Radio Science Bulletin

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INTERNATIONAL
UNION OF
RADIO SCIENCE

UNION
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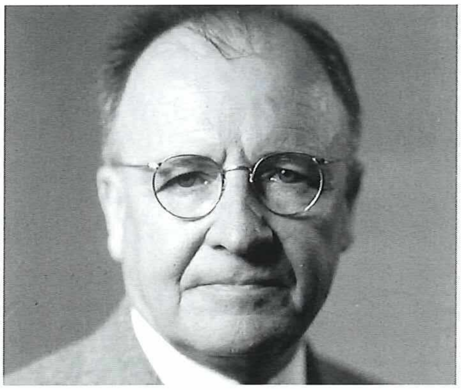
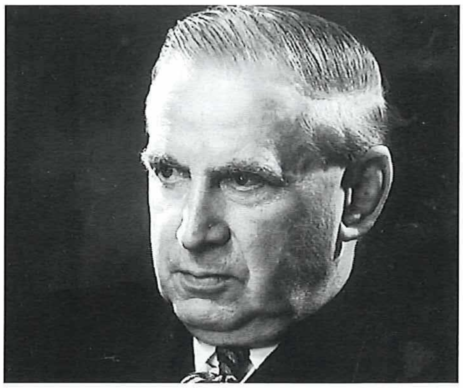

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URSI, c/o University of Gent (INTEC)
St.-Pietersnieuwstraat 41, B-9000 Gent (Belgium)

Front cover : Four URSI awards will be presented during the Opening Ceremony of the upcoming General Assembly in Lille, France. The front cover shows the pictures of Balthasar van der Pol, John Howard Dellinger, Sir Edward Appleton and Issac Koga, four distinguished URSI scientists, after whom the awards are named.

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Editorial

Dear URSI Correspondent,

This Bulletin contains sad news. URSI has lost two prominent members. Prof. Beynon was a Honorary President and has been the President of our Union in 1972-75. Prof. L.J.C. Woolliscroft passed while being in full activity. He was the convenor of the session HJC at the forthcoming General Assembly of URSI. Very recently, he was the first author of a paper published in this Bulletin (June 1995).

With this issue we complete the publication of contributions presented at the URSI 75th Anniversary Symposium on "Space and Radio Science" held in Brussels on 26-27 April 1995. We are particularly happy to publish two lectures which were given during the opening ceremony, as they were not included in the symposium proceedings. The paper by our President, Dr P. Bauer contains a quite interesting analysis of the evolution of URSI scientific goals since its origin and of the related organisation in Commissions. It also stresses the pioneering role played by URSI in other branches of science, such as radioastronomy and geophysics, in close relation with relevant scientific organisations.

Those who attended the symposium were delighted to hear the fascinating talk on Global Satellite Navigation Systems given by Dr. J. Ponsonby in the presence of His Majesty Albert II, King of Belgians. The King had indeed expressed the wish to attend this lecture rather than more formal parts of the opening ceremony. We may presume from the length of the lively private discussion he had with our guest speaker that he particularly enjoyed this contribution. We are happy to reiterate warm thanks and congratulations to Dr. Ponsonby for the outstanding quality of his lecture.

Power transmission electromagnetics is a rather specific topic which however is of interest to many radio scientists, namely because of possible interferences with radio systems, not to speak about bioelectromagnetic aspects and hypothetic health hazards. Upon proposal by Prof. J. Wait, we are happy to reprint with some modifications a paper by Dr. R. Olsen initially published in the IEEE Antennas and Propagation Magazine. Thanks to Dr. Ross Stone, the Magazine editor, for having granted the reprint permission.

P. Delogne, Editor.

Errata

In the March issue of the Radio Science Bulletin, we published a status report on the Review of Radio Science. We have received two comments and decided to publish the complete table of contents in this issue, as it went to Oxford University Press.

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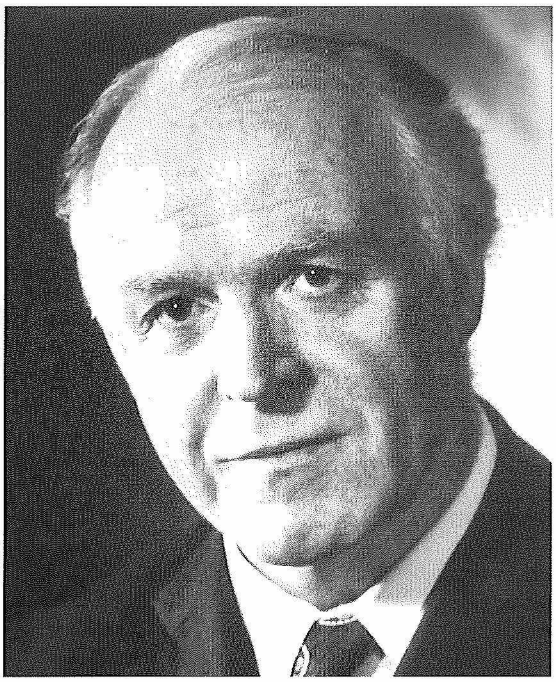
In Memoriam

Sir William John Granville Beynon
1914-1996

Professor Sir Granville Beynon died at Aberystwyth on 11 March 1996. He was a leading figure in international Radio Science for more than half a century and was active in URSI affairs throughout his long and distinguished career.

William John Granville Beynon was born in Dunvant, a suburb of Swansea in South Wales in 1914. He was educated at Gowerton Grammar School and at the University College of Wales, Swansea, where he graduated in physics and obtained his Ph.D. In 1938 he joined the staff of the Radio Division of the National Physical Laboratory at Slough where he began a close and lasting collaboration with Sir Edward Appleton. In 1948 Beynon returned to Swansea as a lecturer in physics and in 1958 he was appointed to the Chair of Physics at the University College of Wales, Aberystwyth, a post which he held until his retirement in '81.



While at Swansea, Granville Beynon formed an active research group which included his life-long colleague and friend Dr Geoffrey Brown and many research students who remember him for his enthusiasm and innovative ideas. During this period he played a very active role in the International Geophysical Year (1957-58) for which he was the "World Reporter for the Ionosphere". The outstanding success of this major international effort owed much to Granville Beynon's scientific and administrative skills. Following his move to Aberystwyth in 1958, he soon established a large and successful research group there. He quickly developed the new experimental techniques which were then becoming available and was one of the earliest workers to use rockets and artificial satellites to observe the ionosphere. In the early 1970s Granville Beynon became closely involved in the development of the European Incoherent Scatter Radar Facility (EISCAT) which was located in Northern Scandinavia to investigate the auroral ionosphere. Incoherent Scatter is one of the most powerful tools available for studying the ionosphere and to innovate tristatic design of EISCAT makes it one of the most advanced systems of its kind worldwide. He had a major influence in the development of EISCAT and it was through his efforts that the UK became a full partner in this prestigious project. He was for many years a member of the EISCAT Council and was its chairman from 1978 to 1981.

Following in Appleton's tradition, Granville Beynon maintained a very close interest in URSI affairs. He held many offices and was an active member of Commission G. He was chairman of several committees including the UK national committee for URSI. He was elected president in 1972, a position to which he devoted much enthusiasm and energy.

Granville Beynon was elected a Fellow of the Royal Society in 1973 and served as chairman or member of several of the committees including the National Radio Science Committee. For his services to science and education he received many honours and awards including the Goddard Prize of the National Space Club of America and the Charles Chree Prize of the Institute of Physics. He was appointed CBE in 1959 and was knighted in 1976.

In addition to his teaching and research Granville Beynon found time for his two leisure activities, music and gardening. He played the violin in the college orchestra at Aberystwyth and was for many years choir master at his local chapel in Dunvant. The great skill and energy which he devoted to his garden are legendary.

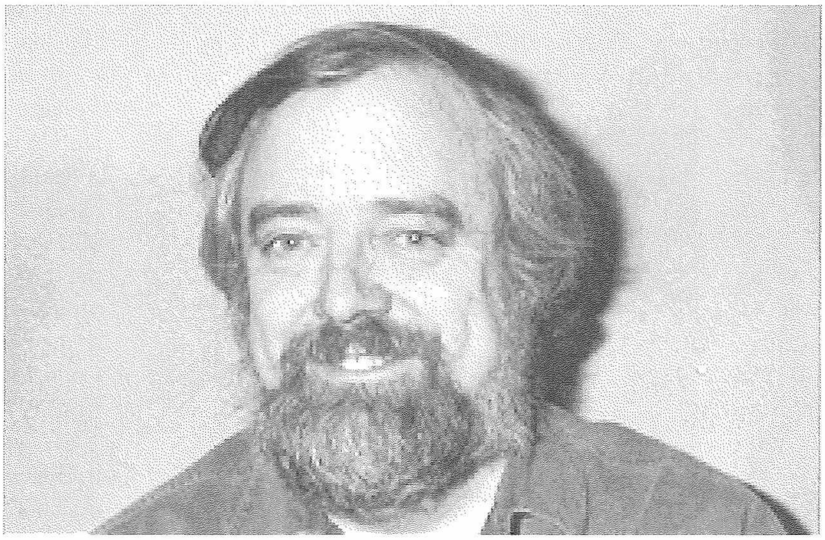
Granville Beynon is survived by his wife Megan and his daughter and two sons.

Tudor B Jones
President of the UK Member Committee for URSI

LES WOOLLISCROFT
1945 -1996

Les Woolliscroft, Reader in the Department of Automatic Control and Systems Engineering, died on 12 March 1996, aged 51. He first joined the University as Research Associate in the Department of Physics in 1972.

Following a period as research associate in the Mullard Space Science Laboratory, University College, London, Les came to the University of Sheffield in 1972 and first held the post of research associate with the title of 'Independent Research Worker' in the Space Physics Group. As UK project scientist at that time, he was responsible for directing a number of highly successful rocket campaigns in northern Scandinavia. This involved considerable planning as well as the design and production of the Sheffield groups instruments. The results from one of these rockets were one of the (then) UK SRC's scientific 'highlights'. During this period he also voluntarily undertook a teaching role in the Department of Physics as well as becoming an Open University tutor. He was much in demand by clubs and societies to give talks on astronomy.



His research reputation grew rapidly, his work being highly interdisciplinary, involving control, computer science and electronic engineering on the one hand and applied mathematics and physics on the other. Working at these interfaces won him great respect and many friends. In 1989 he made the transition from full-time researcher to a combined research and teaching post as Lecturer in the Department of Automatic Control and Systems Engineering where he became Senior Lecturer and then Reader in 1991. His natural enthusiasm and willingness to contribute his time and ideas both to students and to staff were a wonderful asset. He had the knack of leading students (and colleagues) to work things out for themselves and it was only later, on reflection, that you realised that you had been gently guided towards the conclusion.

Les was a Principle Investigator on one of the ESA/ NASA cornerstone missions, CLUSTER. There, his contribution was not only in providing an instrument which was at the heart of the Wave Consortium, but in the planning of the data handling and science analysis facilities to ensure the maximum exploitation of the products of the mission. His vision led him to be always aware of the possibilities of future missions and the projects he set his students enabled him to enter early discussions with at least some preliminary study.

Prior to this he had been a PI on the highly successful AMPTE project to launch three separate spacecraft from the United States, Federal Republic of Germany and the United Kingdom to study the complex interaction between the solar wind and the earths magnetic field. More recently he was involved in contributing to instruments for many scientific space missions including Mars 96 - a Russian mission to Mars; Cassini - a NASA mission to the Saturnian system; and Rosetta - an ESA mission to a comet.

Les had a tremendous enthusiasm for education in all its forms, and in particular for widening access to non-traditional candidates. His association with the Open University for a decade and a half was followed by his involvement in the Department's distance learning programme. He was a major driving force behind the establishment of the programme, and its continuing success lies in great part with his innovative ideas for its teaching and administration. His enthusiasm and organisational flair in distance learning, as in so many areas, has received tribute from numerous distance learning students. One, in particular summed Les up as "... an inspirational friend, teacher and mentor ". During summer schools in Singapore and his many overseas research commitments he was a wonderful companion - his skill at cooking was well matched by his enthusiasm for sampling exotic dishes.

Tributes to Les have come from all parts of the world - 'a man of integrity', 'a fine team leader', 'softly spoken with a commanding presence'. We all valued his wisdom. He is a great loss to the University , to the wider academic community and to a great many of us personally. His wife, Shelagh, and his children, Kate, Mike and Tim have our every sympathy. Amongst other plans, a Student Prize, from private donations, is to be established in recognition of his achievements.

Dr. Hugo St. C. Alleyne

URSI Accounts 1995

I am pleased to introduce the audited accounts of URSI for 1995 in which the following items are noteworthy:

1. There has been a significant reduction in the expenditure of the URSI Secretariat for which we are indebted to the Secretary General and his staff for their constructive approach. There has been a significant reduction in publication expenditure in 1995 following the transfer of the publication of the Radio Science Bulletin to Belgium under the Editorship of Professor Delogne. Only a small expenditure was incurred in the celebration of the 75th Anniversary of URSI due to the successful acquisition of Grants and the considerable efforts by Professors Delogne, Van Bladel, Van Daele and members of the Secretariat in the efficient organisation of this prestigious event.
2. There was an unusually high income in 1995 due to efforts made to recover back dues from Member Academies and the income received from three successive IGARSS events which were paid in one year.

Taken together, the finances of URSI are robust as we enter the year of the General Assembly which we may regard as a satisfactory state of affairs.

Prof. P.J.B. Clarricoats
Treasurer

INTERNATIONAL UNION OF RADIO SCIENCE (URSI)
BALANCE SHEET : 31 DECEMBER 1995

	ASSETS	$
Dollars		
Banque Degroof	29,867.57	
Merrill Lynch WCMA	9,484.40	
Générale de Banque	54,114.11	
Smith Barney Shearson	682.72	
		94,148.80
Belgian francs		
Banque Degroof	9,743.25	
Générale de Banque	159.424.34	
		169,167.59
Investments		
Demeter Sicav shares	22,794.75	
Rorento Units	124,034.97	
Aqua Sicav	64,103.22	
Merrill-Lynch Short Term	30,012.85	
Smith Barney Utilities Fund	81,764.00	
Reinvestment S.B. Utilities	14,593.30	
Smith Barney Grade Bond	49,300.00	
Reinvestment S.B. Grade Bond	10,978.06	
		397,581.15
Other		
Petty cash		953.83
	Total Assets	661,851.37
		======
Less creditors		
IUCAF	12,427.13	
IUWDS	7,070.09	
Social Security	5,290.95	
Administration	6,658.85	
Audit fees	1,864.41	
		33,311.42
Balth van der Pol Medal Fund (1)		13,381.97
	NET TOTAL OF URSI ASSETS	615,157.98
		========

The net URSI Assets are represented by :		$
Closure of Secretariat :		
Provision for Closure of Secretariat		35,100.00
Scientific Activities Fund :		
Scientific Activities in 1996	80,000.00	
Publications in 1996	70,000.00	
Young Scientists in 1996	40,000.00	
Administration Fund in 1996	80,000.00	
I.C.S.U. Dues in 1996	8,000.00	
		278,000.00
XXIV General Assembly Fund :		
During 1996 :		200,000.00
Total allocated URSI Assets		513,100.00
Unallocated Reserve Fund		102,057.98
		615,157.98
		=======

Statement of Income and Expenditure
for the year ended 31 December 1995

I. INCOME		$	
Grant from ICSU Fund		19,800.00	
Contributions from Member Committees		256,007.49	
Correspondents fees		59.59	
Sales of Publications		1.29	
Bank Interest		4,076.06	
Return loan (Support to Symposia under mode C)		14,799.15	
Other Income		21,549.49	
	Total Income		316,293.07
			========
II. EXPENDITURE			
a) Scientific Activities			79,747.47
General Assembly 1996 - Scientific		450.03	
Symposia/Colloquia/Working Groups		61,721.59	
"Space and Radio Science" URSI 75th Anniversary		8,224.65	
Representation at scientific meetings		5,232.76	
Grants to organizations		4,118.44	
b) Routine Meetings			14,742.32
Bureau/Executive committee			
c) Publications			38,680.03
d) Administrative Expenses			67,887.31
Salaries, Related Charges		53,575.69	
General Office Expenses		7,161.83	
Office Equipment		431.66	
Accounting and Audit Fees		4,942.54	
Bank Charges		1,775.59	
e) ICSU Dues			7,405.00
	Total Expenditure		208,462.13
			=========

Excess of Income over Expenditure	107,830.94	
Accumulated Balance at 1 January 1995	499,839.22	
Balance at 31 December 1995	607,670.16	
Appreciation of Belgian Franc	7,487.82	
Accumulated Balance at 31 December 1995	615,157.98	
	========	

Rates of exchange :
1 January 1995: $1 = 32.00 BF
31 December 1995: $1 = 29.50 BF

Observation :
The account indicated with (1) is represented by :
376 Rorento Shares : market value on December 31, 1995 = $22,151.90

Market value of investments on December 31, 1994 ($1 = 32,00 BF) :		
- DEMETER SICAV :	42,703.12	
- RORENTO UNITS (2) :	382,945.12	
- AQUA-SICAV :	84,386.78	
- M-L SHORT TERM :	25,833.00	
- SMITH BARNEY UTIL. :	100,320.07	
- SMITH BARNEY GRADE :	64,067.81	
		700,255.90

(2) including the 376 Rorento of v. d. Pol Fund

APPENDIX

Detail of Income and Expenditure

I. INCOME	$	
Return loan (Support to Symposia under mode C)		
Return ""Loan to IGARSS'93"	4,799.15	
Return ""Loan to IGARSS'94"	5,000.00	
Return ""Loan to IGARSS'95"	5,000.00	
Other income		14,799.15
Reimbursement YS (non participating EMC'95)	954.07	
Reimbursement insurance	86.00	
Reimbursement (bank transfer in '94)	2,332.20	
Reimbursement social security	79.00	
URSI share in profit IGARSS'93	4,381.25	
URSI share in profit IGARSS'94	10,684.96	
Profit on Sale Merrill-Lynch Global Utility	3,032.01	
		21,549.49
II. EXPENDITURE		
Symposia/Colloquia/Working Groups :		
EM Theory Symposium	9,361.42	
IRI Workshop	300.00	
COMMSPHERE'95	5,000.00	
CO25-Symposium	2,000.00	
Radio Emissions from the Stars and the Sun	500.00	
Extra Galactic Radio Sources	2,000.00	
URSI and STEP/GAPS Workshop	2,200.00	
IRAMT'95	2,000.00	
IAU Colloquium 160 Pulsars, Sydney	1,000.00	
Atmosphere Research and Applications using...	500.00	

COST 244 Meeting, Helsinki	1,000.00	
Large Telescope WG Meeting 3 and Workshop	800.00	
EMC'96, Wroclaw	1,000.00	
10th Int. Conf. on Atmospheric Electricity	1,900.00	
CPEM'96	7,000.00	
Biophysical Aspects of Coherence	1,000.00	
Satellite Studies of Ionosphere and Magnetospheric...	1,000.00	
EMC'95, Zurich	3,000.00	
Bioastronomy (EUV Astrophysics), Capri	1,000.00	
MST/2nd Int. School of Atmospheric Radar	1,000.00	
Physics and Engineering of mm and Sub mm Waves	2,000.00	
Commission F Open Symposium, Ahmedabad	5,000.00	
EM Theory Symposium (St. Petersburg)	350.00	
Fourth Trieste College & Workshop	10,810.17	
		61,721.59
Space and Radio Science - URSI 75th anniversary :		
Publications	3,078.14	
Travel expenses	1,798.17	
Administrative costs	3,348.34	
		8,224.65
Grants to Organizations :		
FAGS	2,000.00	
IUCAF	2,000.00	
Union Int. Associations '94	59.22	
Union Int. Associations '95	59.22	
		4,118.44
Publications :		
Printing RSB (No 271-272-273-274)	20,439.66	
Mailing RSB (No 271-272-273-274)	18,115.56	
Transfer to Radio Science Press	72.54	
Printing New Correspondents Cards	52.27	
		38,680.03

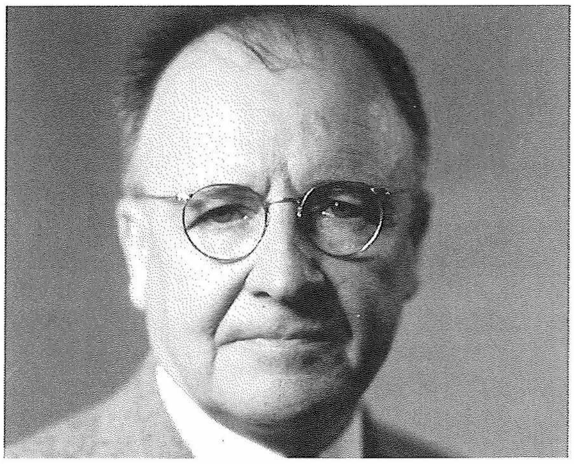
URSI Awards 1996

At its April 1996 meeting in Gent, the URSI Board of Officers decided to give the 1996 Awards to the following distinguished scientists.

