. Continuing our example, a microcomputer could implement a FFT algorithm in software to produce the power spectrum. The main advantage of DSP over analog signal processing is flexibility. By changing the software, the same DSP system can be used for different applications.

The DSP System's features

The system is designed to connect to Macintosh computers. It includes both hardware and Macintosh software. The hardware is based around an ADSP-2105, a programmable single-chip microcomputer, produced by Analog Devices. The 2105 is optimised for DSP and other high speed numeric processing applications. It features a Harvard architecture which allows for simultaneous access to program and data memory. The 2105 runs at 10 Mips and can perform a 1024 point FFT in 3.7 ms. In our device, circuitry includes analog signal input and output capabilities with sampling rates up to 100 kHz at 16 bits resolution, dual serial ports for communicating with terminals etc., an expansion port for adding additional hardware and a SCSI (Small Computer Standard

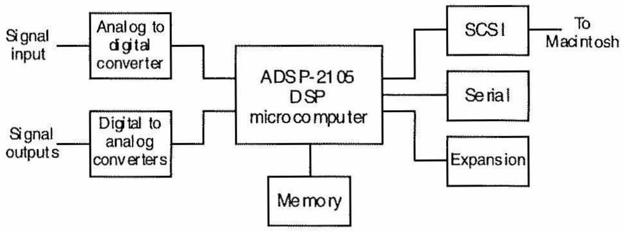


Fig 1. Functional diagram of the Digital Signalling Processing system

Interface) bus which is used to communicate with the Macintosh computer. Figure 1 shows a block diagram of the overall system.

As with any computer, we need the ability to write programs and exchange data with the 2105 processor. That's where our locally-developed Macintosh software, called SpAsm, comes in. SpAsm integrates a text editor, a 2105 assembler, a linker and a SCSI communication package. SpAsm is used for developing DSP programs for the 2105 processor and sending these programs and data between the Macintosh and 2105. SpAsm can read and write MATLAB files. This is useful when, for example, designing digital filters with MATLAB. The filter coefficients can be downloaded and the real filter tested immediately. SpAsm's key feature is that it's an integrated environment. Your DSP source code can be written, assembled and downloaded to the DSP system and the results retrieved all from within the SpAsm program.

Applications

Figure 2 shows the DSP system running GRAFT, a real time spectrum analyser for the Macintosh. VLF radio signals are digitised and a FFT is performed by the ADSP-2105 processor. The spectral data is then transferred, via the SCSI bus, to the Macintosh and the results are display on the Mac's screen in real time.

[GRAFT is detailed in the following article]

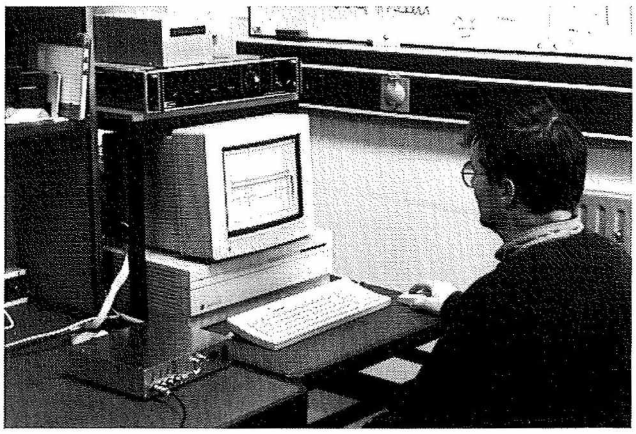


Fig 2.DSP system shown here to the left of an Apple Macintosh IIfx running the application GRAFT (detailed in the following article)

Other DSP applications have included:

- Recording of VLF whistlers
- Analysis of the chaotic motion of a vibrating string.
- Real-time lightning detection and location.

To conclude, we have an inexpensive signal processing tool and development environment which can be used to perform a multitude of DSP tasks.

For further information contact James Brundell at the address below.

James Brundell, Tim Molteno

Physics Department, University of Otago
PO Box 56, Dunedin, New Zealand
e-mail: james@physics.otago.ac.nz

GRAFT: A graphical VLF frequency analysis program for the Macintosh

GRAFT (Graphical Radio Analysis by Fourier Transform) was written to replace and improve on an existing rayspan (electro-mechanical) device, using modern computer technology. The program's main function is to receive VLF data, Fourier-transform it to obtain the power at the various frequencies, and then display this power information on the screen in colour (Fig 1). This display of power (as varying colours) vs time and frequency is often called a spectrogram. In conjunction with the Digital Signal Processing system (DSP) described in the previous article, the program can give this display of the VLF band in real time at sampling rates up to 100 kHz. The data, once collected and processed, can be displayed in other ways to aid analysis.

It was designed to be a stand-alone, Macintosh friendly application, needing only an external source of digitised VLF data, but also to be closely integrated with the DSP, to use its extra power where needed for the fast Fourier transforms (FFT).

The program operates in two main modes. It can sample the data into the Mac, and then FFT the data to give a single spectrogram. The maximum time sampled depends on the sampling rate and size of the display. The data can then be saved as either raw sampled data or processed power data. Various power averages and other information can then be extracted from the data. The display is quite detailed and the modulation of the VLF stations can be clearly seen at the

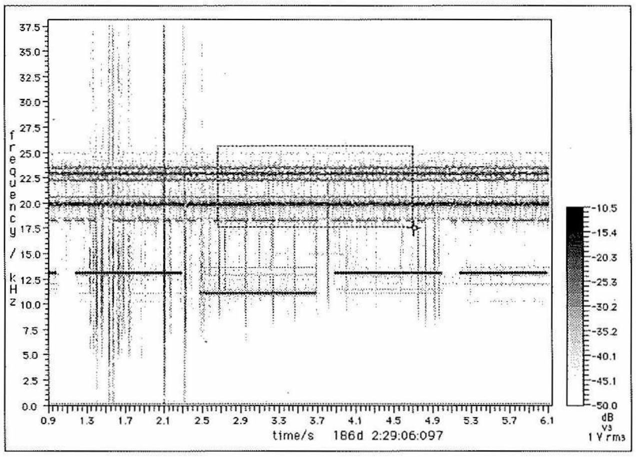


Fig 1. Screen sample showing spectrogram of VLF signals: note Omega and MSK stations. The boxed area shows the data used in Fig 2. GRAFT normally uses colour; greyscale is available for printing purposes (as used here).

default sampling frequency of 100 kHz. The other main use of the program is in the real-time display of the power data. This needs the DSP board for the simultaneous sampling and Fourier transforming of the data. This mode works up to 100 kHz, and gives the same information as the other mode, but without any time limitation problems. In this mode the sampled data is not available to the computer.