The Balthasar van der Pol Gold Medal is awarded to Professor R. HARRINGTON (University of Arizona) with the citation : "For contributions to electromagnetics and the development of the method of moments".

Prof. Dr. B. van der Pol

The John Howard Dellinger Gold Medal is awarded to Professor Tomohiro OGUCHI (Kanto Gakuin University) with the citation : "For theoretical work on the polarization effects of non-spherical raindrops and the multiple scattering effects of hydrometeors".

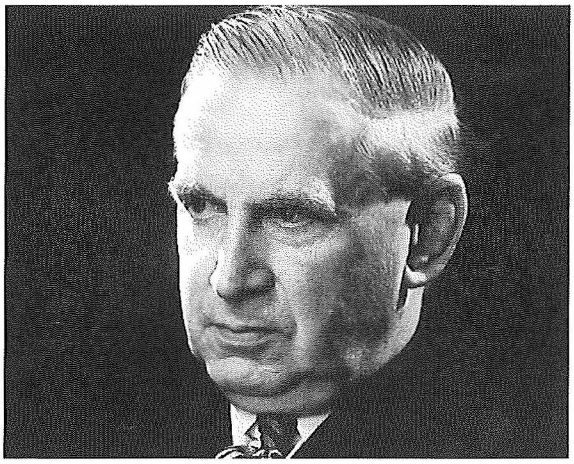


Prof. J.H. Dellinger

The Issac Koga Gold Medal is awarded to Professor Zoya POPOVIC (University of Colorado) with the citation : "For contributions to the field of active microwave circuits, in particular, the original demonstration of the planar grid oscillator, as well as continuing efforts with quasi optical amplifiers and active antennas".

Prof. I. Koga

The Board of Officers submitted its recommendation for the Appleton Prize award to the Royal Society. At its meeting of 18 July the Royal Society will decide on the awardee of the Appleton Prize.



Sir E. Appleton

The Awards will be presented at the Opening Ceremony of the XXV URSI General Assembly in Lille, France, on Wednesday 28 August 1996 at 3.30 p.m.

75th ANNIVERSARY

URSI - 75 Years Space and Radio Science Symposium

URSI - FROM 1922 UNTIL TODAY

P. Bauer

I have been entrusted with the task of describing the work of URSI since its first General Assembly in 1922 up to the present time. It will be appreciated that, given the multiplicity and the very rapid developments of subjects, it seems almost impossible to cover all the aspects of radio science and to do justice to the ingenuity and skill of all those who, over the years, contributed to the growth and reputation of our Union. However, I shall try to refer to the most striking features of the scientific life of URSI, leaving aside the administrative aspects as far as possible.

To apprehend the incredibly fast advances achieved over the past 75 years in our domain of investigations, it seems worthwhile referring in some detail to the programme of the first two General Assemblies. As stated by J.H. DELLINGER in 1963 : «The history of our Union is one of steady growth and of effort to coordinate the international scientific foundations of the fantastically extending roles of radio and electronic applications. Our domain extends over the Earth, throughout the solar system, and out among the galaxies. We can be sure of one thing : when man reaches the outermost limits of the observable Universe, he will materially be assisted by means of radio for communications navigation and control using the electromagnetic waves envisaged by the genius of Maxwell a hundred years ago».

The first General Assembly of the Union was held in July 1922 in Brussels. At that time, only four National Committees had been formed officially, Belgium, France, United Kingdom and the USA. However, the following new Committees adhered to the Union during the same year: Australia, Spain, Italy, Japan and the Netherlands. We find that, although only as observers, two scientists from Norway participated actively in the work of the Assembly.

The Agenda of that first Assembly had been drawn up by General FERRIE and Prof. GOLDSCHMIDT, to be elected later as President and Secretary General of the Union respectively.Among the topics to be considered by the Commissions, General FERRIE quoted :

- measurements of the electromagnetic field and its variations
- study of variations in radio goniometrical measurements
- study of «statics» and disturbances in general
- measurements.

It was considered that it would not be desirable for URSI to cover «tubes» since this might have implied a more industrial character, which had to be excluded.

The scientific Commissions formed in 1922 were as follows:

- Measurements methods and standardisation
- Radio propagation, with two Sub-commissions on the electromagnetic field and on radio goniometry respectively
- Atmospheric disturbances
- Liaison with operators, «practitioners» and amateurs. The latter was to be abolished in 1948.

It is interesting to quote the following comment from the Minutes of that first meeting : «In view of the moral and technical importance of the Commission on Measurement methods and standardisation, as well as of the usefulness of its work for the public at large, the Commission should be numbered ONE since it might draw governmental subsidies».

The second General Assembly was held in 1927 in Washington in conjunction with the International Radio Conference, which may be called the first truly modern conference on telecommunications. Among the participants, we quote the names of DELLINGER, VAN DER POL, MESNY, BUREAU, APPLETON, SMITH-ROSE, KOGA, YAGI, AUSTIN and KENNELLY.

At the meeting of Commission I, it was generally agreed that the unit of frequency was identical with the unit of time interval, and that no independent definition should be given. It was further agreed that although frequency was measured in terms of the astronomical unit of time, it was nevertheless important to compare the national frequency

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standards in order to check the measurement techniques. And indeed URSI has been instrumental in arranging many series of comparison by both physical transport of standards and by the simultaneous measurement of the frequency of radio transmissions.

On the other side, much attention was devoted to radio propagation problems. Between 1922 and 1927, the subject of ionospheric radio had developed rapidly. Indeed, in 1925 Breit and Tuve in the USA and Appleton and Barnett in the UK had showed for the first time that radio waves could be reflected from the ionized portion of the atmosphere. From then onwards, scientists began to realise that, on the one hand, radio provided them with a powerful tool for exploring the upper atmosphere and, on the other hand, that the study of the upper atmospheric physics would help them to understand the propagation of radio waves. May I remind that Edward APPLETON had been President of URSI for more than 10 years, and that he was awarded the Nobel Prize for Physics in 1947. As for TUVE, he developed the pulse echo method, which was in fact the first pulsed radar in the world.

It was during that second Assembly in 1927 that Prof.. Van Der Pol called attention to the need for a separate Commission for such subjects as the general theory of triodes, new developments in the general theory of complex functions, modulation theory and the theory of oscillations of linear and non-linear systems. Each of these topics was to become of foremost importance in the ensuing five years. The formation of a new Commission - on Radio Physics - in accordance with Prof. Van Der Pol's recommendation certainly contributed to the growth of interest and research in those fields.

It is also in the Minutes of this second Assembly that the first mention of possible effects of the troposphere on radio propagation is to be found, as well as direct correlations between weather conditions and the reception of short waves.

Another striking development in the subsequent years was the emergence of radio astronomy. The beginning of this new science was reported first at a meeting of the US URSI Committee in 1932 by Karl Jansky. During an investigation on atmospheric interference on communication systems, he recognised that noise-like signals were being emitted from the plane of our galaxy, their strength being greatest from the galactic centre.

Needless to remind that, during the dark years 1939-1945, URSI's work was reduced to a strict minimum and, indeed, it is thanks to the staff of the headquarters in Brussels, in particular Colonel Ernest Herbays, that we owe the fact that URSI did not die. Nevertheless this period stimulated great advances in the application of radio waves, which played doubtless a key role in the war itself.

Much of this work accompanied the development of the radar at wavelengths reaching down into the centimetric waveband. In this connection, may I remind that Watson Watt, whose name is associated with the radar, had been a regular participant in URSI meetings.

Also during that period, it was realised how important was a detailed knowledge of the ionosphere for radio communications, and also the establishment of networks of ionospheric stations. One should at this point mention the important ionospheric research activity which developed in Lindau under the leadership of one of our Honorary Presidents, Prof. DIEMINGER.

Thus it is clear that, during that period, URSI's primary objective was research on the propagation of electromagnetic waves over ever widening wavelength ranges from very long waves in 1919 to decimetric waves in 1948.

By 1948, it had become clear that there existed a bright future for a new field of solid-state electronics which might have important effects on radio science. At that time, the ground work had been laid for the transistor and the many developments in solid-state circuits.

At the reconvening of URSI in Paris in 1946, the Commission on Radio Physics had displayed an interest in the new area of information and communication theory. In 1948 it was decided to divide the Commission into two : one on Waves and Circuits, and the other on Electronics.

In 1950, the new Commission on Waves and Circuits organised a programme of sessions devoted to information theory, linear circuits, non-linear circuits and applied electromagnetic theory. At the following Assembly, in 1952, the lines seemed to be drawn rather sharply between those interested in information and communication theory, those specializing in circuit theory and networks, and those specializing in electromagnetic theory. Consequently, the Commission was broken into three Sub-Commissions, one for each of the afore mentioned areas. These developments are shown on TABLE I.

At Sydney also, in 1952, there came into being the Electromagnetic Wave Theory Symposium, which is still one of the major and most successful activities of the present Commission on Fields and Waves and which attracts the best experts in the field.

The new Commission on Electronics met for the first time in 1950 in Zurich. In its opinion, the purpose was the discussion of fundamentals rather than devices and, to this end, it included in its programme : fundamentals of vacuum tubes, fundamentals of gaz discharge, fundamentals of semiconductors with application to radio physics, microwave spectroscopy, including magnetic resonance absorption. In 1957, it was felt that the Commission had matured and the meeting took place in an atmosphere of great scientific interest : the maser had been conceived a few years earlier and promised to be a device that could revolutionize measurements. During its short life, up to 1960, many phenomena were studied which were to be used as the basis of devices in every day use in radio measurements.

Quantum electronics, developed by the Nobel Prize Winners for Physics, TOWNES, BASSOV, PROKHOROV - a Vice-President of URSI from 1960 to 1966 - and KASTLER provided another device, the laser, related, insofar as general principles are concerned, to the maser, but operating in the optical and near-infrared regions; The laser extended the spectrum of coherent radiation to the optical regions, thus extending the frequency domain of all forms of communication.

1922	1948	1952
I. Radio Measurements and Standards Sub-commissions : EM Field Radio Goniometry		
II. Radio Wave Propagation	°Radio and Troposphere °Ionospheric Radio °Radio Astronomy °Magnetosphere	
III. Atmospheric Disturbances	°Radio Noise of Terrestrial Origin	
IV. Cooperation with amateur operators (dissolved in 1948)		
V. Radio Physics	°Radio Waves and Circuits °Radio Electronics	Sub-commissions -Information and Communication Theory -Circuit Theory, networks -Electromagnetic Theory

Table I - URSI SCIENTIFIC COMMISSIONS 1922-1963

In 1969, referring to this new device, Prof. SILVER, in his presidential address, stated : «The implications of the new techniques are far-reaching. By pulsing lasers one obtains the counterpart of a radar system by which distances can be measured with phenomenal accuracy. I am sure that all of you now know of the laser experiment being conducted between terrestrial astronomical observatories and the retrodirective reflectors placed on the moon by the astronauts, Armstrong and Aldrin, to determine the Earth-to-moon distance more accurately».

In the 1950's, metrologists wondered whether it was possible to overshoot the precision of quartz clocks, which were used to define the time. Quantum electronics provided a positive response in offering new natural clocks.

One major impact on radio science was the inauguration of the space age in 1957. It is perhaps not irrelevant here to note that three years before, URSI was the first international scientific body to adopt a resolution emphasizing the scientific value of Earth-satellite projects.

From the left to the right : Prof. W.N. Christiansen, Sir Edward Appleton, Prof. Balthasar van der Pol

At its Assembly in London in 1960, URSI formed a Special Committee on Space Radio Research, which provided a focal point for the interests of URSI Commissions, in space science, as well as a link with the ICSU Committee on Space Research (COSPAR). The lectures to be delivered at this gathering will provide a perfect illustration of the close association between space research and radio science.

I already mentioned the creation in 1948 of the Commission on Radio Astronomy. The period 1950-60 saw the development of many different kinds of radio telescopes to meet the specific requirements of various aspects of radio astronomy. At this stage, may I produce a photograph taken during the 1952 General Assembly in Sydney. It shows Prof. CHRISTIANSEN (now one of our Honorary Presidents) explaining the details of his famous 32-element grating interferometer at Potts Hill ; the two visitors are BALTHASAR VAN DER POL AND EDWARD APPLETON. The availability of electronic computers gave rise to new concepts in the design of radio telescopes, and the years 1960-70 marked a golden age in radio astronomy. Positions and intensities of several thousand radio galaxies were determined, thus enabling cosmological studies to be made. Some of the major landmarks in this period are the discovery of quasars in 1963, the discovery of the cosmic microwave background radiation in 1965 by PENZIAS and WILSON (Nobel prize Winners for Physics in 1978), and the discovery of a new type of celestial object, the pulsar, in 1967 by HEWISH (Nobel Prize Winner for Physics in 1974).

On the other hand, very long baseline interferometry was successfully put in operation early in 1967. I won't expand on VLBI from space since you will hear more on this subject during our meeting.

At the end of the 1950's, a very important application of scattering came into being. Prof. W.E. GORDON predicted, from theoretical considerations, that it should be possible to collect the very small amount of energy scattered by individual electrons in the ionosphere, even at altitudes above the maximum F Layer, which are inaccessible to ground-based ionospheric sounders. This was verified afterwards by BOWLES using a high-power radar. In 1966, our Honorary President, Prof. GORDON, was awarded the Balthasar van der Pol Gold Medal in recognition of his outstanding work on the conception of the Arecibo Ionospheric Observatory. The fine instrument in Arecibo was completed by 1963. Although built with a view to studying the ionosphere, it has also important applications in radar studies of the objects in the solar system and in radio astronomical studies of the Universe. At the same 1966 General Assembly, Dr. J.H. CHAPMAN was awarded the John Howard Dellinger Gold Medal for his magnificent achievement of the Alouette I topside ionosphere sounder (Fig. 1) . While referring to the incoherent scatter radar technique, I should mention the important European Incoherent Scatter facility - EISCAT - , which was opened in North Scandinavia in the 1980's. This most powerful ground-based tool, along with other incoherent scatter radars in the world, still provides a wealth of information on the upper atmosphere, the ionosphere, and aurora.

Coming back to 1963, it was recognised at that time that serious attention should be given to the question of the overlapping of topics dealt with by URSI, the Astronomical Union and the Union of Geodesy and Geophysics. From then on and until 1975, there has been a long-standing debate on the proper role and place of URSI within the International Council of Scientific Unions. With a clear vision of the future, Professors Silver and Booker, and Monsieur Voge, made suggestions which played a key role in the discussions. I would like to quote, at this point, some comments made in 1975 by Dr. MINNIS, then Secretary General, whose devoted services contributed greatly to the present strong position of URSI.

«The past contributions of URSI scientists to research in astronomy and in the physics of the upper and lower atmosphere have been very important. However, it is essential to remember that these had their origin in research on the more fundamental aspects of radio science : generation, propagation and detection of electromagnetic waves, theory and design of antennas, development of new electronic devices, etc... The vitality of URSI depends on the emergence of new ideas in basic radio science, which may be later applied either in disciplines that are the concern of the other Unions (astronomy, biology, geophysics, etc...) or in communication science which has been the concern of URSI since its foundation ... URSI must create a milieu that provides all workers in telecommunications science with the forum that they need for international scientific discussions. Access to this forum must be available also to the younger telecommunications scientists, and to those in the developing countries».

Indeed at the General Assembly in Lima in 1975, the URSI Council adopted a resolution on the reorganisation of the Union. The terms of reference were expanded so as to include : «the scientific aspects of telecommunications using electromagnetic waves, guided and non-guided». In this way cables, waveguides and optical fibers were clearly included in the field of research, and the prime interest of URSI was oriented towards telecommunications in the broadest sense. Let me add at once that, in 1990, the terms of reference were further expanded so as to include : «the generation and detection of these waves, and the processing of the signals embedded in them».

An extensive list of recommended topics was also approved in 1975, and the titles of the Commissions were revised. The particular subjects with which URSI is concerned vary in accordance with current progress in the field of radio science. For example, as soon as 1981, the Commission on Physical Electronics and Devices had agreed that optical frequency techniques and devices should be part of the URSI domain, which is reflected in the new title adopted in 1990.

At the Assembly in 1978, the question came up of whether URSI should form a separate Commission to deal with remote sensing of the earth using radio waves. It was

	1975	1978	1981	1984	1987	1990	1993
A.	Electromagnetic Metrology						
B.	Fields and Waves						
C.	Signals and Systems						
D.	Physical Electronics		Electronic and Optical Devices and Applications			Electronics and Photonics	
E.	Interference -- Electromagnetic Noise Environment and Interference						
F.	Wave Phenomena in Non- ionized Media	Remote Sensing & wave propagation & Wave Propagation Remote Sensing -neutral atmosphere, oceans, land, ice					
G.	Ionospheric Radio & Propagation						
H.	Waves and Plasma						
J.	Radioastronomy						
K.						Electromagnetics in Biology and Medicine	

Tabel II - URSI SCIENTIFIC COMMISSIONS 1975-1993

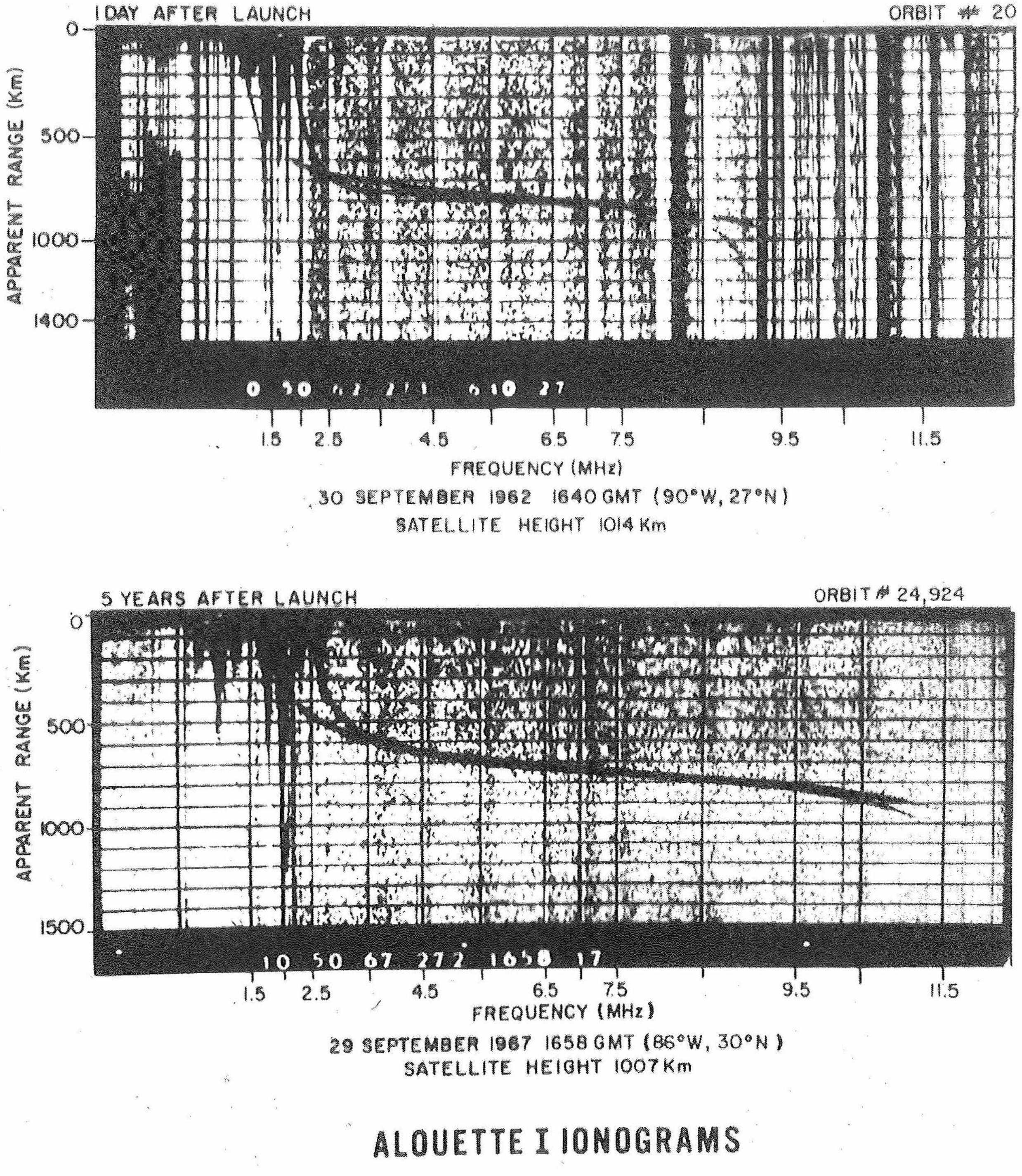

Fig. 1 : Aloutte I Ionograms

then decided to rename Commission F «Wave propagation and Remote Sensing». The Commission was instructed to achieve coordination both inside URSI and with other organisations. Starting with 1988, URSI has been a sponsor, jointly with the IEEE Geoscience and Remote Sensing Society, of the annual IGARSS Conferences.

Our Commission on Electromagnetic Noise and Interference deals, among others, with terrestrial and planetary noise of natural origin and man-made, the composite noise environment, the effects of noise and system performance and the scientific basis of noise and interference control. Ever since 1975, the Commission participates actively in the planning and organisation of the very successful series of international symposia on Electromagnetic Compatibility, which are held alternately in Wroclaw and in Zurich. According to our Honorary President, Professor STUMPERS : «EMC is really a multidimensional field of research and, in our highly technological civilization, an indispensable one».

In 1987, a special conference on URSI's future was convened at the initiative of Dr. MITRA, Prof. GORDON and Prof. VAN BLADEL, in response to the increasing feeling that the functions and goals of the Union needed to be reassessed, and that its links with telecommunications organizations needed to be reinforced. Indeed, it was felt that, in the years ahead, the combination of satellite links, television, fiber optics, and high-speed information transmission had an enormous future potential, and that radio science, including electronics, informatics and opto-electronics, would play a predominant role.

I shall mention here only one of the initiatives taken at that time. It was agreed that greater emphasis should be put on telecommunications and, to this end, it was decided to launch a series of International Symposia on Signals, Systems and Electronics (ISSSE). The aim is to cover the whole range of topics in the area, and to promote the exchange of experience and results between scientists and engineers working in these multidisciplinary domains. The third Symposium in the series will take place this year in the United States.

We have seen that URSI, although primarily concerned with radio communication science, often played a pioneering role in the development of tools in other fields of science. The most recent example is the suggestion, made as early as 1972, that URSI should take an interest in the subject of interaction of electromagnetic fields with biological systems. The Working Group created in 1975 to deal with the subject gave birth in 1990 to the new Commission K on «Electromagnetics in Biology and Medicine». This met for the first time in Kyoto in 1993 with extremely successful sessions. The programme of this afternoon includes a lecture on «Mobile communication systems and biological effects on their users » by Prof. STUCHLY, past chairman of the Commission, who was largely instrumental in the setting up of that body.

At the General Assembly in Kyoto in 1993, Prof. HELLIWELL gave a Tutorial lecture entitled : «Forty years of Whistlers». The phenomenon known as «whistlers» had already been observed at the end of the past century in Austria, but modern work on the subject dates from about 1930. An important contribution was the announcement, at the Sydney General Assembly in 1952, of STOREY's theory that the long ionospheric paths followed the lines of the Earth's magnetic field to large distances from the Earth, and back again to the conjugate magnetic point. The mode of propagation which enabled the low frequency energy to penetrate the regular ionospheric layers was formulated mathematically and became known as the «whistler mode».

To facilitate interdisciplinary cooperation, inter-Union bodies were formed over the years under the auspices of the International Council of Scientific Unions. URSI has participated most actively in the international cooperative scientific programmes launched by ICSU. Examples are the Second Polar year 1932-33; the International Geophysical Year 1957-58; the so-called International Geophysical Cooperation 1959 and the International Quiet Sun Year 1964-65 in which Sir Granville Beynon played a key role on behalf of URSI. Currently, the Union is represented on the International Geosphere-Biosphere Programme, and a special Committee is keeping contact with that major enterprise.

The astronomical and geophysical services, which were grouped together in a Federation (FAGS) in 1956, provide the scientific community with long series of observational data, some of them going back to 1800. URSI is at present represented by two Services : the Sunspot Index Data Centre and the International Ursigram and World Day Service. The latter aims to provide information rapidly to the world scientific community to assist in the planning, coordination and conduct of scientific work in disciplines affected by the sun-earth environment. Special mention should be made of the Inter-Union Commission on Frequency Allocations for Radio Astronomy and Space Science. The need to have radio frequency bands available for scientists to use at various parts of the spectrum was discussed in URSI, starting with 1950. It was the fairly new science of radio astronomy which made the matter urgent. Action was taken, in consultation with the Astronomical Union, in order to formulate the scientific requirements for the protection of radio frequency bands throughout the spectrum.

This leads us naturally to an important feature in the life of our Union : its relations with the International Telecommunications Unions, and its technical advisory bodies. It is of course not possible to enter here into the details of the collaboration mechanisms set up over the 70 years elapsed.

In 1990 a Scientific Committee on Tele-communications was created under the chairmanship of Prof. L. BARCLAY, with the objective of facilitating the cooperation between the Commissions of URSI, and also the cooperation of these with consultative groups of ITU (CCIR and CCITT) for the study of scientific aspects of the telecommunications problems.

In his address at the Opening meeting of the General Assembly in Kyoto in 1993, Dr. Richard KIRBY, Director of CCIR, referred to the new re-structuring of ITU and pointed out : «URSI remains ITU's main scientific connection. Many URSI scientists are deeply involved in telecommunications and the «renaissance of wireless».

1920	1930	1940	1950	1960	1970	1980	1990
Metrology		Information Theory		Laser		Electromagnetics in Biology	
	Radioastronomy		Maser		Remote sensing		
Ionosphere		Solid-state Electronics		Quasars		High Precision Altimetry & Imaging	
			Atomic Clocks		Electromagnetic Compatibility		
Radar			Whistlers	Pulsars		Communication Highways	
			Incoherent Scatter				
Troposphere				Cosmic Noise			

Table III - URSI KEYSTONES

The new ITU-R «Science services» Study Groups can strengthen the voice of science in international recommendations and agreements, for use and protection of their applications in the radio frequency spectrum».

In this talk, it was just not possible to present even and adequate summary of all that has taken place over the years in URSI. Any worthwhile survey of the vast field of radio science and of what was discussed in our Commissions would call for a long series of lectures.

The following text briefly describes the founding of URSI and its present activities and was presented by Dr. P. Bauer in the presence of His Majesty King Albert II.

Sire, Messieurs les Ministres, Messieurs les Présidents des Académies, Chers Collègues, Mesdames, Messieurs

L'Union Radio-Scientifique Internationale, connue dans toutes les langues sous l'appellation U R S I, est l'une des 23 Unions affiliées au Conseil International des Unions Scientifiques. Elle fut créée à Bruxelles en 1919, lors de l'Assemblée constitutive de ce Conseil, et en même temps que les Unions Internationales d'Astronomie, de Géodésie et de Géophysique et de Chimie Pure et Appliquée.

Mais avant d'exposer les buts et activités de l'URSI, telle que nous la connaissons actuellement, quelques mots concernant ses origines me semblent être de rigueur.

En 1907, à la demande du Roi des Belges, Léopold II, des expériences de télégraphie sans fil avaient été effectuées par la firme Marconi près de l'embouchure du Fleuve Congo - actuellement Zaïre - en Afrique. Celles-ci s'étant avérées décevantes, le Roi pria Robert GOLDSCHMIDT, un des pionniers de l'étude de la propagation des ondes électromagnétiques et le futur premier secrétaire général de l'URSI, de se pencher sur le problème des radiocommunications équatoriales. Trois ans plus tard, le Roi Albert Ier reprit cette initiative et trouva un collaborateur idéal en la personne de Robert GOLDSCHMIDT. Dès 1912, une douzaine de stations équipées d'émetteurs de 5kW étaient installées le long du fleuve Congo, permettant une liaison radiotélégraphique sur une distance supérieure à 2 500 km. Simultanément, GOLDSCHMIDT installait dans l'enceinte du parc royal de Laeken une école de télégraphie sans fil, ainsi qu'un émetteur de 300 kW destiné à la liaison Belgique-Congo.

Bien entendu des expériences similaires se développaient ailleurs dans le monde, mais c'est bien ici, à Bruxelles, que germa l'idée de la création de notre Union.

Lors de la Conférence Internationale de l'Heure à Paris en 1912, Robert GOLDSCHMIDT, de concert avec des chercheurs d'autres pays, proposa de fonder un organisme central ayant pour but d'effectuer des recherches sur la propagation des ondes électromagnétiques, ainsi que des mesures de radiotélégraphie. GOLDSCHMIDT mettait à la disposition de cet organisme la station et les laboratoires de Laeken, ainsi qu'une somme de 50 000 francs belges.

En octobre 1913 eut lieu à Bruxelles la première réunoin de la Commission Internationale de Télégraphie sans Fil, à laquelle participaient des scientifiques de sept pays. La réunion suivante se tint en 1914, à Bruxelles également. Des Comités nationaux avaient été créés entretemps dans plusieurs pays et la Commission put dès lors procéder à l'élaboration de ses Statuts et de programmes d'observations. Le Roi Albert Ier avait bien voulu témoigner son intérêt en acceptant de devenir le Président d'honneur de la Commission. Mais la guerre allait éclater en août de la même année, et la station de Laeken fut détruite sur ordre du Roi lorsqu'il fallut abandonner Bruxelles.

En 1919 la Commission fondée en 1913 se transforma tout naturellement en l'Union dont nous fêtons aujourd'hui le 75e anniversaire. Cela se passait dans le bâtiment où nous nous trouvons réunis aujourd'hui.

Le but initial de cet organisme était d'encourager les études scientifiques de radiotélégraphie, et surtout celles d'entre elles qui exigeaient une collaboration internationale. Depuis lors, évidemment, la radiotélégraphie a cessé d'être la seule méthode disponible pour la transmission de l'information au moyen des ondes radioélectriques. Les progrès pour ainsi dire fulgurants réalisés au cours des décennies écoulées ont entraîné l'expansion du domaine d'intérêt de l'URSI. Celui-ci couvre actuellement «tous les aspects scientifiques des télécommunications utilisant les ondes électromagnétiques guidées et non guidées, la production et la détection de ces ondes, ainsi que le traitement des données dont elles sont porteuses».

Le but premier de l'URSI est donc de stimuler et de coordonner, au niveau international, les études scientifiques en radioélectricité, en télécommunications et en électronique. pour ce faire, des Commissions scientifiques ont été formées au fil des années au fur et à mesure de l'apparition de sujets nouveaux. A l'heure actuelle, elles sont au nombre de dix : Métrologie électromagnétique, Ondes et champs, Signaux et systèmes, Electronique et photonique, Bruits et brouillages électromagnétiques, Propagation des ondes et télédétection, Radioélectricité ionosphérique et propagation, Ondes dans les plasmas, Radioastronomie et Electromagnétisme en biologie et en médecine.

Par ailleurs, les membres de l'Union - actuellement au nombre de 32 - sont les Comités formés par les Académies des sciences ou autres institutions analogues. Ces Comités versent une contribution annuelle. Leurs représentants siègent au sein de chacune des Commissions scientifiques et au sein du Conseil de l'Union.

Toutes les décisions importantes concernant les activités de l'Union sont prises par le Conseil, qui siège pendant l'Assemblée générale. Dans l'intervalle des Assemblées, la gestion des affaires est assurée par le Bureau, dont les membres sont élus par le Conseil. Les affaires courantes sont expédiées par un Secrétariat permanent, sous la direction du Secrétaire général. Depuis la création de l'URSI, ce Secrétariat a toujours été situé en Belgique.

L'URSI se réunit en Assemblée générale tous les trois ans pour faire le point de l'état d'avancement des recherches et pour établir les programmes des études futures. Mais aussi, elle constitue un forum de prédilection qui permet aux chercherus du monde entier et, en particulier, aux jeunes scientifiques, de présenter les résultats de leurs études. La politique de l'URSI tend à favoriser la participation à ses réunions de jeunes scientifiques, en général et, plus spécialement, de ceux venant de pays en développement. Les Assemblées générales se tiennent dans différents pays, à l'invitation des Comités Membres.

L'union organise aussi, en collaboration avec l'un ou l'autre de ses Comités Membres ou d'autres organisations, des colloques internationaux consacrés à des sujets plus spécialisés. Ces conférences offrent le très grand avantage de permettre aux participants de nouer des relations directes avec leurs collègues étrangers, et d'échanger avec eux idées et expériences. Il convient de souligner que les réunions de l'URSI sont des lieux de rencontre entre scientifiques radioélectriciens et ingénieurs. C'est ainsi que, dans de nombreux cas, des connaissances résultant de la recherche fondamentale stimulent de nouveaux efforts dans le domaine des technologies, lesquelles affectent directement notre société et notre vie quotidienne. L'URSI reconnaît dès lors la nécessité de maintenir des contacts avec les ingénieurs de l'Union internationale des Télécommunications, l'agence spécialisée des Nations Unies, qui assure la coordination centrale des systèmes mondiaux de télécommunications. Elle communique à cet organisme les résultats des études scientifiques les plus récentes, qui permettent à celui-ci de se prononcer sur nombre de problèmes pratiques. Mais en sens inverse, l'UIT soumet à l'URSI des questions de nature scientifique stimulant ainsi de nouvelles études.

Dans le cadre du Conseil International des Unions Scientifiques, l'URSI entretient des relations étroites de coopération avec d'autres Unions et des Comités scientifiques ayant des intérêts communs. Elle prend une part active aux grands programmes pluridisciplinaires internationaux lancés par le Conseil, tels que, l'Année Géophysique Internationale et l'Année Internationale du Soleil Calme, dans le passé, et l'important programme Géosphère-Biosphère à l'heure actuelle.

Pour conclure, je voudrais souligner le rôle joué par notre Union dans l'approfondissement des connaissances relatives à d'autres disciplines scientifiques. Le terme «radiocommunications» peut être considéré comme englobant non seulement la transmission de l'information d'un émetteur à un récepteur par ondes radioélectriques, mais aussi l'acquisition des données les plus diverses sur les milieux naturels - géographique, géophysique, astronomique et même biologique - par détection de leur rayonnement propre ou part télésondage mettant en oeuvre des techniques dérivées de celles du radar. C'est ainsi qu'ont pu être découverts et étudiés de façon approfondie l'ionosphère, la magnétosphère et, grâce à la radioastronomie, de nombreux corps célestes et composants du milieu interstellaire. Par ailleurs, les applications des techniques radioélectriques ont joué un rôle essentiel dans la rapide évolution de la recherche spatiale en particulier en ce qui concerne l'observation de la terre. Plus récemment, une attention accrue s'est portée sur les interactions entre les champs électromagnétiques et les systèmes biologiques.

Plusieurs parmi les scientifiques associés aux travaux de l'URSI se sont vu décerner le prix Nobel de Physique. Les travaux qui leur ont valu cette consécration permettent de juger de la variété des sujets abordés : ionosphère et propagation des ondes, découvertes du transistor et du laser, théorie de l'information et holographie, physique du solide, radioastronomie.

Notre Union souhaite également que les retombées de ses activités bénéficient aussi concrètement que possible à tous ceux qui voient dans les télécommunications l'un des facteurs de leur développement économique et social, en même temps que l'instrument privilégié de relations harmonieuses entre les peuples et, partant, de la paix dans le monde.

GLOBAL SATELLITE NAVIGATION SYSTEMS : USES OF SPACE-TIME FIXES FROM GEODESY TO SAILING.

John E.B. Ponsonby

1. Introduction

By using a little box that one can hold in one's hand, it is now possible to find one's position anywhere on our planet immediately and continuously to within a few metres. Using a more specialized box and taking some time over the measurement, it is possible to find a position to within a couple of centimetres, and using two boxes it is routinely possible to establish relative positions to within 5mm. These positions are not only in the horizontal plane, for instance latitude and longitude, but also height, and as well as giving spatial position, precise time is also obtained. Thus, as navigators say, precision fixes are obtained in Space and Time.

First I shall explain in scientific and technical terms how this remarkable application of Space and Radio Science is achieved. I shall go on to discuss various scientific technical and adventurous applications of this facility. Finally I shall discuss the future technical, institutional and regulatory prospects.

As my title suggests, the little box determines its position by receiving signals from satellites which have been placed in orbit about the Earth. This is the latest development in the age-long association between the science of astronomy and the navigational arts. In earlier times the navigator and the surveyor used natural celestial bodies and a chronometer carrying precise time to determine his position. Now man-made satellites themselves carry and disseminate the precise time, but otherwise the ingredients are much as before, except for the contribution of Radio Science which allows direct measurement of range to replace earlier reliance on measurement of angle.

2. Three systems

There are three satellite systems to consider. By far the best known is the American Global Positioning System (GPS) which has been "up and running" since it was declared to have achieved its Initial Operational Capability (IOC) in December 1993. Less well known, but as we shall see, technically very similar, is the Russian Globalnaya Navigatsionnaya Sputikovaya Sistem (GLONASS) which may achieve a similar operational status by the end of this year. Both systems have been set up and are run by the military of their respective countries. For reasons that I shall come to, there is talk of setting up a third wholly civilian but international system. So far as I know this is nothing more than talk at present, but the prospect of such a system has strong appeal for the world's civil airlines. Their umbrella organisation, the International Civil Aviation Organisation (ICAO), coined the impartial term Global Navigation Satellite System (GNSS) to refer to this future possibility.