GRAFT also has a means of automating the collection of the average power from set portions of the frequency spectrum, and logging them to a file for later analysis. It can also display a real-time averaged power vs frequency line plot to find the power distribution of any signal. If a whistler has been recorded, there are routines to give an artificial whistler which can be manually fitted to the real one (Fig 3), and the various parameters read off. A dispersion (1/f vs time) plot is available to linearise the whistler so its time of origin can be extrapolated.

GRAFT has been used at Otago for general monitoring of the

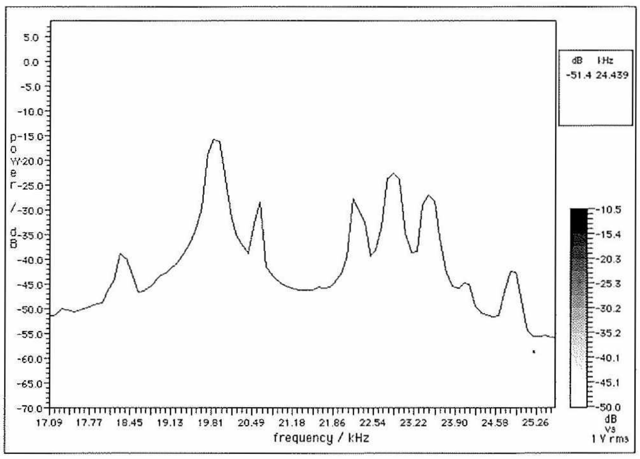


Fig 2. Line-plot of power vs frequency shows the band profile of the signals selected by the box in the previous screen (fig 1).

condition of the VLF band using the real-time display, and also specific monitoring of some VLF stations and received amplitude. It has also been used for research into the effects of solar flares on the ionosphere and VLF transmission, and studies of power line harmonic radiation from data pre-recorded by ISIS satellites (to be published).

The program was written for VLF analysis but can be used as a general frequency analyser for any frequencies in the 0-50 kHz region. Audio data has been successfully studied using GRAFT by simply using lower sampling frequencies to give better frequency resolution.

Features:

- Standard Macintosh application, using the usual menus, keys and mouse etc making it very easy to use. All DSP (and/or ADC) control routines and code built in to the program so no external programs are needed for its use.
- Accepts a variety of data inputs: data straight from an ADC, from DSP board or even pre-digitised signals from disk. This means it can run without DSP or ADC even attached to the computer.
- Uses DSP board for simultaneous sampling and fast computation of Fourier transforms. This allows real-time display of up to 100 kHz sampling rate, and faster data processing for the other modes. The program has internal FFT routines so data processing can still be done with out the external DSP board.
- User-controlled sampling rates from 0-100 kHz and variable sized transforms to get the desired frequency/time resolution.
- The user can select an area of the display with the mouse (see Fig 1) and the program will show the average power of the area, either as a single number or as an average power vs frequency line plot (Fig 2).
- The colour power scale can be set by the user to get best contrast for the signals, or to focus in on some fine detail, or has automatic scaling to get best power spread for the data. The actual colours used in the power display can be changed for personal preference or to produce grey-scale pictures for printing purposes.
- Fourier transform can have 1024 or 2048 points in real time, and there are 256 and 512 point transforms available using the internal FFT routines. There is also a choice of four different data windows for all the transforms:-Square, Parzen, Hanning, Hamming.
- Whistler analysis with manual curve fitting of an artificial whistler (Fig 3) and also a dispersion (1/f) display to aid the curve fitting.
- Programmable automatic frequency/power measurements and data logging over extended periods of time.

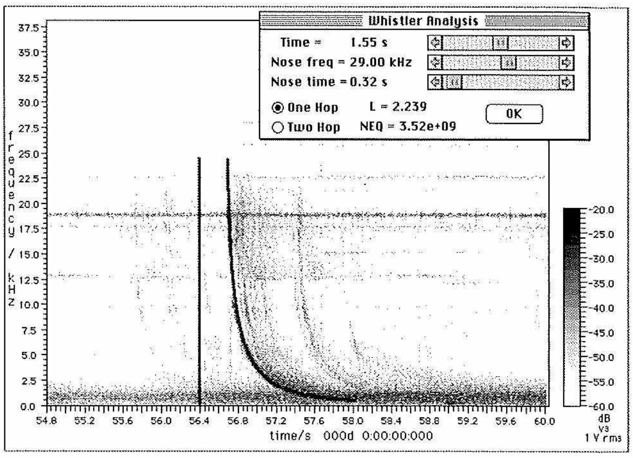


Fig 3. Screen-shot demonstrating GRAFT's Whistler Analysis curve-fitting function: a model whistler curve (seen here in black) is fitted to the displayed event and adjusted in shape using the controls in the dialog box.

- Optional input from a time code reader to give the absolute time on the display. (The time code reader was produced as a MSc project in the Department.)

Requirements

- Macintosh computer, with 14" or bigger colour monitor, and at least 3 Mb free RAM.
- A maths coprocessor (can be emulated but is very slow).
- A source of digitised data is also needed.
- For real-time display a DSP board and a Mac II (or faster) are required.

Although GRAFT will run without one, the DSP board is recommended to get the best from this software.

For further information please contact Neil Thomson, at the Otago Physics Department address below.