3. Basic Ideas

All three systems are based on the same main idea. Measurement of the distance of a user receiver from a satellite by timing the one-way propagation delay of radio signals using the defined velocity of light (and radio waves).

Velocity of light $c = 299.792458 \text{ m.}\mu\text{s}^{-1}$ (1)

This can be done if the precise time of transmission is known and if the precise time of reception can be measured.

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The measurement serves to establish the position of the user receiver to the extent that the precise position of the satellite is known at the instant of transmission. By precise time I mean time correct to a few nanoseconds and by precise position I mean a few metres. Time at this level of precision is carried on a satellite by an on-board atomic clock, usually a caesium beam standard. At the altitude they operate, the satellites' orbits can be established and predicted sufficiently far ahead in time, say a day ahead, to this level of spatial precision. We shall be hearing tomorrow afternoon of the possibility of yet more precise atomic clocks becoming available for use in the micro-gravity of space.

The key ingredients of the systems are the predictability of the orbits and the ability to transport precise time in an on-board clock. The radio signals transmitted carry precisely timed fiducial marks required for the range measuring function, as well as data which allows the user receiver's computer to work out the precise position of the satellites at these special moments. The satellites broadcast their own precision ephemerides as well as low precision "finding" ephemerides, so called almanacs, of all the other satellites in their constellations.

As well as the primary range measurements, the Doppler frequency shift of the carrier frequencies of the signals can be used as independent precision observables of the user's line-of-sight velocities towards the satellites. The simpler user receivers don't measure the Doppler shift, but high precision receivers, especially those of geodetic quality which measure the RF carrier phase directly, certainly do.

4. Spheres and hyperboloids

If a user receiver has knowledge of precise time, then it is easy to see that measurement of the arrival time of a signal gives the one-way propagation delay, and this puts the position of the receiver on a sphere of position centered on the position of the satellite at the instant of transmission.

When two such measurements are made to two satellites simultaneously, the position of the receiver is established as on the circular position line which is the intersection of the two spheres of position.

If measurements are made to three satellites simultaneously, then two independent circular position lines are obtained which intersect in two positions, one of which is the position of the user receiver. It is usually obvious which is the desired result, the one near the surface of the Earth, the other ambiguous position being usually far out in space. So given precise time, measuring the range to 3 satellites simultaneously generally gives a spatial FIX at the observer's position. The result will be satisfactory provided the satellites are well distributed in direction and provided they are not collinear in space. If necessary the ambiguity can be resolved by means of a fourth range measurement provided all 4 satellites are non-coplanar.

Unfortunately most user receivers are not equipped with portable atomic clocks carrying precise time. The ordinary user receiver is too small to contain an atomic clock, and so on "turn on", it starts off scarcely knowing the time to better than a few seconds. So instead of measuring the true ranges it measures pseudo ranges, the true ranges plus some offset due to the clock error, which is common to the range measurements to all the satellites. This error is then an extra unknown which must be found from additional measurement.

What can be done is to measure the difference of the time of arrival of signals from various satellites. With 2 satellites for instance, one difference of signal arrival times, puts the user on a surface of position which is an hyperbola of revolution; a hyperboloid with the instantaneous positions of the satellites at its foci.

With 3 satellites and two independent arrival time differences, the user gets two independent hyperboloid surfaces of position which intersect on a position line in space. With 4 satellites 2 such position lines are obtained. Provided no three satellites are collinear and all four are non-coplanar, they cross to give a unique FIX in space. Once the position in space is known, the true ranges to the satellites can be computed, and the clock error established. Thus from measuring the times of arrival of signals from 4 satellites, on an arbitrary time scale, a user receiver can compute a FIX in space and time; a 4-dimensional relativistic SPACE-TIME FIX.

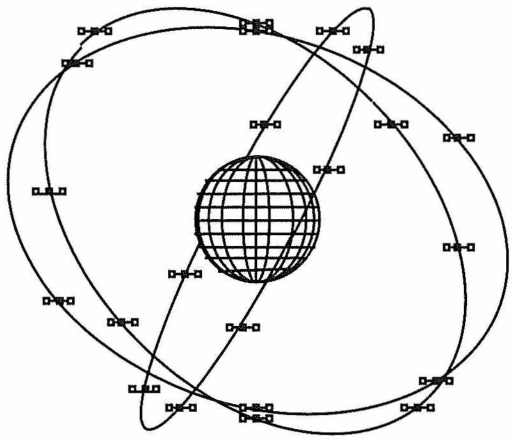
The spatial position is determined in the first instance in one or other of two fundamental geodetic reference systems: WGS-84 for GPS and SGS-85 for GLONASS, which unfortunately are not precisely the same. The time is referred to UTC(USNO) or UTC(SU) respectively.

The computer in the user receiver then uses a model of the geoid, the shape of the free ocean surface, to convert the spatial FIX position to geographical coordinates according to some locally appropriate MAP DATUM, plus height above mean sea level (msl).

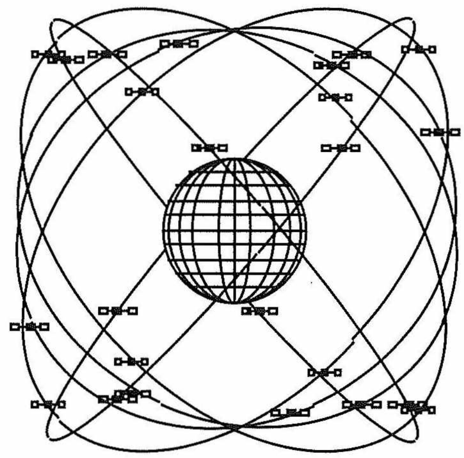
Now of course the navigator is not in the end satisfied by being given his position, however precisely, as numbers. The mariner is concerned to give an adequately wide berth to charted shoals and rocks and the aviator may be concerned to bring himself into coincidence with a runway and in both cases what really needs to be known is where they are on the chart to hand. Unfortunately many tens of Map Datums have been used for mapping various parts of the world and it is often unclear which was used to prepare a given chart. Besides, most existing nautical charts, are based on "low-tech" surveys made in the last century and were never intended to be relied on at the level of precision which satellite systems have suddenly made available. So existing charts and maps are the weak link in the whole satellite positioning enterprise and it is somewhat unnerving to see what blind faith some navigators are wont to place in them.

5. Constellations and Orbits

As we have seen, there has to be a minimum of 4 satellites simultaneously visible at all times to every user. To ensure this both GPS and GLONASS when complete, will have constellations of 24 satellites in high orbit about the Earth. Both use near circular orbits at an altitude of about three Earth radii at the upper edge of the outer Van Allen belt. GPS is the somewhat higher, its satellites complete two orbits in each sidereal day, whilst the GLONASS complete an extra 1/8th of an orbit in the same time. The orbits are



GLONASS Constellation



GPS Constellation

inclined to the plane of the equator so that there are several, typically a minimum of six above the horizon everywhere and at all times. GLONASS is to have 8 satellites spaced mutually 45° around three orbital planes at inclination i = 64.48°, whilst GPS has 4 satellites spaced 90° around six orbital planes at i = 55°, this being the highest inclination achievable by the Space Shuttle used to launch them. The velocities of the satellites are nearly 4 km.s^{-1} in their orbits.

One significant difference between GPS and GLONASS is the way in which the orbits are described in their broadcast ephemerides. GPS broadcasts classical osculating Keplerian elements updated every hour, whilst GLONASS broadcasts cartesian coordinates and velocity components updated every half hour. This latter scheme lessens the computational burden on the user receiver's computer and the decision to adopt this form of orbital parameterization doubtless reflects Russia's relative weakness in the field of microcomputers.

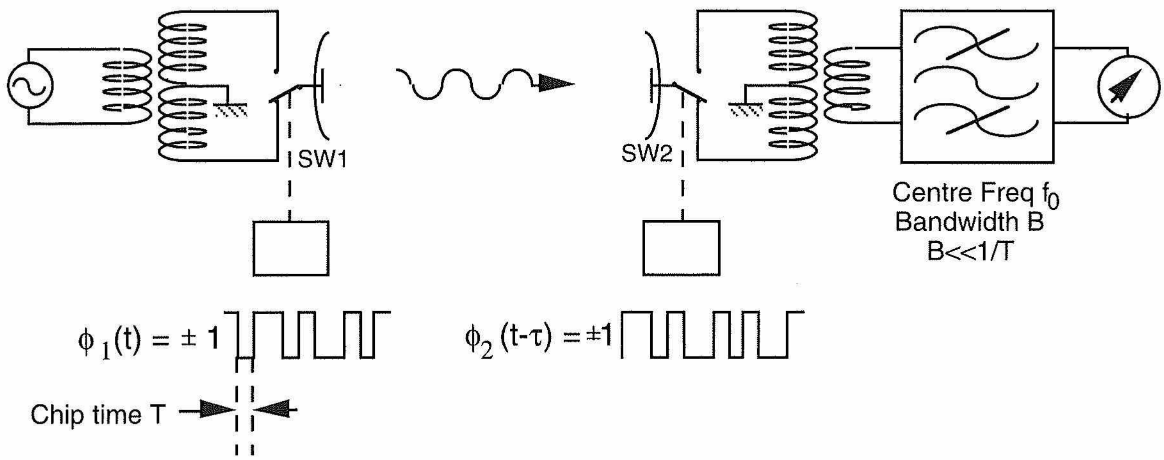
6. Range and Velocity Measurements

	GPS	GLONASS
Constellation structure		
Number of satillites	24 + 3 spares	24 + 2 or 3 spares
Number of orbital planes	6	3
Number of satellite planes	4 (90° apart)	8 (45° apart)
Orbital parameters		
Inclinations	55°	64.8°
Semi-major axes	25,560km	25,510km
Period	11h 58m	11h 15.75m
Orbits/sideral day	2	2.125
Velocity	3879m/s	3952m/s
Orbital specification	Osculating Keplerian elements up-dated every hour	Geocentric cartesian coordinates up-dated every half hour

I have talked about making precise measurements of the one-way time of flight of signals as if single RF pulses were used, but in the same breath I have also mentioned the measurement of velocity by Doppler shift, and it may be supposed that narrow-band signals, essentially CW's, are needed for that purpose. There seems to be an incompatibility here. However a short RF pulse needed for fine range resolution, necessarily has a wide bandwidth, whilst a narrow-band signal necessarily has long duration. It emerges that these Fourier properties are what are really necessary. Fine range resolution requires not a short pulse but a wideband time-structured signal and fine frequency resolution requires not a narrow-band signal but a signal of long duration, so there is no incompatibility. Both can be had simultaneously by using a continuous wide-band signal.

7. Spread Spectrum Signals

The radio signals transmitted by the satellites are of the form called Direct Sequence Spread Spectrum (DSSS). The radio frequency carriers are digitally phase modulated. Unlike communication systems however, where the modulation represents information, and is therefore by definition unpredictable, the DSSS scheme carries wholly predictable pseudo-random bit streams which are known in advance, at least to the intended user receivers. The basic idea can be understood in terms of a rudimentary system where the sinewave output of an oscillator at frequency f_0 is phase-reversal (BPSK: Binary Phase Shift Keyed) modulated by switch SW1 that in effect multiplies it by +1 or -1. The switch dwells in each position for an integer multiple of a fundamental time interval T called the "chip" time, and goes back and forth following its assigned pseudo-



Rudiments of Direct Sequence Spread Spectrum

random code. What emerges from the switch is a series of short segments of sine wave, some +ve and some -ve. This process redistributes the RF power into a continuous spectrum of the form:

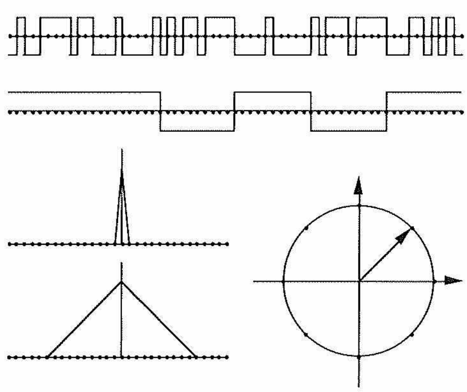
$$P(s) = sinc^2 (sT) \quad (2)$$

[$sinc(x) = \sin(\pi x) / (\pi x)$] where s is frequency measured from the carrier

At the receiving end a similar reversing switch SW2 chops up the incoming signal a second time according to a pattern built into the receiver. If the two pseudo-random patterns are incoherent, their overall result is to leave the signal chopped up in time and therefore spread in frequency and only some small fraction BT of the total power passes through the subsequent filter ($B << 1/T$), from which it emerges looking much like Gaussian random noise.

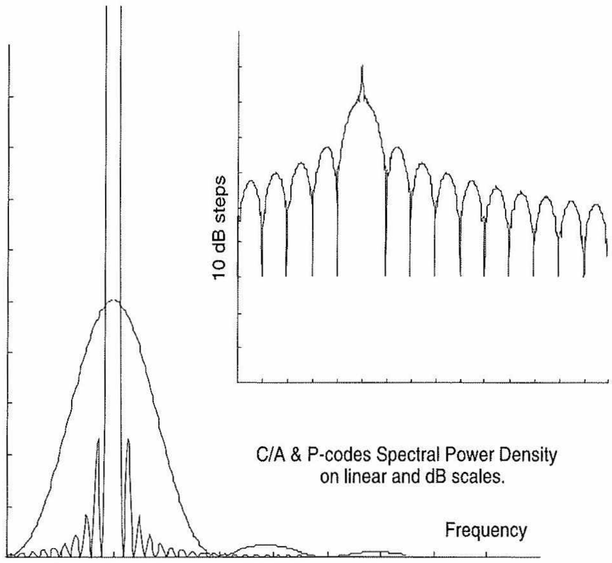
However if the modulation applied in the receiver exactly matches that of the incoming signal, then the second switch undoes the work of the first and restores the signal to its original CW form, which now of course passes unattenuated through the filter. The factor $1/BT$, by which the power level increases, is termed the processing gain. The full processing gain is only realised when the local modulation is exactly in step with that on the incoming signal. Any misalignment in time results in incomplete despreading and a fall off of the recompressed power. It falls to zero if the misalignment reaches as much as $\pm T$; one chip time. The receiver has a mechanism, a Delay Lock Loop (DLL), to maintain its pseudo-random code in precise synchronism with the incoming signal and it typically holds the alignment to better than $\pm T/10$. This is the basis of the timing and hence the range measurements. The matching of the modulation on the incoming signal with the pattern generated in the user receiver is analogous to, and as highly specific as, the matching of a key to a lock.

Having despread the signal, the reconstructed CW is of course Doppler shifted just as it would have been had it existed as a CW all along, so precise velocity measurement can be performed simultaneously with the ranging function. What I have described is a simplification. In both GPS and GLONASS the RF carrier is divided into two components mutually in phase quadrature and each component is independently BPSK modulated in the manner I've described but using two different "chip" rates. One component carries the relatively slow so-called C/A (Common Access) code, with chip rates of 1.023 & 0.511 MHz for GPS & GLONASS respectively, and the other the P-(precision) code ten times faster. In effect the carrier is QPSK (Quadrature Phase Shift Keyed) modulated. (It is no coincidence that the chosen numbers 1023 and 511 should



both be of the form 2^n-1) In both systems the high precision P-Code is reserved for the use of the military proprietors and it is the C/A codes that provide the Standard Positioning Service (SPS in GPS nomenclature) that are made available to the civilian user. There are however ways of using and getting some of the benefits of the P-codes, without being granted privileged knowledge of the codes themselves.

The autocorrelation functions of the two pseudo-random codes are triangular functions falling to zero at one chip time and the resulting RF power spectrum is the sum of their Fourier Transforms. The GLONASS spectra follow this theoretical form quite closely out to ten or more sidelobes from the centre frequency, except that they have null spikes in the nulls of the lobe pattern due to data unbalance. Incidentally these slowly diminishing sidelobes, and especially the null spikes, cause intolerable interference to Radio Astronomy in adjacent and nearby frequency bands. The early GPS satellites also had spectra of this form, though without null spikes, but the newer GPS satellites fortunately incorporate filters which reduce the second and subsequent sidelobes by several 10's of dB.



C/A & P-codes Spectral Power Density on linear and dB scales.

With GLONASS the same 511 step periodic pseudo-random sequence, which repeats every 1ms, is used by all the satellites in the constellation, and they are mutually distinguished by each in principle having its own RF carrier. (This was the original conception. It has since been agreed that two satellites, antipodal pairs 180 apart in the same orbit, will share the same carrier. So the number of carriers will be reduced from 24 to 12. This will reduce the interference caused to Radio Astronomy.) So GLONASS uses DSSS for ranging but Frequency Division Multiple Access (FDMA) for selecting the satellites. With GPS on the other hand, all the satellites use the same carrier frequency but each satellite uses its own peculiar 1023 step periodic (also in 1 ms) pseudo-random sequence (a Gold Code). So GPS is a Code Division Multiple Access (CDMA) system and is the more efficient user of the radio spectrum.

The signal strengths of the two systems are substantially the same. For both, the spread spectrum signal from a single satellite is well below the level of the thermal noise in the spread bandwidth at the user receiver. In the case of the GPS CDMA system, the *un-despread* signals from all the visible but unselected satellites add what appears as a few extra % to the noise above which the signal from any selected satellite is raised by the *processing gain.* The contribution of even 10 unselected satellites only degrades the signal to noise ratio of a selected satellite by about 1dB.

Actually what I have said is still not the whole truth, as the RF carriers are twice BPSK modulated. As well as the high bit rate pseudo-random spreading codes there is also 50 bps data imposed. Since this is information bearing it cannot be predicted by the user receiver and it remains on the carrier after the *despreading* process. To pass this data the post-despreading filter has B ~ 100Hz. With this bandwidth the chip rates give processing gains [-10 log (*BT*) db] from ~ +37dB for the GLONASS C/A code, to ~ +50dB for the GPS P-code. The 50 bps data carries the ephemeris and the almanac etc. broadcast by each satellite. The data streams are of course divided into words and frames etc., slightly differently for the two systems, but the details need not concern us today.

Both systems transmit the same C/A & P-codes on two coherently related RF carriers described as L1 & L2. Together these allow suitably equipped user receivers to measure the relative delay between the two channels and solve in effect for the total electron content of the ionosphere along the line-of-sight, using the fact that the ionospheric delay goes as f^{-2}. This allows a precise correction for the ionospheric delay to be applied. This is absolutely necessary for high precision geodetic receivers. Simple single frequency receivers have to make do with ionospheric corrections derived from predictions whose parameters are

	GPS	GLONASS
Radio frequencies	L1 : 1575.42 MHz L2 : 1227.60 MHz	L1 : 1602.0 + n x 0.5625 MHz L2 : 1246.0 + n x 0.4375 MHz n = 0, 1, 2, 3 ... 12
Multiplexing system	CDMA	FDMA
Polarization	Right Hand Circular	Right Hand Circular
Ranging system	DSSS	DSSS
"Chip" rates	C/A code 1.023 MHz P-code 10.23 MHz	C/A code 0.511 MHz P-code 5.11 MHz
Pseudo-random code repeat time	C/A code 1.0 ms P-code 604800 s (1 week)	C/A code 1.0 ms P-code 1.0 s
Received signal power with +3dBi antenna	L1 C/A > -160.0 dBW P > -163.0 dBW L1 C/A > -166.0 dBW P > -166.0 dBW	L1 C/A > -161.0 dBW P ? L1 C/A ? P ?

Comparison of GLONASS and GPS radio system parameters

	GPS	GLONASS
Navigation message structure:		
Superframe duration	12.5 m	2.5 m
Superframe capacity	37500 bits	7500 bits
Superframe spare capacity	~2750 bits	~620 bits
Data rate	50 bits/s	50 bits/s
Frame duration	30 s	30 s
Frame capacity	50 words/frame	15 words/frame
Word length	30 bits	100 bits
Space and time references:		
Time scale	UTC(USNO)	UTC(SU)
Geodetic frame	WGS-84	SGS-85

Comparison of GLONASS and GPS navigation message structures and space and time reference frames

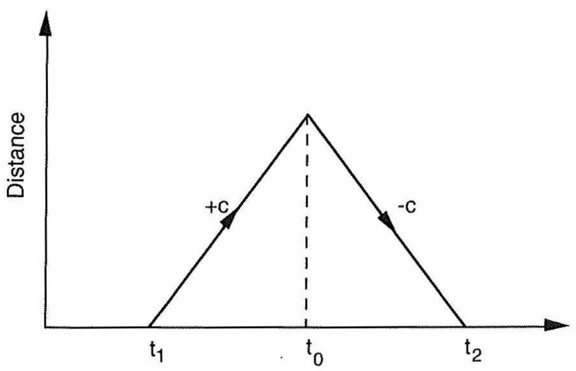
broadcast along with the ephemerides by the satellites themselves. The L2 channels only carry the spreading modulation and not the 50 bps data, so they can be despread into a narrower bandwidth and with thus higher processing gain.

8. Relativistic effects

I have explained that these systems give a relativistic SPACE-TIME FIX and it is interesting that they are inherently relativistic, relying as they do on an ability to synchronise widely separated and relatively moving clocks. The systems only achieve the precision of FIX that they do, by paying proper attention to certain relativistic effects.

Now 90 years ago, before the foundation of URSI, the matter of the synchronization of clocks was investigated by Albert Einstein in what came to be called his Special Theory of Relativity. Based on the Principle of the constancy of the speed of light for all non-accelerated observers, those in inertial frames of reference, he defined how clocks at rest in such a frame may be synchronized. What we now call Einstein Synchronization within an inertial frame, is based directly on that principle. It simply asserts that the time it takes a light signal to go from A to B is equal to the time it takes to return from B to A. So clocks may be synchronised by a two-way exchange of signals.

Unfortunately it turns out that strictly speaking there is no such thing as an inertial frame of reference and in particular the frame defined by the surface of the Earth is



Einstein Synchronization

non-inertial both because it is a rotating frame and because it is in the Earth's gravitational potential well. In this frame the velocity of light is neither constant nor even rectilinear. Light follows spiral paths. Consequently it is neither possible to synchronize the clocks on the satellites nor those at various places on the Earth's surface using Einstein Synchronization. If a naïve attempt is made to synchronize clocks on the Earth's surface by this method, a very peculiar thing is found to happen. If A is synchronized with B and B is synchronized with C, then it is found in general that C is not synchronized with A. This so called transitivity failure is due to the Sagnac Effect. Thus if a clock in Brussels is synchronized with a clock in Paris and another clock in London is also synchronized to Paris, it will be found that London and Brussels are out of step by ~ 50 picosec. This may not seem much, but in this time light travels 15mm and this is about three times the standard error of a GPS geodetic position determination.

To overcome this difficulty a universal Coordinate Time has to be introduced which does not proceed at the rate of local proper time. Imagine a non-rotating Earth-Centred Inertial frame (ECI) within which Einstein Synchronization can be carried out, and that this frame is well populated with clocks all reading this Coordinate Time. The real clocks on the satellites and on the ground, all moving in the ECI, are then offset from their proper rates, so that they find themselves in synchronism with all the Einstein Synchronized clocks as they sweep past them. This offsetting of the clocks is required to correct for Special Relativistic Time Dilation, the slow running of a moving clock, and for the General Relativistic blue shift, fast running of a clock, viewed from a position of lower potential in the Earth's gravitational field. It turns out that for the GPS and GLONASS satellites, the gravitational shift is several times bigger than the time dilation effect, so in both systems allowance for the resultant blue shift is made by a negative fractional frequency offset of the atomic clock controlled master oscillators ~ $4x10^{-10}$.

The actual fractional frequency offsets of the master oscillators are slightly greater for GPS than for GLONASS, reflecting the fact that the GPS orbits are at greater altitude and hence greater gravitational potential.

GPS 10.22999999545 MHz
instead of 10.23 MHz -4.45×10^{-10}

GLONASS 4.99999999782 MHz
instead of 5.00 Mhz -4.36×10^{-10}

Note that these are large compared to the typical fractional frequency error of $\sim 10^{-13}$ of a caesium clock.

The gravitational shift is significant even on the surface of the Earth. For instance the *proper time* of the master clock at the GPS control center at Colorado Springs, at an altitude of 1830 metres above msl runs +16ns.day compared to *coordinate time*. Uncorrected this gravitational shift would give rise to metre scale position errors within a few hours.

The three main relativistic effects are the Special relativistic time dilation due to the motions of the satellites, the General relativistic time dilation due to the potential of the Earth's gravitational field and the Sagnac effect arising from the Earth's rotation. All three are important at the metre level of position determination. Their naïve neglect would result in positional errors at the several 100's metre level. There are numerous secondary relativistic effects, due to the eccentricity of the satellite orbits varying the velocities and the gravitational shift, the altitude and velocity of the user receiver etc.. The application of relativity theory to satellite navigation systems is sufficiently complicated for there to be much scope for confusion and for proper doubt to arise as to whether the systems have been wholly correctly specified relativistically.

9. Applications

There are many applications of the global navigation satellite systems, and there is only time to sample a few on a quick traverse of the Geodesy to Sailing axis. Space applications don't seem to lie on this line but it should be mentioned that since the navigation satellites are so high above the Earth they can be used for locating space craft in low earth orbit (LEO). A convenient way of keeping track of a LEO is now to equip it with a GPS receiver and get it to report its position to its ground control by telemetry.

9.1 Geodesy

The highest precision positioning with GPS is obtained in geodetic use. Commercially available equipment achieves internally consistent survey at 5mm +1ppm of separation between a mobile and a fixed receiver. The mobile moves either continuously in *kinematic* mode maintaining phase-lock, or discontinuously in some form of *stop-go* mode, possibly with the receiver being turned off between sites. 9 channel dual frequency (L1 & L2), dual code (P & C/A) RF carrier phase-tracking receivers, use all visible satellites and apply the best possible ionospheric corrections. This is especially important at high latitudes. The high precision positions are obtained retrospectively by physically connecting the mobile to the fixed receiver to enable corrections recorded by the fixed receiver to be applied to the recorded readings of the mobile. There is no physical connection between the two receivers during the survey and in particular they do not need to be maintained within line-of-sight of each other. Note that 5mm corresponds to $\sim 10°$ of RF phase.

9.2 Differential GPS (DGPS)

A similar procedure is used in real-time for precision navigation. A fixed receiver at a known position measures the ranges to the visible satellites and computes the range errors it finds compared to the satellites' broadcast ephemerides. It then transmits these residuals to the mobile receivers over an auxiliary VHF radio link. The mobile uses the information to correct its own range measurements. This scheme removes the errors in the ephemerides, those due to the ionospheric and those introduced by Selective Availability (S/A) which is the deliberate degradation of the GPS SPS, and to which I shall return later. This way of working is termed Differential GPS (DGPS). There has of course got to be line-of-sight visibility between the fixed and mobile receivers for the VHF link, but it can provide coverage over the area of a harbour or an airfield and the corrections can be broadcast to any number of mobile receivers. I have the impression that DGPS is used mainly with simple single frequency receivers. Certainly my hand held GPS has provision to accept differential correction data at a serial input port. The positional accuracy depends on the quality of the receivers and on the velocities involved. At the best, geodetic quality positioning of a few mm, is possible in slow moving applications, such as the positioning of oil rigs at sea. For fast moving applications metre scale accuracy is obtained, sufficient to get a ship through a narrow harbour entrance or an aircraft onto a runway. There are numerous organisations involved in setting up DGPS systems.

9.3 Environmental Survey

GPS is already widely used for environmental surveys of various kinds. Noting the position of botanical specimens, interesting trees in the forest for instance. Here special kit is needed to raise the antenna above the canopy since trees blanket the L-band signals. Returning to standard positions for pollution sampling is another form of survey.

9.4 Expedition

Handheld GPS receivers are increasingly being relied on by explorers and adventurers. An ex-student of mine, Carl Holt, obsessed with the arctic used it on an expedition to Spitzbergen in summer 1993 and again in 1994 on a four man expedition walking on skis across Greenland. Most of the Greenland icecap is entirely featureless but towards the western edge the ice is extremely broken up and he and his friends were no longer able to pull their sledges. So they had to leave some of their kit and go ahead twenty miles with what they could carry. Using GPS they were able to go back and retrieve what they had left behind. It is doubtful whether any other form of navigation would have allowed them to do this in this sort of ground. Incidentally they carried two GPS receivers.

9.5 Road

There is a huge potential use of GLONASS and GPS on the road particularly coupled to digital maps. Unfortunately in towns, buildings and tunnels cause frequent loss of signal and the satellite system needs to be supplemented by some form of dead reckoning to be universally acceptable. I have nonetheless found the use of the handheld of value in my car and I think it could be equally useful on a motorcycle.

9.6 Air

At the moment neither GPS or GLONASS are accepted as sufficiently reliable for commercial airline service. Amateur fliers are not permitted to use it as their primary instrument navigation system but it is nevertheless widely used as an auxiliary to DME/VOR. Certain aviators who carry no other electronic navigational aids report that a small GPS receiver meets all their requirements.

9.7 Sailing

An ingenious use of GPS is to label video signals with precise time and position. The digital information can be inserted in the frame flyback time. This is useful for police surveillance but has also been used for outside broadcast (OB) purposes. A particularly interesting use is for televising sailing dhow races in the Persian Gulf. The problem is to keep the directional antenna on the shore for the video link pointing at the OB boat. Inserting GPS position data into the video waveform allows the shore crew to know where to point their antenna.

More generally in the maritime field a GPS receiver is now standard equipment on the bridge of a well found ship and it is increasingly becoming equally standard on yachts of all types. Whilst it is always stressed and rightly, considering how adverse an environment is a small boat for electronic equipment, that electronic navigational systems should always be regarded as aids to navigation which supplement but do not replace traditional means, already yachtsmen are being advised that the prices of handheld receivers are now so low, that they should no more think of putting to sea without a GPS receiver as without lifejackets and other standard items of safety equipment.

Presently available GPS receivers come with a wide range of auxiliary functions besides their primary position finding facility. They allow routes to be built up from a series of way-points, and they have anchor watch and man-over-board functions. They can be coupled to radars, to autopilots and to electronic charts. All these extras are easily provided given that the receiver proper necessarily contains an astonishingly powerful microprocessor with capacity to spare.

Unlike a communication antenna, which needs to be mounted high up the mast to maximise range, a GPS or GLONASS antenna should be mounted low down where it will suffer the minimum transverse acceleration. This is because acceleration gives a changing Doppler frequency shift and puts the greatest demands on the RF carrier tracking loops in the receiver.

10. Selective Availability (S/A)

At some point the military proprietors of GPS became alarmed at the quality of the positioning service obtainable using the low precision C/A code. It was at the few tens of metres level and scarcely inferior to that obtained using their privileged and cryptographically secure P-codes. The fear arose that in a military conflict it could be of utility to an enemy of the USA. So the dismal decision was reached to deliberately degrade the quality of the positioning service provided by the C/A codes, but to do it in such a way that the service available to the privileged US military user would be unaffected.

Naturally it has not been made public precisely how the degradation has been implemented but it is clear that the potential exists to introduce deliberate errors at two points. The first is by deliberately corrupting the broadcast ephemerides, telling lies about the position of the satellites, and the second is by "messing around" with the on-board master clocks so that their fiducial time marks are advanced and retarded by a few 10's of nanoseconds on a time scale of a few 10's of seconds. It is thought it is done according to some secret code so that suitably equipped military receivers can compensate for it. This degradation is *Selective Availability* (S/A). It is presently applied so as to introduce position errors usually not exceeding 100 metres, the accuracy of the so called Standard Positioning Service (SPS). It naturally also has the effect of giving rise to spurious velocity errors. A stationary GPS receiver will typically indicate a velocity of up to ~ 1 mph in some arbitrary but constantly changing direction. Sometimes however it will read zero.

At the time of the Gulf War in 1992, before GPS had attained IOC, but when it was nevertheless much used, there was a marked shortage of military receivers with the capability of compensating for S/A. So civilian receivers, largely yachtsmen's types, were pressed into service in the desert. To allow these to achieve maximum precision, the S/A, introduced remember to deny the full accuracy of the system to the enemies of the US, was suppressed for the duration of the war but it was reapplied again after the cessation of hostilities.

The application of S/A has had further bizarre consequences. Great efforts have been made to circumvent its degrading effect. As I mentioned earlier the most widely pursued approach is DGPS. It is ironic and comical that civilian agencies of the US government are devoting resources to these enterprises which seek to thwart the efforts of the DOD to deny the full precision to civilian users.

GLONASS has no S/A and it is said the satellites haven't the necessary hardware to allow anything of the kind to be applied. As a result the positioning service provided by GLONASS is at present more than an order of magnitude better than the SPS of GPS. This fact deserves to be better known than it is.

11. Institutional arrangements

As yet there are no handy little GLONASS receivers on the market but doubtless they will come. GPS receivers however are rapidly becoming "consumer" items costing a few 100's US$, and the number of civilian users vastly outnumber the military users, and the amateur users vastly outnumber the professionals. However civilian users, whether walking the deserts or sailing the oceans use it strictly on an "own risk" basis. There is no guarantee that the positioning service will always be available and the system owners, the US DOD, reserve the right to deny the use of it whenever it suites them to do so.

This situation is perhaps acceptable to yachtsmen, but it most certainly is not satisfactory for airlines. The airlines of the world will not entrust their fare paying passengers to a navigation system which is owned and operated and at the whim of the military of a foreign power. This goes for GLONASS just as much as for GPS. Quite apart from deliberate unannounced denial of the service, and the continuing absurdity of S/A, there is also the question of technical failure. Neither GPS nor GLONASS have the technical means to enable a failure of a satellite to be detected and the user informed on the time scale of a few seconds appropriate to critical phases of flight, such as blind landing. Neither system alone is sure to have enough satellites well placed at all times to provide the necessary redundancy. However if the two systems were amalgamated there would be adequate redundancy, but still the objection of relying on the military of foreign powers would remain. The joint system would only be acceptable if it were civilianised and entrusted to some international organisation, perhaps a new Specialized Agency of the United Nations, that would be able to guarantee and be accountable for the continued availability of the service.

The airlines of the world are otherwise keen to use this technology. ICAO coined the term Global Navigation Satellite System (GNSS) to describe a future civilian system and there is talk of setting up such a system independent of both GPS and GLONASS. It is questionable however whether the world really needs three competing systems and there certainly isn't radio spectrum readily available for a third system. Much the best would be amalgamation and civilianisation, though it is technically difficult so long as they are based on different geodetic frames and on rival versions of UTC, and the political obstacles are considerable.

A small step towards civilianisation of GPS which seems to be going ahead is a move by INMARSAT (International Maritime Satellite Organisation) to transmit GPS-like signals from its new geostationary satellites using spare Gold codes. These will not have S/A applied and they will add welcome redundancy to GPS within their operational footprints but they cannot of course cover the polar regions.

One great inconvenience which I mentioned earlier is the multiplicity of geodetic datums. It would greatly help if all navigational maps and charts were reissued on WGS-84. ICAO have mandated the introduction of WGS-84 for world wide aviation use as from 1st January 1998 but it is a huge task. There are over 500,000 positions to be redefined in the European region alone. It will clearly take decades to convert the world as a whole to one reference frame for all purposes. Here I am afraid in solving one problem Radio Science has created another!

12. Concluding remarks

When I was a small boy I did a lot of travelling around Africa and elsewhere and I naturally became very keen on geography and studying maps. I remember suggesting to my father, wouldn't it be a grand idea to paint the lines of latitude and longitude that appear on maps actually on the ground, much as lines are drawn on football fields. Today virtually that very thing has been done. Invisible electromagnetic grids have been laid down over our whole planet, over the oceans and over the territories of all nations, largely it must be said without seeking or obtaining their permission, and which a little box like this can sense to tell us where it is. These systems are great planetary-scale engineering achievements and splendid applications of Radio Science. Individually and still more jointly, they provide a facility of immense utility, and they present a wonderful example of the beating of swords into ploughshares. Their inception brings home to us very forcibly, notwithstanding that we are still divided into petty nation states, that first and foremost we are all spacemen and spacewomen, fellow crew members of Spaceship Earth.

Power Transmission Electromagnetics

R.G. Olsen

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1. Abstract

Over the years many issues related to electromagnetic analysis of power lines have been raised. These include some related to the operation of power lines and others related to effects of the power line electromagnetic environment. Concern about the latter has been responsible for a renewed interest by the media. In this article, an overview of these issues will be given. When appropriate, the topics will be placed in the context of methods commonly used by those trained in the electromagnetics of antennas and propagation.

2. Introduction

For several reasons it is important to understand the electromagnetic fields associated with the electric power transmission and distribution system. Historically, it was important for determining that the system operated efficiently and reliably. For example, electromagnetic field analysis was used to determine equivalent transmission line parameters for system power flow, loss and stability studies. Electromagnetic analysis has also been used in studies of lightning protection and insulation failure. Another concern has been safety from the hazards of electrical shock. Such shocks may occur both by direct contact with the power system or indirectly by contact with systems which are electromagnetically coupled to the power system. Electromagnetic coupling can also cause interference with wire communication systems such as telephone and railroad signaling circuits. Mitigation of this interference requires an understanding of parameters which affect the coupling.

As the voltages of power lines have increased, other effects of power lines on the environment have become of concern. For example, electromagnetic interference to broadcast communications from corona on high voltage power lines has been an issue since the 1930's. More recently, there has been concern about possible health effects from exposure to extremely low frequency (ELF) electric and magnetic fields. It is this issue which has brought considerable media attention to the power line environment.

The main purpose of this paper is to review the theory of electromagnetic phenomena associated with electric power lines for those who have a background in the application of electromagnetic theory to antenna and propagation problems. One goal is to explain how quasi-static analysis used by power engineers can be understood in the context of the more general analysis techniques commonly employed in the electromagnetics community. This exercise has two benefits. The first is that quasi-static theory is much simpler than the more general theory and should be used when possible. For this reason, the conditions for which quasi-static theory is applicable should be understood. This can be done by developing quasi-static approximations as limiting cases of the more general theory. The second benefit is that well known electromagnetic analysis tools can be used to generalize the quasi-static theory in those situations for which it is necessary. Examples of this are the application of reciprocity theory to the study of undesired coupling between power lines and other systems and the use of traveling wave antenna concepts to explain VHF/UHF interference from corona on power lines. Another goal of the paper is to familiarize the electromagnetics community with some of the historic and more recent problems which affect the design of electric power lines. These include issues which affect the operation of such lines as well as their environmental impact.

3. Definition of the problem

The most common system for the transport of electrical energy is the overhead transmission line which consists of several wires above the earth as illustrated in Figure 1. This is the system which will be considered here. Underground power lines consist of several insulated wires either buried directly in the earth or encased in a duct or a pipe. Although they are becoming more common they will not be considered here in order to conserve space [1].