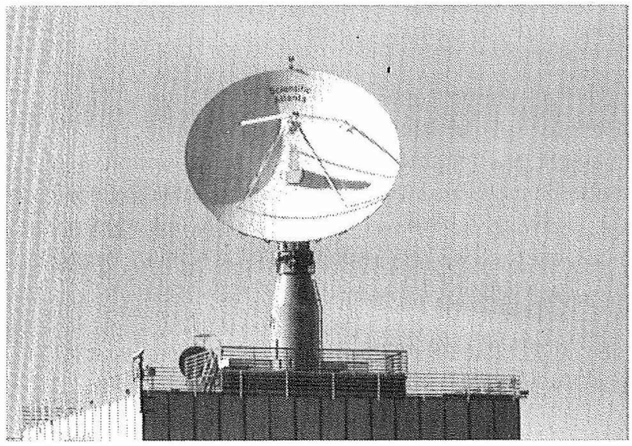
Paul Connor*,
James Brundell†, Neil Thomson†, Tim Molteno†
**Chemistry Department, †Physics Department,*
University of Otago, PO Box 56, Dunedin, New Zealand
email: thomson@newton.otago.ac.nz
fax +64-3-479 0964

New Products and Services: Contributions to this department are welcome. These are not peer refereed so the authors must be in a position to bear some responsibility for the product or service described. Thus claims for products must be based on first-hand knowledge and authors must have authority to offer services. All products and services should be appropriate to radio science and use by readers should be attainable in principle (eg, though a joint research project) if these are not commercially available.

The Alaska SAR Facility: What it is. What it does.

Introduction

The Alaska Synthetic Aperture Radar Facility (Alaska SAR Facility, ASF) is a NASA project housed within the University of Alaska's Geophysical Institute at Fairbanks, Alaska. The Geophysical Institute engages in a wide range of topics primarily focused on high-latitude research. As part of the university research environment, ASF uniquely integrates the acquisition of satellite remote-sensing data, processing, archiving, and world-wide data distribution in support of scientific research and applications. Staffed by over 50 people including scientists, engineers, technicians, management, and administration, the ASF is one of the eight Distributed Active Archive Centers (DAAC) which comprise the NASA Earth Observing System Data and Information System (EOSDIS).



The Alaska SAR Facility 10-metre tracking antenna shown on the roof of the Geophysical Institute at the University of Alaska Fairbanks.

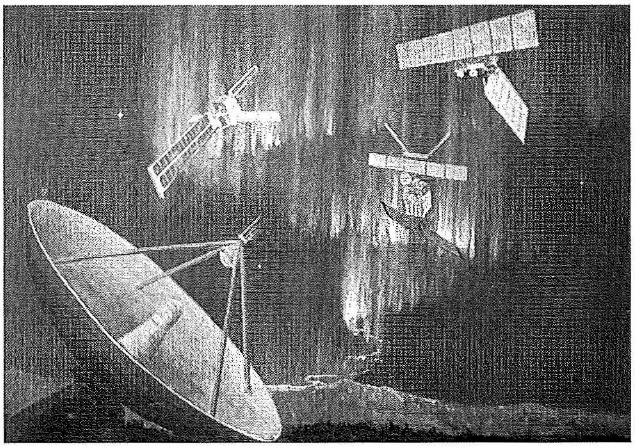
Brief History of ASF

The establishment of the ASF was the culmination of a long-term planning effort dating back to the brief but successful SEASAT mission in 1978 which demonstrated the value of spaceborne SAR for remote sensing of sea ice and oceans. The ASF project is funded by NASA, with major development activities occurring at the Jet Propulsion Laboratory (JPL) in Pasadena, California. Data is acquired under agreements between NASA and foreign flight agencies, which allow the University to distribute products for research purposes.

Daily Operation

The Alaska SAR Facility operates 24 hours per day, 365 days per year. At the present time signal data from 8-10 passes per day of the European satellite ERS-1, and 2-4 passes per day of the Japanese satellite JERS-1 are being recorded. This workload will increase in 1995 when RADARSAT is launched by the Canadians.

In order to obtain nearly complete earth coverage, most free-flying SAR satellites are in polar orbit. ASF's location at 65° N provides excellent coverage of the Arctic to observe sea ice and other high latitude phenomena. In addition, a ground station at a higher latitude receives more passes per day than one at lower latitudes. Thus Alaska is an ideal site for a ground station.



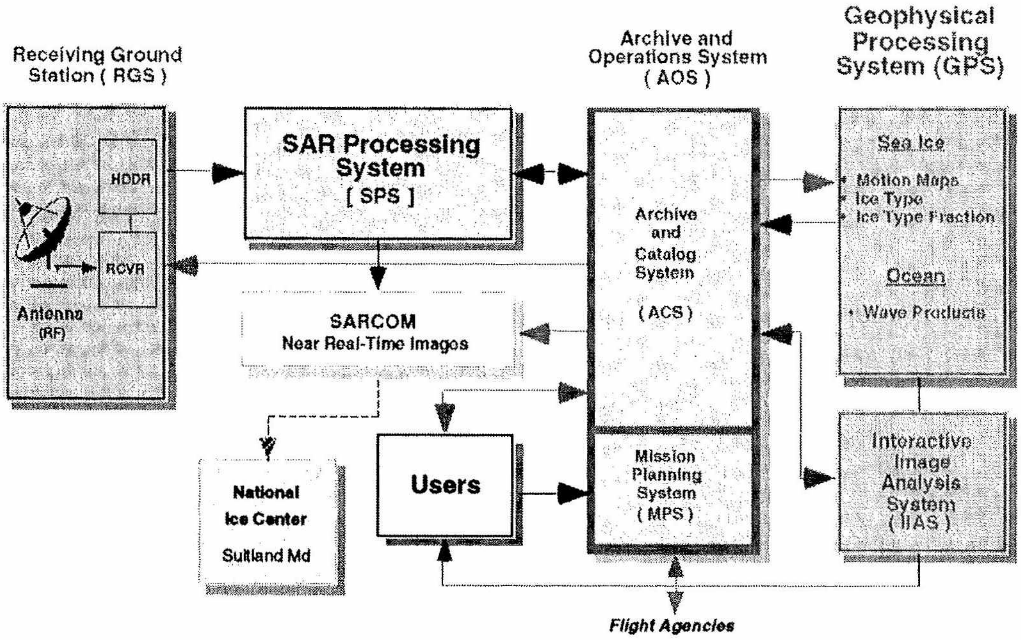
An artist's rendition of the ASF antenna and three SAR satellites, ERS-1, JERS-1, and RADARSAT. "Birds of a Feather" by Donna Eldora Sandberg ©1989 Geophysical Institute

The operation of the station is highly automatic; the actual down linking and recording of the data can be done by only one station operator. However, the normal staffing compliment is two operators on each shift which includes data acquisitions, processing, and the filling of requests for copies of the data from scientific users. In addition to the operators who record and process the data, there are a number of software and hardware engineers, maintenance personnel, and archiving and distribution specialists.