It is often acceptable to approximate the geometry of a power line before solving for its fields. In fact, it is often assumed without justification that the earth is homogeneous and flat and that the wires are infinitely long and horizontal. The conditions for which these approximations can be

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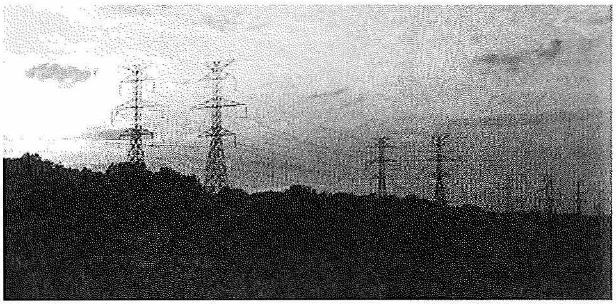

Figure 1 - A typical power line (photo courtesy of Black and Veatch, Kansas City, MO)

made are not easily stated and beyond the scope of this article. However, results based on these approximations are more often found to be useful than not. One of the most notable questions raised about the assumption of horizontal wires is what wire height to use since the wires are higher near the towers than between them. In some cases, the average height will be used while in others the minimum height will be used. When these simplifications can be made (as will be done here), the power line problem can be analyzed as a two dimensional one and the solution simplified considerably. In some cases, generalizations can be made which still allow two dimensional analysis. These include extensions to allow for multilayer earth and variations in earth height transverse to the line [2]. In those cases for which two dimensional analysis cannot be used,

located at a height $y=d_n$ above the earth, a horizontal distance $x=h_n$ from some specified reference axis and is parallel to the z axis. It has been assumed that all sources and fields vary with time as $\exp(j\omega t)$ where is the radian frequency.

The intrinsic impedance per unit length of each wire is defined as

$$Z_{si} = \eta_s / (2\pi a)\,\text{ohms/m} \tag{1}$$

where η_s is the surface impedance of the wire defined as (At lower frequencies it may be ncessary to use a more accurate expression for the impedance of a round wire [5]. In the limit as $\omega \longrightarrow 0,\ Z_{si} \longrightarrow (\pi a^2 \sigma_s)^{-1}$.)

$$\eta_s = \sqrt{\frac{j\omega\mu_o}{\sigma_s}}\ \text{ohms},\ \text{Re}(\eta_s) \geq 0 \tag{2}$$

This simple formula is valid if $a > 3\delta_s$ where δ_s (wire skin depth) $= (2/\omega\mu_o\sigma_s)^{1/2}$ and σ_s is the conductivity of the wire.

4. The power line as an open waveguide

It is appropriate to describe this problem as that of wave propagation in a uniform open waveguide. As is traditional in the analysis of waveguides, the first issue is to identify the modes of the structure in the absence of sources. Later,

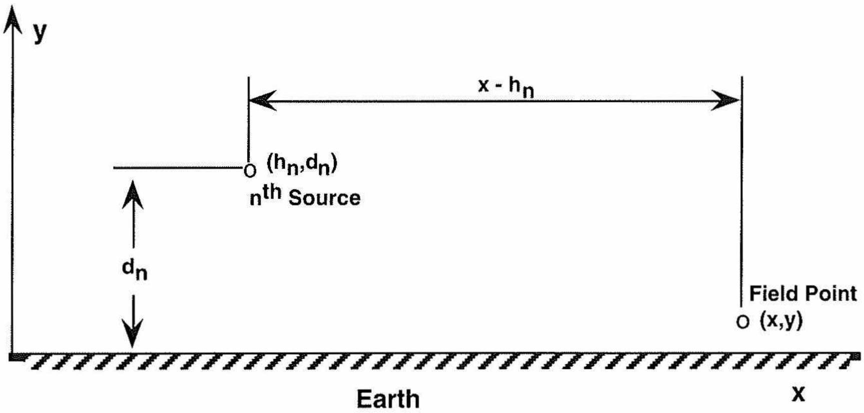

Figure 2 - Definition of geometric variables for a two dimensional line source

alternative methods have been used but always after first making the quasi-static approximation. One example is the calculation of ELF magnetic fields directly under a power line for which conductor sag between towers is an important factor [3]. In principle, three dimensional analysis similar to that used to study periodic waveguides could be used without the quasi-static approximation but the author is not aware of any such work [4].

The simplified two dimensional problem described above is illustrated in Figure 2. Here N solid wires of radius a and intrinsic impedance Z_{si} are located in free space above a homogeneous earth with permittivity $\varepsilon_o\varepsilon_g$, permeability μ_o and conductivity σ_g. ε_o *and* μ_o are the permittivity and permeability of free space respectively. The nth wire is

sources will be added and used to study the relative importance of the different modes. In this article, only the case for a single wire above earth will be described. The more general (and practical) case for multiple wires can be found in [6].

Since this is an open waveguide, the spectrum of the fields consists of a finite set of discrete modes and one or more continuous spectra. The fields of each discrete mode are assumed to vary as $\exp(-\Gamma_s z)$ and are bounded to the region near the wires. The fields of the continuous spectrum on the other hand carry radiated energy away from the wire.

Wait has found an implicit expression which can be solved for the propagation constant (Γ_s) of any mode on this structure in terms of the well known two dimensional Sommerfeld integrals [7]. Using this expression, Kuester, Chang and Olsen showed that there are two discrete modes and three sets of continuous spectra [8]. One of the discrete modes is the well known «quasi-TEM « mode and the other a "surface attached" mode. The properties of quasi-TEM modes have been discussed by dos Santos and Finganier[9].

To excite such a waveguide, several types of sources have been used. These include series voltage sources on the wire, electrically short multipoles and an arbitrary distribution of fields over an aperture [8], [10]- [12]. Using voltage source excitation, Chang and Olsen showed that when the height of the wire is small compared to a free space wavelength and the earth is a reasonably good conductor, the quasi-TEM mode is the dominant part of the current distribution spectrum [10]. Clearly this is the case for power frequency excitation and typical power line heights because the free space wavelength (λ_o) at 60 Hertz is 5000 km. If the field point is also close to the wire with respect to a free space wavelength, then the total transverse fields are well approximated as those of the «quasi-TEM» modal fields. This is generally true at 60 Hertz but may not be true for the analysis of corona generated interference fields at higher frequencies [13].

The above conclusion is especially interesting in light of the allegation in the popular literature that the 60 Hertz electromagnetic fields associated with a power line should be described as "radiation" [14]. Clearly, this is not valid for practical cases when the continuous spectra (i.e. radiation fields) can be ignored. This means that it is not proper to describe 60 Hertz power line fields as "radiation". An alternative discussion of this topic can be found in [15].

5. The transmission line approximation and quasi-static field analysis

Wait has shown that when the height of the wire is small compared to a free space wavelength (the same conditions identified above) that the quasi-static approximation can be made and the implicit expression for s of the quasi-TEM mode reduces to a simple explicit expression of the form [7]

$$\Gamma_s^2 = Z_s Y_s \tag{3}$$

where $Z_s = Z_{si} + Z_{ss} + Z_g$,

$$Z_{ss} = \frac{j\omega\mu_o}{2\pi}\ln(2d/a) \quad \text{and} \tag{4}$$

$$Z_g = \frac{-j\omega\mu_o}{2\pi}\frac{2}{k_g^2}\int_0^\infty (u-\lambda)e^{-\lambda 2d}d\lambda, \tag{5}$$

where $u = (\lambda^2 - k_g^2)^{1/2}, \mathrm{Re}(u) \geq 0,$

$k_g \approx (\omega\mu_o\sigma_g)^{1/2}e^{-j\pi/4}$ and

$$Y_s = \frac{j2\pi\omega\varepsilon_o}{\ln(2d/a)} \tag{6}$$

Z_s and Y_s are respectively the series impedance and parallel admittance per unit length of the equivalent transmission line. Z_{ss} is the external self impedance of the wire above a perfectly conducting earth while Z_g is the well known Carson integral which represents the effect of an imperfectly conducting earth on the impedance.

Equations (3) - (6) are equivalent to the expressions derived by Carson in his classic 1926 paper [16]. In this paper Carson used a combination of circuit theory and quasi-static field analysis to identify equivalent transmission line parameters for the propagation of the quasi-TEM mode. He also developed simple methods to calculate the electric and magnetic fields which will be described shortly.

Before doing this, it is perhaps useful here to comment on a difference in perspective relating to ELF electric and magnetic field coupling. According to Maxwell's equations, sinusoidal steady state electric and magnetic fields are coupled (i.e. if one is known then the other can be computed from the first) unless the frequency is precisely zero. Yet it is often stated by power engineers that the electric and magnetic fields of a power line are uncoupled and, as a practical matter, they are treated that way. In fact, power engineers calculate the electric and magnetic fields separately and relate them to power line voltage and current respectively. This difference in perspective can be resolved in the following way. It has been shown that the electric and magnetic fields of a power line are coupled by the spatial derivative of the fields along the direction of the transmission line [15]. Since $\Gamma_s \cong j2\pi/\lambda_o$, and the free space wavelength is so large at ELF, the term $\exp(-\Gamma_s z)$ is usually set equal to 1 and the variation along the power line is ignored in the analysis of ELF fields. As a further practical matter, it is nearly impossible to accurately measure the spatial derivatives of the fields along the wire axis because they are so small compared to variations in the geometry of the line. Thus the information needed to calculate one field from a calculation or measurement of the other is not available. Note that it might be tempting to assume an $\exp(-j2\pi z/\lambda_o)$ variation of the fields. This cannot be done, however, because both forward and reflected waves exist on a power line. Thus, while it is in principle possible to calculate the magnetic field given the electric field or vice versa, it is not done in practice and the source of electric field (voltage or more directly charge) is treated as if it were independent of the source of magnetic field (current).

Using (3)-(6) (or its generalization to the multiple wire case), it is possible to study one of the more important problems for power transmission engineers: that of calculating the power lost to dissipation in both the wire and the earth. That this is important can be illustrated in the following way. In the process of transporting 300 megawatts of power 100 miles on a 345 kV transmission line, approximately 5 megawatts will be lost due to heating of the power line conductors. This is enough power to supply electricity to between 2000 and 5000 homes. It is the desire to reduce this loss which has led to the use of higher voltage power lines (to reduce the current for a given power flow), to the use of larger conductors (to reduce wire resistance) and to the proposal for the use of superconducting cable. It is important to point out that while resistive loss in the wire is usually the dominant loss, earth loss and corona loss also exist. The latter will be discussed in a later section. A related point here is that on alternating current (AC) power lines, the current does not flow uniformly throughout the conductor because of the skin effect [5]. This phenomena leads to a frequency dependent series resistance as incorporated into the internal impedance of (1) and (2). The resistance increases as $\omega^{1/2}$ for higher frequencies and is asymptotic to $1/(\pi a^2 \sigma_s)$ as $w \to 0$. Thus lowering the frequency reduces the power loss. It is this result that led to the development of direct current (DC) transmission lines for long distances despite the fixed cost of converting from AC to DC at both ends.

Once the quasi-static approximation has been made, it can be shown that simple models for calculating the dominant electric and magnetic fields of a power line can be derived. The transverse ELF electric field can be calculated by setting the propagation constant (Γs) equal to zero, and assuming that the earth is perfectly conducting. This is permissible for typical earth conductivities and distances which are small compared to a free space wavelength. Perfect image theory can then be used and the earth replaced with images of each wire at a depth equal to the height of the wire. In this case, the transverse electric field is conservative in its plane and a unique voltage can be defined. Using this the electric field can be related to the charge per unit length of the wire through the capacitance between the wire and the earth [17,18]. For a single wire at (x,y) = (d ,0), the electric field in space is

$$E_x(x,y) = \frac{-V}{\ln(2d/a)} \left[\frac{x}{(y+d)^2+x^2} - \frac{x}{(y-d)^2+x^2} \right] \text{volts/meter} \quad (7)$$

$$E_y(x,y) = \frac{-V}{\ln(2d/a)} \left[\frac{(y+d)}{(y+d)^2+x^2} - \frac{(y-d)}{(y-d)^2+x^2} \right] \text{volts/meter} \quad (8)$$

where V is the voltage on the wire with respect to perfectly conducting earth. This is the same result obtained if two dimensional electrostatic theory had been used from the beginning. For multiple wires, well known methods are available for the equivalent calculation [18,19]. Note that in this case if the voltages are given, a two step solution must be used. First, the charge per unit length on each wire must be found be inverting a matrix of Maxwell potential coefficients. This information can then be used to solve for the electric fields everywhere using well known solutions for the electric fields of a line source of charge above a perfect earth.

The calculation of the ELF magnetic field is a bit more complicated. Consider a single wire carrying a phasor current I. For this calculation, the earth can be replaced with an image at a complex depth proportional to the skin depth of the earth. The results are [20]

$$B_x(x,y) = -2I \left[\frac{(y-d)}{(y-d)^2+x^2} - \frac{(y+d+\alpha)}{(y+d+\alpha)^2+x^2} \right] \text{milligauss (mG)} \quad (9)$$

$$B_y(x,y) = +2I \left[\frac{x}{(y-d)^2+x^2} - \frac{x}{(y+d+\alpha)^2+x^2} \right] \text{(mG)} \quad (10)$$

where $\alpha = \sqrt{2}\delta_g e^{-j\pi/4}$ and $\delta_g = (2/\pi\omega\sigma_g)^{1/2}$ is the skin depth of the earth. The current and all distances are assumed to be in SI units. Here, the final result was written in milligauss because of its common use in the United States. In Europe, the more common unit is the SI unit microtesla (μT) which is related to milligauss by 0.1 μT = 1.0 mG.

The first term of either (9) or (10) is the magnetic field of a line current source in free space. The second term is the complex image and approximates the magnetic fields of the induced eddy currents in the earth. The expressions have been shown to be reasonably accurate in the quasi-static regime.

At power system frequencies the image can be (and often is) ignored because the image depth is on the order of 1000 meters below the earth. One must be more careful, however, when dealing with either harmonic frequencies or transients. If the complex image term can be ignored, the transverse magnetic field can be written as

$$B_x(x,y) = -2I \left[\frac{(y-d)}{(y-d)^2+x^2} \right] \text{mG} \quad (11)$$

$$B_y(x,y) = +2I \left[\frac{x}{(y-d)^2+x^2} \right] \text{mG} \quad (12)$$

Equations (11) and (12) are valid if all significant distances are much less than a skin depth in the earth. This is the same result which would have been obtained had two dimensional magnetostatic theory been used from the beginning.

6. The ELF electric and magnetic field environment and the concern over health effects

Twenty five years ago the electric field was the major concern when possible health effects of electric power lines were discussed. This was because calculations of electric current induced in a human under typical transmission lines showed that the electric field was the dominant contributor [18,21]. In response to this concern, a number of states established limits on the magnitude of the power frequency electric field [22]. Since 1979, with the publication of a landmark epidemiological study, the concern has been gradually shifting to magnetic fields [23]. In this study, a surrogate for the magnetic field (rather than the magnetic field itself) was found to have a weak but statistically significant association with childhood leukemia. It is useful to note at this point that an association does not necessarily imply cause and effect and in fact no compelling evidence for cause and effect has been found. Subsequent epidemiological studies, while of better quality have failed to either establish or reject an association between magnetic fields and health outcomes. Nevertheless, they show a consistent association with the magnetic field surrogate. This consistency is what drives the continued interest and research in this area. It is interesting to note that no study has found a statistically significant association between the electric field and any health outcome.

In recent years, there has been a great deal of research in this area and vigorous debate about whether there are or are not any health hazards of exposure to ELF magnetic fields at levels associated with the power transmission system. While the consensus among scientists at this time is that there are "biological effects" at some level (exactly what level is controversial) of magnetic field exposure, there is no consensus that there is sufficient evidence for health hazards or that there is any basis for exposure regulations [24]. Public concern, however, is quite evident and media coverage has generally been increasing. As a result, the government and utilities have invested heavily in research and utilities have incurred costs of staff to monitor the issue and defend against litigation. Further, there have been increased costs of construction and construction delays. According to the Department of Energy, these costs has been estimated to be on the order of one billion dollars per year.

Before proceeding with a discussion of characteristics of power system ELF magnetic fields it is useful to note that there are reasons for studying these fields other than their potential health hazards. One is that power frequency magnetic fields cause interference with cathode ray tubes (CRT's) and that this has created a need for the development of magnetic field shielding schemes. Another is the problem of inductive coupling to wire communication systems and other systems such as pipelines and railroads which may share a common right of way. These issues will be discussed in more detail later.

Consider next some characteristics of electric and magnetic fields on power lines. First, it is useful to note that the voltage on power lines is constant to within roughly 10%. This means that it is possible to calculate the power frequency electric field from a given line with reasonable accuracy at any time. No more will be said about this since well known techniques are available for calculating electric fields from multiple wire lines [18,19]. The behavior of the current and hence the magnetic field, however, is very different. These are very dependent upon power system configuration and operating conditions. For example, on a given line the current can vary over a given day by a factor of more than four. Significant seasonal variation is also observed. These variations occur because of more or less predictable shifts in the demand for electric power due to daily lifestyle patterns and seasonal weather changes. Another source of power line current and magnetic field variation is current unbalance. To understand this is first necessary to discuss some basics of power system design.

Most power lines are three phase lines. This means that one wire (the «A phase») has a nominal electrical phase of 0 degrees, the second wire (the «B phase») a nominal electrical phase of -120 degrees and the third wire (the «C phase») a nominal electrical phase of 120 degrees. Typically a power line consists of these three phase wires and possibly a grounded neutral wire and/or shield wires. At the terminations of the line it may be grounded through a grounded wye connected transformer [25,26].

Ideally, the currents and voltages on the phase wires are "balanced" which means that they have equal amplitudes and are spaced in phase by exactly 120 degrees. On such a balanced system the «net current» (i.e. phasor sum of the phase, neutral and shield wire currents) is zero. In practice,however, power lines are "unbalanced" primarily because many loads are «single phase loads» connected between two phase wires or one phase wire and the neutral wire and these loads are not distributed equally between phases. With this unbalance, the net current may not be zero and there must be a compensating current called a «return» current flowing somewhere in the earth or in some unintentional grounding path such as a water pipe. This fact can have a profound effect on the magnetic field because earth return currents are far from the power line and (as will be illustrated later) the more widely spaced the power line and return currents the larger the magnetic fields. A final comment is that the unbalance is a random function of time because loads are switched on and off randomly.

This all results in the fact that the magnetic fields of a power line may vary considerably during the day and year and that as a consequence, it is necessary to define this field statistically. In fact , a computer program has been written in just this way [27]. In this program, a probability distribution for the magnetic field over a year is calculated by incorporating statistics on current unbalance, and daily and annual variations in current amplitude. One reason why one must be careful with the definition of magnetic field levels is that attempts to regulate magnetic fields are complicated by the question of how to define the magnetic field at a point near a power line by a single number.