Users are located all over the United States, Canada, and a few other international locations. They obtain data by accessing a catalogue system via computer network (Internet). Once logged in, they may perform searches of the holdings, place requests for data products, check on the status of their account and request future data acquisitions. A user desk has been established to monitor the flow of orders, perform troubleshooting services, and maintain a local image-browse facility.

Some of the metrics of the system include:

- Downlink data rates for the RGS are as high as 105 Mb/s.
- An archive storage cassette holds 47 gigabytes.



Alaska SAR Facility Functional Block Diagram

- An optical disk jukebox containing 89 platters containing 2 gigabytes each for on-line accessible archive.
- A bank of 43 terrabytes of off-line data archive.
- A special purpose SAR processor capable of 3500 Mips.
- An X-band gain over noise temperature (G/T) for the 10 meter dish of 32.5.

What is SAR and How Does it Work?

Synthetic aperture radar theory was developed in the 1950s. Initially it was used in airborne SARs, but now is also installed on spacecraft as a way to conduct large-area global sensing. The concept of SAR is to use a radar signal with a well-defined horizontal and vertical beam width to illuminate an area and receive the echo just like any other radar. What makes SAR so different is in how that returned signal is used. Normal radar takes the returned signal and presents the information as range and intensity (measure of signal amplitude) in a display or in a computer. The key to SAR is that each resolution cell (smallest part of an image) is calculated from multiple echoes using the *phase* information of the signal as well as the amplitude. The number of echoes used per cell in the calculation is based on the synthetic aperture of the radar, which in the case of a satellite is a distance along the satellite's flight track.

The processing algorithms for SAR processing are based on proven theory which states that the range resolution along the track is one-half of the length of the antenna. Thus, the shorter the antenna's real aperture the better the resolution. This is counter-intuitive for many people who think that better resolution comes with larger apertures (antennas). This is one of the major differences between real aperture and synthetic aperture radars. For SAR the resolution increases as the antenna size decreases — but as antenna size decreases the received signal level decreases (thus intuition still applies, but for SAR the best information from the signal is in the phase and not the amplitude).

The raw SAR data are downlinked from a satellite to ground stations such as ASF and others around the world.

The satellite with a SAR may or may not have an on-board tape recorder. If it does not, then the only area imaged by the satellite must be where there is mutual visibility between the ground station, the image location, and the satellite. This area is defined as the station mask, and is a function of the horizon as seen by the antenna and the altitude of the satellite.

Real-time data may be downlinked at rates as high as 105 megabits per second while the tape recorder downlink may run as high as 60 Mb/s. A typical pass may be as long as 10 minutes. This results in single pass data received in the neighbourhood of 63 gigabits. Both raw data and processed data are archived on high-density data recorders which have storage capacities of as high as 47 or 57 gigabytes per cassette cartridge depending on the brand and model.

A typical SAR image from currently operating SAR satellites is 100 km by 100 km. A resolution cell is on the order of 12.5 meters by 12.5 meters. Quick calculation shows that there are a large number of resolution cells per image and each cell takes 650 to 900 computer calculations to derive. A standard full-resolution image produced at ASF is 64 MBytes in size.

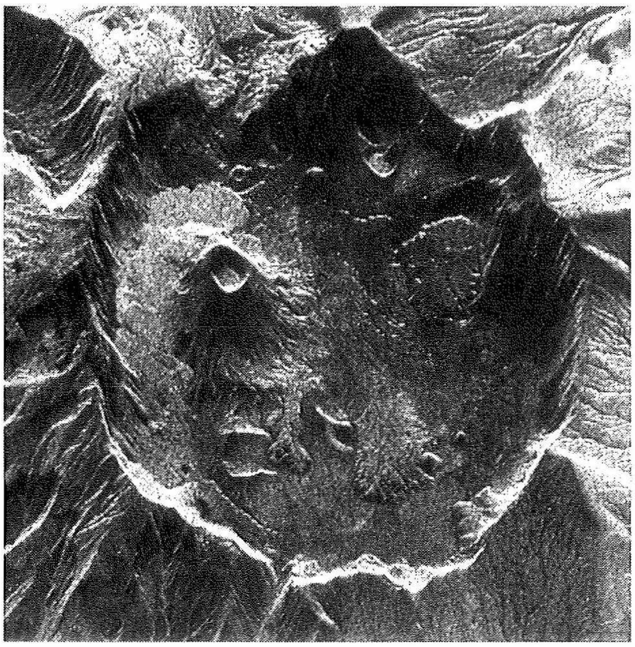
Data Sets

ERS-1 (European Remote Sensing Satellite-1), placed in orbit in July 1991, is the first civilian satellite to carry a SAR instrument since SEASAT. The first ERS-1 SAR data provides an all-weather, all-season look at the earth. Direct reception from the ERS-1 satellite at ASF is limited to an area within a 3000 km radius of Fairbanks (the station mask), which includes Siberia, Alaska, northern and western Canada, and portions of the Pacific Northwest. The ERS-1 C-band SAR was designed to provide high-quality imagery and launched a new era in remote sensing

JERS-1 (Japanese Earth Resources Satellite-1) acquisition began at ASF in May of 1992. This satellite with an L-band sensor emphasises land resource applications including geology, geomorphology, glaciology and vegetation monitoring. This satellite carries a tape recorder which allows limited acquisition of data outside the ASF station mask.