The magnetic field of a multiple wire power line will be considered next because some insight can be gained into the issue of reducing magnetic fields. For a multiple wire line with N phase wires and no shield or neutral wires the magnetic fields can be written by superimposing (11) and (12) for each current. Here, it will be useful to express these formulas in a slightly different form. Suppose that R_a is defined as the distance from the field point to the origin of a set of coordinates near the center of the set of conductors. Then the magnetic fields of the set of wires can be expanded in a Taylor series in inverse powers of R_a . The field becomes

$$B_x(x,y) = \frac{2\sin(\phi)}{R_a}\sum_{n=1}^{N} I_n + \frac{2(1+2\sin^2(\phi))}{R_a^2}\sum_{n=1}^{N}\delta_n I_n - \frac{\sin(2\phi)}{R_a^2}\sum_{n=1}^{N} h_n I_n + \mathrm{O}(1/R_a)^3 \qquad (13)$$

$$B_y(x,y) = \frac{2\cos(\phi)}{R_a}\sum_{n=1}^{N} I_n + \frac{2(1+2\cos^2(\phi))}{R_a^2}\sum_{n=1}^{N} h_n I_n - \frac{\sin(2\phi)}{R_a^2}\sum_{n=1}^{N}\delta_n I_n + \mathrm{O}(1/R_a)^3 \qquad (14)$$

where $\sin(\phi) = d_a/R_a$, $\cos(\phi) = x/R_a$, $R_a = \sqrt{d_a^2 + x^2}$ and $d_n = d_a + \delta_n$. The geometric variables are defined in Figure 3.

It can first be noted that if the so called «net current» is zero, (i.e. $\sum I_n = 0$ since there are no shield or neutral wires in this example), the $1/R_a$ term is zero and the fields decay at least as fast as $1/(R_a)^2$. Since «balanced currents» are a special case of zero net current, it is clear that balanced currents are desirable. Note also in this example that if the power line is ungrounded, the net current is automatically zero at its ends [26]. If the net current is not zero then the magnetic field decays as $1/R_a$ (*Ultimately, the magnetic fields must decay as $(1/R_a)^2$ because there must be a compensating (i.e. return) current flowing in the earth. This additional term is accounted for by the terms of (9) and (10) but which have been ignored in (13) and (14) because the return currents are far from the power line.*) Given zero net current, the fields can be further reduced if the spacing between wires (i.e. δ_n *and* h_n) is reduced or the distance R_a is increased. Information about such strategies for reducing magnetic fields from power lines is available in [28]. Additional reduction of the magnetic fields is possible under certain conditions that the coefficients of successive powers of the series above can be set to zero. Consider first the case for which two three phase power lines are operated in parallel as shown in Figure 3. If the currents on the two lines are split equally and the electrical phase of the wires in opposite corners (e.g. phase A in the upper right and lower left) are the same then the coefficients of the $(1/R_a)^2$ terms are zero and the magnetic fields decay as $(1/R_a)^3$. Several power lines have been proposed which satisfy these conditions, the most well known of which is the called a double circuit low reactance line [26]. It should be emphasized, however, that the performance claimed for these lines depends upon the assumptions of current balance, equal current splitting

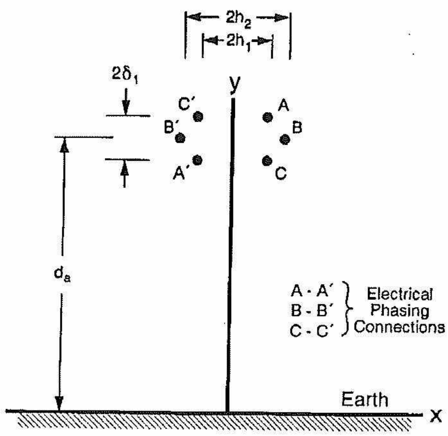

Figure 3 - Two parallel three phase power lines electrically phased to reduce magnetic fields

and zero net current [26]. It is found that satisfactory balance conditions usually exist on high voltage transmission lines but not necessarily on lower voltage distribution lines.

Before proceeding to another subject, it should be pointed out that the reduction of magnetic fields is not necessarily done without penalty. It can be shown, for example, than many power lines designed for reduced magnetic fields have larger electric fields at the conductor surface and hence more corona related audible noise and high frequency electromagnetic interference (EMI). Another issue is that of worker safety. Magnetic fields can be reduced by reducing wire spacing. However, this compromises the safety of workers who conduct maintenance while the power line is energized.

For a number of problems such as calculations of magnetic fields in homes or substation environments, it is necessary to use a computer program for calculating the fields in complicated three dimensional environments [29]. Such programs apply the Biot Savart law to current segments of arbitrary length and construct the geometry of the problem with superpositions of segments. If the currents are known, then these programs can be used to calculate the fields quite accurately. However it is not often an easy problem to determine the currents. Measurement, if possible, is time consuming. Calculation is also problematic since the information required to do so is often not readily available. For example, calculations of current on parallel paths which include the earth require a knowledge of grounding and/or junction resistances which are not easily determined.

The shielding of 60 Hertz fields is another subject for study. For the electric field, shielding is relatively easy and even structures such as homes act as unintentional shields [30]. The shielding of magnetic fields, however, is a more difficult problem. Generally, this can be done using either magnetic materials for what is called "flux shunting" or conducting materials for the generating of eddy currents which oppose the original sources of magnetic fields. What is known can be summarized in one of several references [31] - [34].

7. Electromagnetically induced voltages and currents

It has been well known for many years that voltages can be induced on conducting objects in the vicinity of a power line. Since early in this century studies concerned with lightning induced voltages and with interference between power lines and electric railroad and telephone systems have been reported [35]. Other studies have centered on safety issues such as shocks from vehicles parked under power lines and gas pipelines which share the right of way and the possibility of unintentional detonation of electrically fired explosives [36]-[38]. For these studies, both electric and magnetic field induction have been considered. For electrically small systems, these effects can be superimposed and usually one or the other is dominant [39].

At power system frequencies, most induction calculations can be done with simple quasi-static techniques [36,40]. Of special interest to electromagnetics specialists, however, are topics for which propagation effects must be considered. One situation for which this is the case is for analysis of buried bare wires such as proposed for mitigating induced voltages on gas pipelines [41]. For such wires the effective wavelength at 60 Hertz is approximately that of plane waves in the earth (i.e. 1 - 10 km) [42]. Given this, the analysis of mitigation wires greater than 100 meters in length requires that propagation effects be taken into account.

At higher frequencies, the simple quasi-static techniques described above cannot be used even for systems which are entirely in free space. In this case, coupled transmission line analysis is used to study the compatibility of power lines and parallel systems [43]. This analysis is limited by the assumption of quasi-TEM modes to frequencies for which the spacing is a small fraction of a free space wavelength. For localized sources such as lightning at an arbitrary distance from the power line, models have been developed for coupling of known incident fields to quasi-TEM modes on power lines. [44,45]. It is interesting to note that, as a lightning receptor, a power line behaves very much like a Beverage antenna [46]. Specifically it has been shown that that a power line is most sensitive to lightning fields incident at grazing angles of incidence [47].

At even higher frequencies, the power line can no longer be considered as a transmission line with only quasi-TEM modes. Hence results based on the technique described above give no guidance for the problem of transition to coupling to radiation modes. An alternative method which allows for this is to apply reciprocity theory in which the object under study is treated as a receiving "antenna" as done in many Antenna theory texts [48]. With the use of the proper currents (i.e. including the continuous spectrum) , this approach can be used to study coupling even when simple transmission line theory is not valid.

There is one interesting use of intentionally coupled systems which relates to the previous section on ELF magnetic fields of a power line. One scheme to reduce magnetic fields is to construct an impedance loaded loop in the vicinity of a power line [49]. The magnetic fields generated by the currents induced in this loop may be used to partially cancel the power line magnetic fields. Additional cancellation can be obtained if the currents in the loop are set using an active feedback network [50].

8. Wideband electromagnetic interference from corona

Early in this century it was found that corona on power lines created electromagnetic interference with the AM broadcast service. Even though this service has become less important in recent years, there has been concern about interference with other services such as television, aircraft navigation, amateur radio, radio telescopes and other sensitive communication facilities. Although not presently regulated in the United States, this interference is regulated in Canada and regulations are being considered in Europe [51]. The possibility of regulation and concern for the compatibility of power lines and other systems has led to considerable research in how to predict and mitigate this interference.

Corona can be described in the following way. Using (8), it can be shown that the electric field at the bottom surface of a single smooth wire is approximately

$$E_y(0,d-a) = -\frac{V}{a\ln(2d/a)} \tag{15}$$

This field is enhanced by conductor surface irregularities and during foul weather by water drops which collect on the bottom of the conductor. The latter is the reason that conductor corona phenomena (at least for AC power lines) are significantly greater during rain [18]. The case for DC power lines is different and is discussed in [52].

For high voltage power lines, this electric field is large enough to initiate partial discharges (i.e. corona) through avalanche breakdown of the air [53,54]. These avalanches leave large quantities of charged particles in the air surrounding the conductor which move rapidly under the influence of the electric field and hence constitute an impulsive current close to the surface of the conductor. This current induces a corresponding impulsive current on the conductor which in turn generates an electromagnetic field. Note that there is also a field due to direct radiation from the moving charges but that this field is usually small because the length of the avalanche is short and the fields from short antennas are proportional to their length. Since the currents are impulsive, the resulting electromagnetic fields are wideband. In fact, interference fields from conductor corona have been detected at frequencies of up to 1 GHz. Another characteristic of the fields is that (since they are generated by many independent corona streamers) they are incoherent and should be described by their power spectral density. The resulting fields which are called electromagnetic interference (EMI) or radio noise are those commonly experienced while listening to AM broadcast radio while passing under a power line.

Historically, EMI fields were calculated in the following way. It was assumed that the currents excited on the power line by corona streamers consisted entirely of discrete quasi-TEM modes. Once the currents were determined, the fields were calculated using the quasi-static formulas discussed earlier. Both of these assumptions are valid only at low frequencies. The amplitude of the corona induced currents must be determined empirically because corona is a random process and our knowledge of corona is very limited. The amplitudes of the induced currents are determined using the "generation function" which relates the corona amplitude to surface electric field, conductor geometry, altitude and weather conditions. The generation function is determined using tests of conductors in so called corona cages under different environmental conditions and/or long term measurements of EMI.

For calculations of EMI, more care must be used than for the ELF fields discussed earlier. This is because, even at 1 MHz, distances to field point locations can easily exceed one twentieth of a wavelength, the commonly accepted limit for quasi-static calculations [13]. This issue was first recognized when measurements of radio noise decayed with distance from the power line more slowly than the $(1/R_a)^2$ predicted by quasi-static theory.

This observation prompted the development of EMI prediction algorithms using the full Sommerfeld integral approach. The first efforts to do so were published in the

Russian literature [55]. Later, more complete analyses were published in the United States. These theories can be divided into three ranges. In the first, (valid at and below approximately 2 MHz), the induced currents were still calculated using the quasi-TEM approximation while the fields were calculated using appropriate approximations to the Sommerfeld integrals [56,57]. With this theory, it was shown that the measured decay rate of EMI away from the power line was correct. However, the theory was still limited to field points near the earth and distances within approximately one third of a wavelength from the power line. It was also shown that vertical rod antenna (vertical electric field) and horizontal loop antenna with its loop plane parallel to the power line (horizontal magnetic field) measurements would not be related by the impedance of free space as often assumed. The second theory developed was for frequencies greater than 30MHz for which asymptotic approximations to the Sommerfeld integrals could be found [58]. In this case, it was shown that the current induced on the conductor acted very much like a traveling wave antenna and geometric optics approximations for the fields could be used. One interesting and unexpected result was that the EMI field is reduced by orienting the receiving antenna directly at the power line. This occurs because traveling waves on wires radiate poorly normal to the wire. In the frequency range between 2 MHz and 30 MHz, it was necessary to calculate the induced currents and fields without using quasi-static or quasi-TEM approximations. The results have been reported in [59,60]. In this case, a model useful for a wide range of frequencies with no limitations on the location of the field point was developed. This, for example, can be used to study interference fields between power lines and airborne receivers.

The main method for reducing EMI from power lines is to reduce the amount of corona. This is usually done by replacing a single conductor with a "bundle of conductors". This process distributes the charge among several conductors which reduces the surface electric field and allows the use of smaller conductors. «Bundled» conductors can be observed on many transmission lines with voltages above 200 kV.

9. Other Corona Effects

Although not specifically an electromagnetic effect, another related corona phenomena is that of audible noise [18,61]. This occurs because corona streamers create acoustic waves which are detectable to the human ear. Models for the prediction of this have been developed and are quite accurate.

As mentioned earlier, there is another source of power loss which may have an impact on the economics of power transmission. This is what is called corona loss. Unfortunately, the process is complicated enough that it is difficult to model and at present only empirical expressions are used to calculate the loss [62] . It has been shown that high voltage transmission lines at higher altitudes may experience corona loss comparable to resistive loss [63]. This fact may require that larger conductors than otherwise normal or bundled conductors be used.

As a last topic under corona phenomena, consider the case of a DC transmission line. Here, the significant difference is that a space charge may be developed which fills the space between the wires and the earth [64]. Thus, Poissons equation must be solved in this region rather than just LaPlace's equation. The problem becomes nonlinear and hence significantly more difficult.

10. Grounding systems

There are a number of electromagnetics issues related to the grounding of power systems. Since the earth is conductive, any current flowing in it will cause differences in potential between different points on its surface. This phenomenon leads to concerns about the safety of grounding systems [65]. Related to this is an issue commonly called «stray voltage» which has recently received quite a bit of media attention [66]. When sufficient «stray voltage» exists, farm animals may receive small shocks which may affect production.

It is interesting to note that, in the popular media, the issue of stray voltage is often incorrectly linked with the issue of ELF magnetic fields. The former is an acknowledged problem with a known cause and well defined procedures for mitigation. As mentioned above, the potential for health effects of the latter is still a controversial issue.

There is another aspect of power system grounding which overlaps a problem of concern to antenna engineers for some years: that of antenna system grounding [67]. At high enough frequencies, the power system ground can no longer be analyzed using quasi-static techniques. Rather, the same full wave method used to analyze antenna grounding systems must be used. Although personnel safety is not an issue at these higher frequencies, it is important to understand the response of the grounding system because of concerns about equipment failure due to lightning. In some recent work, the relationship between the quasi-static and full wave methods has been explored and the conditions for which quasi-static theory is valid outlined [68].

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Conferences

CONFERENCE REPORTS

INTERNATIONAL WORKSHOP ON DIRECT AND INVERSE ELECTROMAGNETIC SCATTERING

Tübitak, Turkey, 24 -30 September 1995

The *International Workshop on Direct and Inverse Electromagnetic Scattering* was held from September 24 to 30, 1995 at the campus of Marmara Research Centre of TÜBITAK (The Scientific and Technical Research Council of Turkey) in Gebze, Turkey. It was organized and supported by Marmara Research Centre and TÜBITAK. This Workshop was also sponsored by the Institute of Radio Frequency Technology of DLR (German Aerospace Research Establishment), IEEE (Institute of Electrical and Electronics Engineers), AP- MTT Turkish Joint Chapter and URSI (Union Radio-Scientifique Internationale).

This Workshop was intended for researchers interested in direct or inverse problems in electromagnetic scattering and related techniques and systems. The major topics were as follows :

- Generalized and Approximate Boundary Conditions
- Wiener-Hopf Technique and Applications
- Applications of Analytical Methods in Electromagnetics
- Applications of Computational Methods in Electromagnetics
- Inverse Scattering and Microwave Imaging

The scientific programme consisted mainly of invited lectures. Approximately one hour was given for each lecture. Although the scope of the meeting was wide enough to gather a sufficiently large number of participants, it was preferred to keep the number of lecturers small in order to spare time for discussions. The Scientific Committee, which was chaired by Prof. Dr. M. Idemen (Turkey), has formed a good composition of disciplines. There were mathematicians, mostly specialized on Wiener-Hopf and other related techniques, and engineers among the lecturers. There was the third group of lecturers to establish a link between the mathematicians and engineers.

Dr. W. Keydel, Director of the Institute of Radio Frequency Technology of DLR, gave the keynote address at the Opening Ceremony held on September 25. During the Workshop, 29 presentations were made at single session which allowed participants to follow all of them. Although the context of the lectures were organized for experts, young scientists also gained a rewarding scientific experience at the Workshop.

All participants stayed at the hotel in the campus of Marmara Research Centre at Gebze which is a town located only 40 km. away from Istanbul. The city of Istanbul occupies a strategic location on the traditional crossroads between Europe and Asia. The history of the city goes back to 660 BC and there are many monuments and museums within the city which reflect its history. A Welcome Reception was given on September 25 and a Workshop Dinner on September 29 at the restaurant of the hotel. On September 27, a sightseeing tour was organized in Istanbul starting at 14:00 in the afternoon, including a visit to local carpet centers, and which ended at a fish restaurant on Bosphorus on the European side of Istanbul. On September 30, a full day tour was organized to visit the historical places in Istanbul including a boat trip along the Bosphorus.

The Proceedings of the Workshop were to be published after the meeting. During the preparation of the Proceedings for publication, Addison Wesley Longman Limited has shown interest to publish it as a volume in Pitman Research Notes in Mathematics Series. It will be edited by A.H. Serbest and S. Cloude and is planned to be published in 1996. So, enquiries for the book should be addressed directly to the Longman Group Limited, UK.

The Organizing Committee of the Workshop is very grateful to Marmara Research Center and TÜBITAK for their generous supports and the facilities they have provided for the organization. Also, the Committee would like to express its appreciation and gratitude to all sponsoring agencies and lecturers for their invaluable contributions.

Prof. Dr. A. Hamit Serbest
Chairman of the Organizing Committee
International Workshop on
Direct and Inverse Electromagnetic Scattering

IAU Colloquium 160 Pulsars: Problems and Progress

Sydney, Australia, 8 - 12 January 1996

The Colloquium, sponsored by IAU Commission 40 and co-sponsored by IAU Commission 42, was held at the University of Sydney and hosted by the Research Centre for Theoretical Astrophysics, University of Sydney, and the Australia Telescope National Facility, CSIRO, with additional support from URSI Commission J, Mount Stromlo and Siding Spring Observatories, the Anglo-Australian Observatory and the CSIRO International Scientific Liason Office.

The main aim of the Colloquium was to review recent advances in pulsar studies, with particular emphasis on the theory and observations of the pulsed emission, the origin and evolution of millisecond pulsars and the use of pulsars as probes of circumstellar and interstellar material. It was attended by 165 scientists from 20 countries.

There were 26 invited talks, 36 contributed talks and 101 poster papers. Two sessions early in the programme were devoted to 1-minute 1-viewgraph oral presentations by poster authors which, with firm chairmanship, successfully introduced these authors and their work to the Colloquium. A highlight of the Colloquium was a debate and discussion on the origin and evolution of millisecond pulsars, led by a panel of eight experts in the field. Prof. J. H. Taylor gave an evening public lecture on "Binary pulsars and Einstein's gravity" which was attended by over 400 people, including many Colloquium participants. On Tuesday evening, the ATNF and AAO hosted a barbecue at Epping, including tours of instrumentation laboratories at both institutions. The conference dinner was held on Thursday evening at Taronga Park Reception Centre, a venue with magnificent views of Sydney Harbour and the city skyline.

On the first day, Monday, radio pulsar surveys, pulsar-supernova remnant associations and precision timing observations were discussed. There are now over 700 pulsars known, with 50 in binary systems and 58 with pulse periods in the millisecond range. Most of the binary companions are low-mass white dwarfs; only five neutron star - neutron star systems are known. Of the younger pulsars, about 10 have reasonably convincing associations with supernova remnants and 20 are known to exhibit large period glitches. On Tuesday, radio pulse observations relevant to the emission mechanism, with emphasis on polarization and microstructure properties, were discussed, along with observations and interpretations of pulsar wind nebulae. Pulsar electrodynamics, high-energy pulse emission and aspects of binary pulsars were discussed on Wednesday. Thursday morning was devoted to the panel discussion on millisecond pulsar evolution mentioned above and, in the afternoon, papers on radio pulse emission mechanisms and high energy pulse emission observations were presented. On Friday, papers were presented on topics in interstellar medium effects, pulse emission processes and binary pulsars. Observational techniques, including facilities available at the various observatories and standards for data archiving, were also discussed.