ASF produces a number of different ERS-1 and JERS-1

SAR image (© ESA 1992) of west Fairbanks on 25 April 1992. This was the first time SAR data were obtained directly over the Alaska SAR Facility, indicated by the star-shaped impulse response from the 10-m parabolic receiving antenna on the roof of the Geophysical Institute, University of Alaska, Fairbanks. This 1024 by 1024 pixel (12.5 by 12.5 km) subscene of a standard full resolution scene also shows Fairbanks International airport, the Chena and Tanana Rivers, field and street patterns, highways, and the Alaska Railroad.

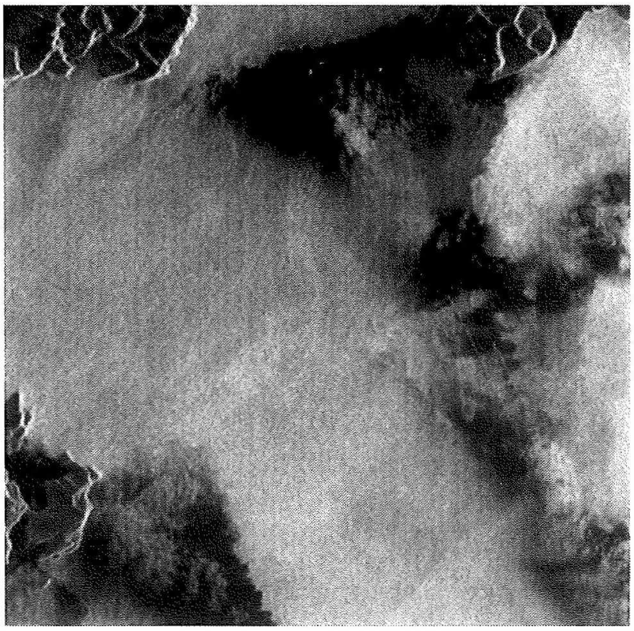


SAR image (© ESA 1992) of Aniakchak Caldera, Alaska Peninsula 10 September 1992. The caldera is about 10 km in diameter and formed 3400 years ago during a large ash eruption. This 1024 by 1024 pixel (12.5 by 12.5 km) subscene of a standard full resolution scene also shows vent mountain and other smaller pyroclastic cones, and a number of lava flows.

products for distribution to users in digital and non-digital form. Data are initially processed into Standard Full Resolution scenes with ground dimensions of 100 by 100 km, 12.5 m pixel size and 30 m spatial resolution. A Standard Low Resolution product, with the same ground dimensions but 100 m pixel size and 240 m spatial resolution, is derived from the Standard Full Resolution product by application of an 8 by 8 averaging technique. The Full and Low Resolution products are also available as geo-coded scenes with a Universal Transverse Mercator or a Polar Stereographic Projection.

The standard products are available in digital form on 8 mm tape or 9-track CCT, and in non-digital form, including positive and negative transparencies, a standard 10 by 10 inch positive print and 5x and 10x enlarged prints. Complex image data are also available on tape for interferometric studies of topography and feature motion. ASF also distributes raw signal data on tape for those who wish to correlate their own signal data into scenes.

ASF also operates a Geophysical Processor System (GPS) which performs automated analysis of SAR scenes to produce higher-level data products. The GPS products presently include: (1) sea-ice classification (concentration of different types of sea ice and area of open water; (2) sea-ice motion vectors and, (3) ocean wave spectra (wavelength and direction).



SAR scene (© ESA 1992) of eastern Prince William Sound, Alaska, 28 March 1992. The generally grey appearance suggests that it was windy at the time and the rough water surface was contributing to strong returns to the radar antenna. The smaller, dark patches are probably locally calm areas. There are two prominent V-shaped features on the right side of the scene; they are ship wakes, perhaps from fishing vessels or oil tankers heading for Valdez, the location of the Trans-Alaska Oil Pipeline Terminal. The Exxon Valdez ran aground near Bligh Island in the upper right corner of the scene.

Two additional satellites which ASF will support are currently in development.

ERS-2, which is scheduled for launch in 1994, will have a SAR essentially identical to the ERS-1 SAR (other on-board sensors will be different from those on ERS-1, but their data are not received at ASF).

RADARSAT is being built by the Canadian Space Agency (CSA) and is scheduled to be launched by NASA in early 1995. This C-band SAR will bring considerable enhancement to the satellite SAR remote sensing capabilities as it will have more modes of operation, and thus cover much larger areas at low resolution, or smaller areas in greater detail than ERS-1 or JERS-1. RADARSAT will have an on-board tape recorder and will downlink data from throughout the world at ASF.

Because ASF is a Distributed Active Archive Center (DAAC) of NASA's EOS Data and Information System (EOSDIS), in the future it will be able to provide access to other data sets located across the country, and across the spectrum of research. This will be facilitated by the use of common data formats and catalogue systems.

In addition, non-SAR data sets currently available from the Geophysical Institute's GeoData Center include Landsat and AVHRR imagery, and Alaska High Altitude Photography. These in-house collections provide coverage of Alaska since the early 1970s.

Who Uses ASF?

ASF serves users from a variety of backgrounds and organisations. We have current research projects from research faculty at a number of universities, government agencies (NASA, USGS, CRREL, NOAA, etc), and high-school teachers. The research includes studies of sea-ice geophysics (floe size, distribution, motion, type, air/ice/ocean interactions), vegetation regeneration after fires, fisheries studies, lake-ice growth, glacier mass balance and dynamics, volcano monitoring, geological mapping, ocean wave environment, etc, and operational support (field camps, ship cruises, etc) via the National Ice Center. Examples of SAR scenes and ASF data are shown in this article. They include Fairbanks, Alaska; the caldera of Aniakchak Volcano, and ship wakes in Prince William Sound.

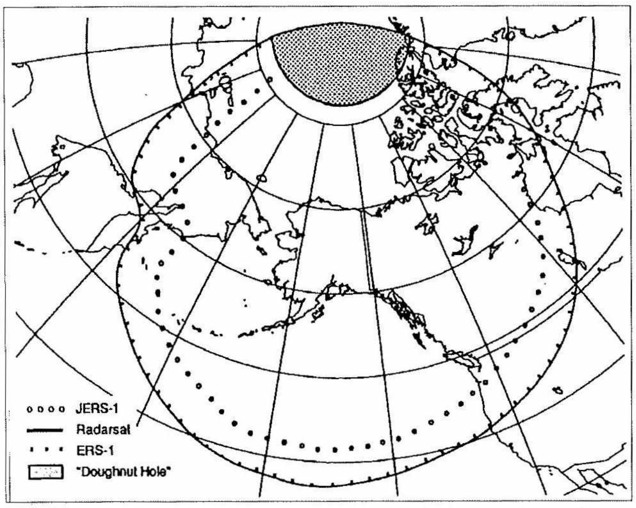
Data can be requested and acquired for ongoing activities, or generated from the catalogue of retrospective data. We can provide small amounts of JERS-1 data from outside the ASF station mask. We can also support limited amounts of near real-time applications.

How to Become a User

As part of NASA's agreement with the European Space Agency (ESA, ERS-1) and the Japanese National Space Development Agency (NASDA, JERS-1), ASF is authorised to distribute data to users for research purposes. How-

Figure 2. World Wide Ground Stations

Alice Springs, Australia	Kumamoto, Japan
Hobart, Australia	Saitama, Japan
Cuiabá, Brazil	Tromsø, Norway
Gatineau, Canada	Pakistan
Prince Albert, Canada	Riyadh, Saudi Arabia
Beijing, China	South Africa
Cotopaxi, Ecuador	Maspalomas, Spain
Aussafuel, France	Kiruna, Sweden
Germany	Taiwan
Great Britain	Tasmania
Hyderabad, India	Bangkok, Thailand
Parepare, Indonesia	West Freugh, UK
Israel	Fairbanks, Alaska, USA
Fucino, Italy	O'Higgins, D/Antarctica
Hatoyama, Japan	Syowa, Jap/Antarctica



ASF Station mask: the area imaged by the satellite where there is mutual visibility between the ground station, the image location, and the satellite.

ever, before ASF can release data to a user, the user must become an approved user by completing a short (two-page) proposal and signing a research agreement. This proposal identifies the researcher's project goals, geographic area of research, amount and type of data needed, as well as the timing of data requests. Once approved by NASA, users order products on a cost-of-reproduction basis. People interested in becoming research users of ASF data should contact the ASF User Services at +1-907-474 7869. (Internet ID: mps@vixen.asf.alaska.edu)

What is the ASF Future

The future for ASF may include the addition of a second antenna (needed to handle schedule conflicts as more spacecraft are supported). In the near term this will add support for the ERS-2 and RADARSAT as described above, but in the more distant future, additional spacecraft missions are on the drawing boards at NASA and other flight agencies. The receiving, processing, and archiving systems will receive upgrades to be prepared for the RADARSAT era, while the cataloguing and archiving system is scheduled to be further upgraded with a standard system NASA is installing in all the DAACs late in this decade.

If there is a SAR system aboard one of the NASA Earth Observing System (EOS) satellites scheduled for operations in the early part of the next century, ASF would probably be involved in the reception, processing, archiving, and distribution of those data. The model for an EOS SAR is a multi-frequency, multi-polarisation instrument scheduled for launch and operation aboard the Space Shuttle in April 1994. This SIR-C/X-SAR will be a three-frequency (C-, L-, and X-band) SAR instrument.

In summary, the ASF is evolving from the development stage to the fully-functional receiving, processing, cataloguing, and archiving system. The system performance is being significantly improved in all areas. With a high latitude location, ASF is an attractive site to support any polar-orbiting, earth-observing spacecraft. The future for ASF looks busy and promising.

Carl A Wales, Martin Jeffries, Tom George, Cindy Wilson, Brett Delana, Greta Reynolds, Larry Sweet and Donna Sandberg

Alaska SAR Facility
Geophysical Institute
University of Alaska Fairbanks
PO Box 757320
Fairbanks, AK 99775-7320, USA

ASF Data Products

Product Type	Media	Data Characteristics
STANDARD		
Computer Compatible	CCT	12 second segment Signal Data
Complex Image Data	CCT	8 m pixel spacing, 30 × 50 Km area 10 m resolution
Full-Resolution Images	CCT, Film	12.5 m pixel spacing, 30 m resolution, 8K × 8K pixels
Low-Resolution Images	CCT, Film	100 m pixel spacing, 240 m resolution, 1K × 1K pixels
GEO-CODED		
Geo-Coded Full Res.	CCT, Film	12.5 m pixel spacing, 30 m resolution, 8K × 8K pixels
Geo-Coded Low Res.	CCT, Film	100 m pixel spacing, 240 m resolution, 1K × 1K pixels
GEOPHYSICAL		
Ice Motion Vectors	CCT	Ice Displacement Vectors, 5 km grid, 100 km × 100 km (nominal)
Ice Type Classification	CCT	Ice Type Image, 100 m pixels, 100 km × 100 km (nominal)
Ice Type Fraction	CCT	Fraction of Ice Classes, 5 km grid, 100 km × 100 km (nominal)
Wave Product	CCT	Wave Direction & Wavelength, 6 km × 6 km subsections, from Full-Res image

[CCT: Computer Compatible Tape]

Special Subscription Offer to URSI Correspondents

JOURNAL OF ATMOSPHERIC AND TERRESTRIAL PHYSICS

The *Journal of Atmospheric and Terrestrial Physics* is an international journal concerned with the interdisciplinary science of the Earth's atmospheric and space environment. Papers are published on the results of experiments and their interpretations, and on theoretical or modelling studies. Papers dealing with remote sensing carried out from the ground or with *in situ* studies made from rockets or from satellites orbiting the Earth are particularly suitable. Plans for future research, often carried out as an international programme, are also discussed. Besides original research papers, discussion papers and short reports, the journal includes commissioned review papers on topical subjects and special issues arising from chosen scientific symposia or workshops.

The journal covers the physical processes operating in the troposphere, stratosphere, mesosphere, thermosphere, ionosphere, magnetosphere and heliosphere. Phenomena occurring in other 'spheres' and supporting laboratory measurements are also considered. The journal deals especially with the coupling between the different regions. Regarding the upper atmosphere, the subjects of aeronomy, geomagnetism, auroral phenomena, radio wave propagation and plasma instabilities are examples within the broad field of solar-terrestrial physics which emphasise the energy exchange between the solar wind, the magnetospheric and ionospheric plasmas, and the neutral gas. In the middle and lower atmosphere, the topics covered include dynamics, radiation and chemistry, atmospheric electricity and electrodynamic effects, including lightning and its effects, and anthropogenic changes. Helpful, novel schematic diagrams are encouraged as is the use of colour.

Editor-in Chief: **MICHAEL J. RYCROFT**
College of Aeronautics, Cranfield Institute of Technology, Cranfield, Bedford MK43 OAL, UK

Editor Emeritus: **SIR GRANVILLE BEYNON, FRS**

A Selection of Papers

W.J. BURKE (USA), Early Trimpi events from lightning-induced electric fields in the ionosphere: an alternative explanation.

F.S. KUO, K.E. LEE, H.Y. LUE & C.H. LIU (Taiwan), Measurement of vertical phase group velocities of atmospheric gravity waves by VHF radar.

J.S. MURPHREE, R.D. ELPHINSTONE, M.G. HENDERSON, L.L. COGGER & D HEARN (Canada), Interpretation of optical substorm onset observations.

R.A. VINCENT (Australia), Long-period motions in the equatorial mesosphere.

M. LOCKWOOD, I.W. McCREA, G.H. MILLWARD, R.J. MOFFETT & H. RISHBETH (UK), EISCAT observations of ion composition and temperature anisotrc in the high-latitude F-region.

B. V. KRISHNA MURTHY, K. PARAMESWARAN, K.O. ROSE & M. SATYANARAYANA (India), Temperature dependences of stratospheric aerosol extinction at a tropical station.

V.I. FOMICHEV, A.A. KUTEPOV, R.A. AKMAEV & G.M. SCHVED (Russia), Parameterization of the 15 $\mu m CO_2$ band cooling in the middle atmosphere (15-115 km).

R. FURRER, W. DÖHLER, H.-J. KIRSCH, P. PLESSING & U. GÖRSDORF (Germany), Evidence for vertical ozone redistribution since 1967.

R.P. KANE (Brazil), Long-term variation of stratospheric temperature at the North Pole.

S.E. PRYSE & L. KERSLEY (UK), A preliminary experimental test of ionospheric tomography.

Indexed/Abstracted in: *Curr Cont, ASCA, Cam Sci Abstr, Curr Cont/Phy Chem & Earth Sci, INSPEC Data, Curr Cont Sci Cit Ind, Curr Cont SCISEARCH Data, Meteoro & Geoastrophys Abstr*

(00211)
Subscription Information
1994: Volume 56 (14 issues)
Annual subscription (1994) **£810.00** **US$1245.00***
ISSN: 0021-9169

Special Rate for URSI Correspondents for 1994 £75.00 US$115.00
Associated Personal Price for those whose library subscribes £160.00 US$246.00

*Sterling prices quoted apply worldwide except the Americas. US dollar prices quoted apply in the Americas only. Prices include postage and insurance.

PERGAMON *An imprint of Elsevier Science*

North America:
Elsevier Science Inc, 600 White Plains Road, Tarrytown, NY 10591-5153, USA

UK & all other countries:
Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK

APPLICATION FOR AN URSI CORRESPONDENT

I wish to become an URSI Correspondent for the 1994-96 triennium.
Subscription to the *Radioscientist* & **Bulletin** (12 issues) is included in the fee.

(Please type or print in BLOCK LETTERS)

Name: Prof./Dr./Mr./Mrs./Ms.______________________________
Family Name First Name Middle Initials

Present job title: ______________________________

Years of professional experience: __________

Professional affiliation: ______________________________

Company name: ______________________________

Department: ______________________________

Street address: ______________________________

City and postal/zip code ______________________________

Province/State ______________________________ Country ______________________________

This is my ☐ home ☐ business address.

Phone ______________ ext.__________ Fax ______________

E-mail (Internet, if possible)______________________________

Areas of interest (*Please fill appropriate circles*)

○ A	Electromagnetic Metrology	○ F	Wave Propagation & Remote Sensing.
○ B	Fields and Waves	○ G	Ionospheric Radio and Propagation
○ C	Signals and Systems	○ H	Waves in Plasmas
○ D	Electronics and Photonics	○ J	Radio Astronomy
○ E	Electromagnetic Noise & Interference	○ K	Electromagnetics in Biology & Medicine

The fee is US$40
(The URSI Board of Officers will consider waiving the fee if a case is made to them in writing.)

Method of payment: ***VISA*/MASTERCARD**

Credit card No ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ Exp. date ______________

Date: ______________ Signed ______________

Return this form to:

The URSI Secretariat
c/o University of Gent/INTEC
Sint-Pietersnieuwstraat 41
B-9000 GENT, BELGIUM
fax +32 9 264 3593

U.R.S.I.

There are two forms below. The left one is for radio scientists and engineers who wish to become URSI Correspondents who thereby receive the *Radioscientist & Bulletin* and enjoy several other benefits of Correspondentship (substantial discounts on URSI-sponsored journals and on future URSI conferences held jointly with other bodies with membership discounts). If you were a registered participant at the Kyoto General Assembly (August-September, 1993), or if you are an URSI official (eg, if your name and address was in the list recently published in the URSI *Information Bulletin*), you are already a Correspondent and should have received your "membership" card in June or July. In which case you do NOT need to fill in either form. But if you have received no "membership" card please fill in the form and pay (US$40 for the 3-year period, 1994-1996) by credit card. Your status will be checked and you will not be debited if your "membership" card was lost in the mail or if you are entitled to free Correspondentship anyhow. Payment other than by *VISA* or *MasterCard* can only be accepted by URSI HQ by prior arrangement. If paying the fee presents serious difficulties, fill in the form and accompany it with a letter stating your case for not paying the fee. The second form (right) is for institutions and libraries, and for subscription agencies. Only annual (Jan - Dec calendar year only) subscription is available (US$25 pa). Individuals, even if currently inactive in radioscience, should apply for Correspondentship (using the form on the left) which is financially more attractive. In either case, copies of the issues already published will be sent to you if at all possible. We suggest you photocopy the form you need at maximum enlargement for easy filling-in. The completed form may be airmailed or faxed but **must be signed** to validate the credit card number (a restriction imposed by the credit card authorities) — applications received by email cannot be used for fee payment.

Subscription form for the *Radioscientist* & **Bulletin**

(4 issues only: March, June, September, December, 1994)

(*Please type or print in BLOCK LETTERS*)

Name: ______________________________

Company /Institution Name: ______________________________

Department: ______________________________

Street address: ______________________________

City and postal/zip code ______________________________

Province/State ______________ Country ______________

Phone ______________ext.__________ Fax ______________

E-mail (Internet, if possible)______________________________

The subscription fee is US$25 for 1994 only. Air lifted delivery is included in the fee.

Method of payment: ***VISA*/MASTERCARD**

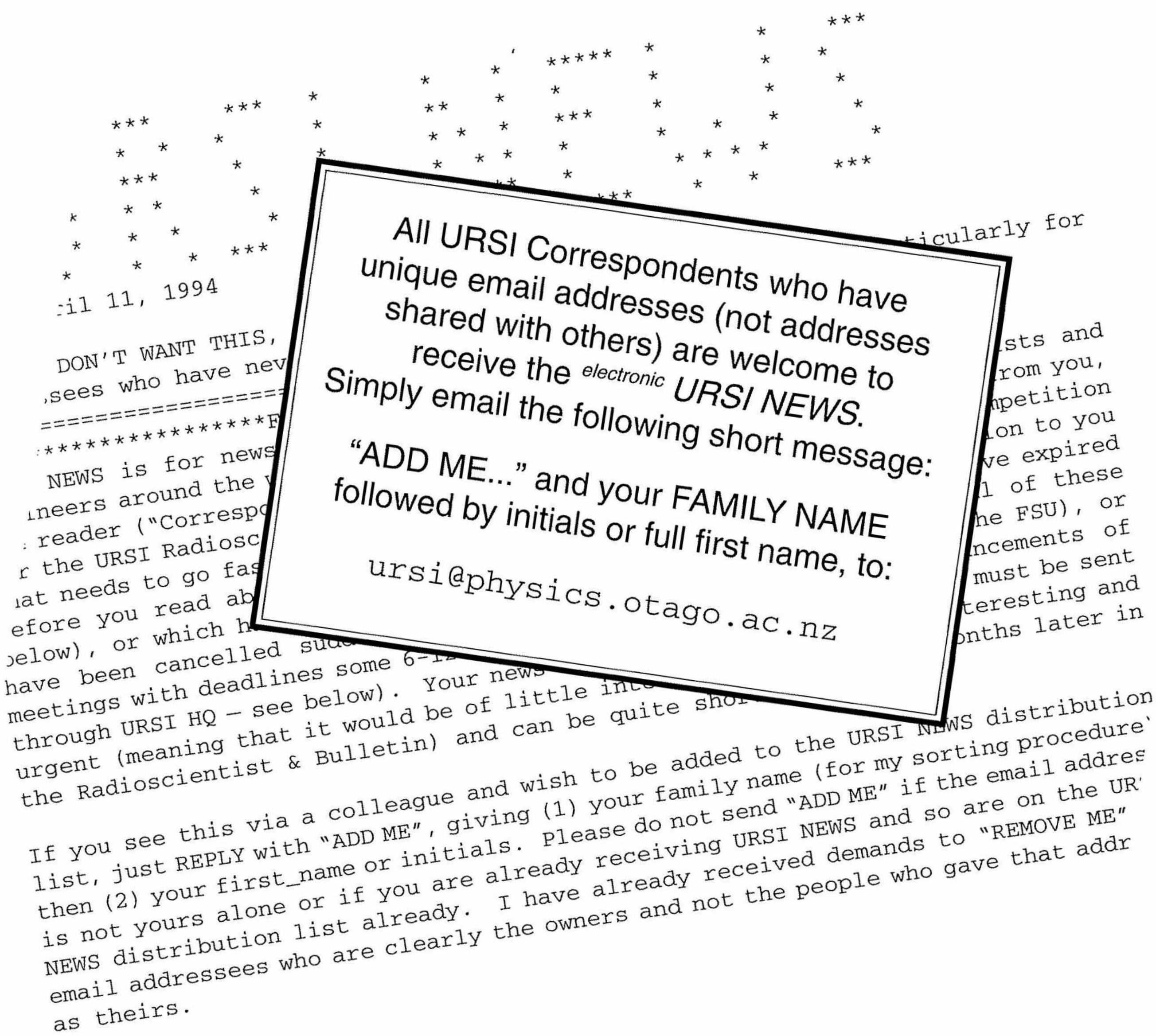
Credit card No ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐

Exp. date ______________

Date: ______________ Signed ______________

Return this form to:

The URSI Secretariat
c/o University of Gent/INTEC
Sint-Pietersnieuwstraat 41
B-9000 GENT, BELGIUM
fax +32 9 264 3593


All URSI Correspondents who have unique email addresses (not addresses shared with others) are welcome to receive the electronic URSI NEWS.
Simply email the following short message:
"ADD ME..." and your FAMILY NAME followed by initials or full first name, to:
ursi@physics.otago.ac.nz
If you see this via a colleague and wish to be added to the URSI NEWS distribution list, just REPLY with "ADD ME", giving (1) your family name (for my sorting procedure) then (2) your first_name or initials. Please do not send "ADD ME" if the email address is not yours alone or if you are already receiving URSI NEWS and so are on the URSI NEWS distribution list already. I have already received demands to "REMOVE ME" from email addressees who are clearly the owners and not the people who gave that address as theirs.