The Colloquium was an outstanding scientific and social success, with many new results being presented and extensive debate on topical issues. The Colloquium Proceedings will be published in the Astronomical Society of the Pacific Conference Series and will appear in late 1996.

R. N. Manchester and
D. B. Melrose
Co-Chairs, SOC

EUSAR'96

Königswinter, Germany, 26 - 28 March 1996

EUSAR'96, the European Conference on Synthetic Aperture Radar, has been held for the first time. Meetings site was the MARITIM hotel in Königswinter,Germany. This new conference has been organized by FGAN , DLR, and VDE and has been co-sponsored by EUREL, URSI, IEEE and DGON. EUSAR'96 was initiated and chaired by R. Klemm, FGAN-FFM, Germany.

SAR has grown so dramatically in the recent past, particularly through advances in computing power and microwave technology that it has become a discipline independent of real aperture radar. SAR is no longer adequately covered by the traditional international radar conferences. The existing conferences on remote sensing are devoted mainly to SAR applications rather than to SAR techniques and technologies. The gap between radar and remote sensing conferences is filled by EUSAR'96 and its follow-up events.

SAR is an imaging technique with the following typical applications: Mapping vegetation types, monitoring vegetation regrowth, timber yields, assessment of environmental damages, mapping soil moisture for agriculture, generation of snowcover and wetness maps for agricultural water management, measuring rainfall rates in tropical storms, monitoring of ship traffic, detection of oil slicks on the ocean, measuring ocean surface current speeds, mapping sea-ice, finding minerals (oil, gas, metals), mapping changes of topography, volcanic activities and others. For military purposes SAR evolves to become an indispensible reconnaissance tool with day and night capability, doppler evaluation for handling moving objects, polarimetric and multispectral analysis for target classification. A prominent application will be the verification of disarmament treaties.

The large number of submissions confirmed us in our opinion that there is a worldwide need for this conference. 20 European and non-European countries and 4 international organisations from all 5 continents contributed to the EUSAR'96 program. About 70% of all worldwide SAR activities have been present at EUSAR'96. The technical program included 86 oral and 57poster papers. All papers have been published in the the EUSAR conference proceedings (580 pages). A commercial exhibition and a SAR image display presenting the state of the art in SAR technology have completed the scope of EUSAR'96. The number of attendies was 275 coming from 22 countries from all 5 continents. In view of the facts that 1. SAR is a special discipline of radar, 2. EUSAR'96 was held for the first time, this is a very good number and reflects the worldwide interest in this subject.

The conference has been be opened by four keynote speakers, two from Germany (DARA, MoD) and two from international organisations (ESA,WEU). Thereby both the civilian and military sides have been covered. A subsequent plenary session contained overview papers given by two leading SAR experts.

W. Keydel (DLR, Germany) presented the state of the art for civilian spaceborne and airborne SAR systems. Currently five spaceborne SAR-Systems are in use (ERS-1, ERS-2, ESA; J-ERS-1, Japan; ALMAZ-1, Russia; SIR-C/X-SAR, USA, Italy, Germany; Radarsat, Canada; 1995. Currently 19 airborne SAR systems are being operated by the following countries: Canada, Denmark, Germany, Netherlands, France, Russia, Sweden, USA. The individual properties have been described in this presentation.

The presentation of A. Freeman (JPL, USA) entitled "SAR Applications in the 21th Century" gave an excellent prospective view of future SAR applications. First of all an overview of those techniques has been given which will be of special importance to environmental monitoring with future SAR systems: Multifrequency SAR, Polarimetry, Across-track interferometry, along-track interferometry. Another new discipline is SAR with multi-channel antennas. This technical introduction was followed by a detailed overview of potential applications in the future. These include mapping of the erath's surface, environmental and agricultural monitoring as well as oil and mineral exploration and desaster management.

The conference was subdivided in 9 sessions: Air- and spaceborne systems, image enhancement and evaluation, polarization, interferometry, antennas and T/R modules, image generation, processing and simulation, moving targets, applications, calibration, thus covering the entire spectrum of SAR techniques and technology.

Some conclusions from EUSAR'96 can be highlighted. To exploit the whole content of the backscattered wave field future SAR systems will have to make use of multi-dimensional data acquisition and processing techniques (multi-frequency, multi-polarization, different interferometric techniques, multi-channel antenna). These requirements may be in contradiction with cost and design constraints, especially with spaceborne applications. A large number of airborne SAR systems are currently worldwide in operation, most of them being experimental. Many of them offer already simultaneous multi-frequency or multi-polarization operation. One of them uses a multi-channel antenna. Spaceborne radar has a lot of special promising properties compared with spaceborne optics. However, the spaceborne SAR sensor is extremely expensive and is very much limited in weight, volume, and power consumption. Future work has to be directed towards development of cheap solutions for spaceborne SAR sensors and their associated subsystems. Two airborne systems using a multi-channel phased array antenna were presented at EUSAR'96 (AN/APG-76, Northrop-Grumman, USA; AER-II, FGAN-FFM, Germany). A multi-channel antenna offers the possiblity of spatial signal processing with various applications (jammer suppression, MTI, azimuth correction for moving targets, platform motion compensation).

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COMMSPHERE'97

Lausanne, Switzerland, 11 - 14 February 1997

COMMSPHERE, the International Symposium on the Future of Telecommunications and the Electromagnetic Environment, is an international forum of concerned scientists, experts and administrators, for interdisciplinary discussions of the challenges facing the future of telecommunications and other usage of the electromagnetic radiation. The conference is sponsored by URSI, in collaboration with ITU-R.
Organization : Swiss Federal Institute of Technology of Lausanne, in collaboration with Telecom PTT of Switzerland and the URSI Member Committee of Swiss Switzerland.

Structure

The conference is structured for 5 half day plenary discussion sessions, one day of parallel workshops and a summarizing session.

Symposium Organization

Symposium Chairman : Prof. M. Ianoz,
Swiss Federal Institute of Technology of Lausanne
Tel : +41-21 693 26 64, Fax : +41-21 693 46 62
Email : michel.ianoz@lre.de.epfl.ch

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Secretariat : Mrs. Marcela Lenz,
Swiss Federal Institute of Technology of Lausanne
Tel. : +41-21 693 27 86 Fax : +41-21 693 46 62
Email : marcela.lenz@lre.de.epfl.ch

Papers

The sessions will comprise both contributed and invited papers, focused on the topics. One page summary should be sent to the secretariat no later than August 15, 1996. Authors will be notified by October 1, 1996. Photo ready manuscripts are due December 1, 1996. Authors are encouraged to contact the topic organizers.

Topics Global

1. Information Superhighway - the wireless arm,
   Integrated wireless access networks,
   Service and environment adaptive air interfaces
2. Developments in spectrum management policies and techniques - domestic and global,
   Domestic and international laws - needs for changes,
   Spectrum sharing, modulation techniques, adaptive systems and adaptive coordination,
   Evolution of spectrum management and monitoring techniques,
   Future spectrum regulation and spectrum market
3. Radio astronomy and the EM environment - People to Nature Communications Issues
4. Health effects of radio transmission
5. Personal communications satellites,
   LEO/MEO/GSO systems and services,
   Interference and interaction with other systems and services,
   Channel characterization
6. Communications development in developing countries
7. The EM interference environment,
   Modeling of EM interference,
   Environment adaptive systems,
   EM interference of wireless radio to life supporting and other critical systems,
   EM emmission and sensitivity standards policy
8. Wave oriented space-time signal processing
9. Smart antennas in wireless communications

Tenth International Conference on Antennas and Propagation (ICAP'97)

Edinburgh, Scotland, United Kongdom, 14 - 17 April 1997

Introduction

The first international Conference on Antennas and Propagation was held in London in 1979. Since then, this conference series has developed into one of the major international events in this area. This is the tenth in the series and we aim to hold a meeting with technical excellence that marks this important milestone. Our venue of Edinburgh proved successful in 1993 and we believe that in 1997 it will provide first class facilities combined with local colour and interest for the visitor.
Antennas and propagation continue to be key components in most radio and radar based systems. The phenomenal growth in mobile communications and the emerging area of advanced vehicular control and communications are

examples of application areas that are demanding new solutions and that are stimulating industry, academia and government alike.

It is an exciting time to be working in antennas and propagation and our aim is to provide a conference that is informative, timely and attractive.

We look forward to seeing you in Edinburgh in April 1997.

Scope

Contributions on Antenna and Propagation topics over the entire radio spectrum are welcomed in the following topic areas:-Antennas and Related Topics Propagation and Related Topics; A1 Multibeam antennas; A2 Antennas for mobile and personal communications; A3 Remote sensing antenna systems; A4 Numerical techniques for antenna problems; A5 Adaptive antennas; A6 Active antennas; A7 Array antennas; A8 Microstrip and conformal antennas; A9 Wideband antennas; A10 Reflectors and lenses; A11 Horns and feeds; A12 Satellite antennas; A13 Millimetrewave and quasi optical antennas; A14 Wire antennas; A15 Broadcast antennas; A16 Radomes; A17 Wire antennas; A18 Measurement techniques; A19 Mechanical aspects of antennas; A20 Transient response and time domain analysis; A21 Radar cross sections; A22 Teaching methods; A23 Others; P1 Propagation factors for personal and mobile communications; P2 Propagation factors for mobile satellite services; P3 Propagation in fixed service satellite systems; P4 Remote sensing; P5 Radio and radar meteorology; P6 Propagation via the ionosphere; P7 Transionospheric propagation; P8 VHF and UHF propagation; P9 Tropospheric propagation; P10 Millimetrewave propagation; P11 Propagation aspects of frequency management; P12 System planning; P13 Propagation countermeasures; P14 Propagation simulation; P15 Propagation in biological media; P16 Underground and subsurface propagation; P17 Teaching methods in propagation; P18 Others

Deadlines

Intending authors should note the following deadlines:

Receipt of synopsis : 30 August 1996
Notification of acceptance : End of October 1996
Receipt of full typescript : 20 December 1996

Working Language

The working language of the Conference is English which will be used for all printed material, presentations and discussions.

Conference Prize

The Organising Committee will award two prizes for best papers at ICAP 97, one for Antennas and the other for Propagation.

Programme and Registration

The provisional programme and registration form will be published a few months before the event and will be sent to those who complete and return the attached form.

Scholarship Scheme

Student IEE members and Younger IEE members presenting papers at the Conference may be eligible for an IEE Scholarship to assist with the cost of registration fees and reasonable accommodation charges. Please contact the IEE's scholarship department for further details. varied art galleries, museums, the famous Botanical Gardens and of course, Edinburgh Castle.

Contact

ICAP'97 Secretariat Conference Services
The Institution of Electrical Engineers
Savoy Place London WC2R OBL
United Kingdom
Tel: + 44 (1) 71 344 5467
Fax: + 44 (1) 71 240 8830
Email: lhudson@iee.org.uk / mswift@iee.org.uk

1997 International Symposium on Radio Propagation

Qingdao, China, 12 - 16 August 1997

The 1997 International Symposium on Radio Propagation (ISRP'97) is planned to be held in Qingdao City, China, from 12 to 16 August 1997. The symposium is organized by the CIE Propagation Society (CIE/RP-S). It is the continuity of the symposia held successfully in 1988 and 1993.

Objective

The objective of the symposium is to provide an international forum for the presentation of the recent research results of the radio propagation and to prompt professional interactions and co-operation in the radio community.

Language

The working language of the symposium is English.

Conference publication

The proceedings will be distributed to all registered participants at the conference.

Schedule

Intending authors should note the following deadlines:

- receipt of abstract 30 September 1996
- Notification of acceptance 30 November 1996
- Receipt of photo-ready summary 15 March 1997

Topics

Papers on any topic of radio propagation are welcome. The topics listed below are especially proposed :

- Electromagnetic theory & wave propagation theory

(transient electromagnetic field, computational electromagnetic waves and numerical methods, etc)
- Topospheric propagation and radiometeorology
- Earth-space radio propagation
- Ionospheric propagation & ionospheric physics
- IRI & the applications
- Waves in plasmas
- LF, VLF and ELF propagation
- Radio sounding of the environment
- Mobile communication
- Scattering and inverse scattering
- Antenna theory
- Noise, interferences, electromagnetic compatibility & spectrum management
- Detecting systems and techniques for radio propagation
- Propagation problems in modern communications, radar systems, remote sensing, navigation, etc.
- The applications of radio propagation in some other fields like : the near space detection, environmental monitoring and protection, earthquake EM wave, the biological effects, formation analysis imaging and geographical exploration, etc.

Contact

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URSI CONFERENCE CALENDAR

URSI cannot be held responsible for any errors contained in this list of meetings.

July 1996

Fifth International Symposium on Bio-Astronomy
Capri, Italy, 1-5 July 1996
Contact : Prof Stuart Bowyer, Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA, Fax +1-510 643-8303, e-mail: bowyer@ssl.berkeley.edu

NATO Advanced Summer Institute on New Directions in Terahertz Technology
Chateau de Bonas, near Toulouse, France, 1-11 July, 1996
Contact : NATO ASI Secretary, Physics Department, University of Nottingham, Nottingham, NG7 2RD, United Kingdom, Fax : +44 115-951-5180, E-mail : NATO@Nottingham.ac.uk

COSPAR Scientific Assembly
Birmingham, United Kingdom, 14-21 July 1996
Contact : Prof. S. Grzedzielski, 51, bd de Montmorency, F-75016 Paris, France, Tel. : +33 1-4525 0679, Fax : +33 1-4050 9827, E-mail : cospar@paris7.jussieu.fr

CHIRAL'96
Moscow - St. Petersburg, Russia, 23-30 July 1996
Contact : Dr. Alexei Vinogradov Scientific Centre for Applied Problems in Electrodynamics IVTAN, Izhorskaya 13/19 127412, Moscow, Russia, Fax : +7-095 484-2633, E-mail : vin@eldyn.msk.ru

August 1996

XXVth URSI General Assembly
Lille, France, 28 August -5 September 1996
Contact : Dr. M. Lienard, Université de Lille, Dept. Electronique, Bat. P3, F-59655 Villeneuve d'Ascq Cedex, France, Tel: +33 20-337206, Fax: +33 20-337207, e-mail : agursi@univ-lille1.fr, Web Page: http://www.univ-lille1.fr/ursi

September 1996

8° Colloque internationale et exposition sur la Compatibilité électromagnétique
Lille, France, 3-5 September 1996 (co-located with the URSI General Assembly)
Contact : Prof. P. Degauque, Université des Sciences et Techniques de Lille 1, UFR/IEEA, Bâtiment P3, F-59655 Villeneuve d'Ascq Cedex, France, Tel. +33 20-434849, Fax +33 20-337207

International Conference on Plasma Physics,
Nagoya, Japan, 9-13 September 1996
Contact : Prof. A. Iiyoshi, Director-General, National Institute for Fusion Science, 464-01 Nagoya, Japan, Fax : +81 52-789-4200, E-mail : iiyoshi@nifs.ac.jp

Sixth International Conference for Mathematical Methods in Electromagnetic Theory (MMET'96)
Lviv, Ukraine, 10-13 September 1996
Contact : Prof. Z. Nazarchuk, Karpenko Physico-Mechanical Institute, 5 Naukova St., Lviv 290601, Ukraine, Tel. +380-322-637038, Fax +380-322-649427

ECOC'96 - 22nd European Conference on Optical Communication

Oslo, Norway, 15-19 September 1996

Contact : ECOC'96 Secretariat, Norwegian Telecom Research, P.O. Box 83, N-2007 Kjeller, Norway
Tel. : +47 63-80 9341, Fax : +47 63-81 9810, E-mail : krosby@tf.tele.no

IEEE ISSSTA'96

Mainz, Germany, 22-25 September 1996

Contact : Prof. P.W. Baier, Research Group for RF Communications, University of Kaiserslautern, P.O. Box 3049, D-67653 Kaiserslautern, Germany, Tel/Fax +49-631-205-2075/3612, e-mail: baier@rhrk.uni-kl.de

23rd International Conference on Lightning Protection (ICLP)

Firenze, Italy, 23-27 September 1996

Contact : Prof. C Mazzetti, Dept. of Electrical Engineering, University of Rome "La Sapienza", Via Eudossiana 18, I-00184 Rome, Italy, Tel. : +39 6-4458 5534, Fax : +39 6-488 3235, E-mail : elettrica@risccics.ing. uniromal.it

Int. Symp. on Antennas and Propagation (ISAP)

Chiba, Japan, 24-27 September 1996

Contact : Prof. Kiyohiko Itoh, Faculty of Engineering, Hokkaido University, Sapporo 060, Japan, Fax : +81-11-706-7836, e-mail: itoh@densi001.hudk.hokudai.ac.jp

Sommerfeld Centennial Workshop 1996
Modern Mathematical methods in Diffraction Theory and its Applications in Engineering

Freudenstadt, Germany, 30 September - 4 October 1996

Contact : Prof. H. Chaloupka, University of Wuppertal, Fuhlrottstr. 10, D-42119 Wuppertal, Germany, Tel. : +49 202-439 2938, Fax : +49 202-439 2864

Book Reviews

High-Resolution Radar, Second Edition

by D.R. Wehner

Artech House, 1994, 593 pages, ISBN Number: 0-89006-727-9
Hardcover, $89.00

This is an very useful book for practitioners of radar technology. It should be seen more as a reference book than as a text book for classroom teaching. The reason is because the book is mainly multidisciplinary, covering topics in signal processing and wave propagation, and hence, it may be difficult for use in classroom teaching.

Chapter 1 gives an introduction to the fundamentals of radar and signal processing required for radar technology.

Chapter 2 illustrates the application of the radar-range equation to high-resolution radars. It discusses how antenna gain and wavelength affect the echo power of radar. It also gives the definition of radar cross section, and discusses the sources for backscatter in a target. Discussions on receiver-system sensitivity, matched filter signal-to-noise ratio, and the constraint played by the time-bandwidth product are particularly useful. Then the book goes ahead with discussing the radar resolution.

Chapter 3 presents the design of a high resolution radar. It introduces simple concepts like instantaneous frequency, phase and group delays. It also talks about distortions due to amplitude and phase distortions. Particularly interesting is the concept of paired echos and remedies for it. This Chapter goes into a more detailed discussion of matched filters. It talks about wideband mixing and detection, data sampling in time and frequency domain, and transmitted-frequency stability requirements. It discusses phase noise and related issues. Some interesting discussions are made on waveguide distortion, but it is not easy for a non-expert in waveguides to understand them. A survey of wideband microwave power sources is given, plus a brief description on wideband antennas. A succinct description of coherent and noncoherent radars is given.

Chapter 4 is closely related to signal processing in a high-range-resolution (HRR) radar. Short-pulse waveform, binary phase coding, continuous discrete frequency coding, stretch waveforms, chirp waveforms, pulse compression are discussed. Particularly interesting is the section on hardware for pulse compression and waveform processing. Digital pulse compression techniques and radial motion effect are also discussed. The chapter ends with a section on display, recording and preprocessing of HRR target responses.

Chapter 5 deals with synthetic HRR radars. This refers to synthesizing range profiles, usually obtained from time domain data, using frequency domain data. The concept of such synthesis, as in stepped-frequency radar, is discussed, including the effect due to target motion. A section is devoted to the hopped-frequency radar, but with the obvious reason for using hopped frequency is not given. Range-extended target, distortion and degradation due to a frequency error, or the effect of a moving target are discussed.

Chapter 6 is on synthetic aperture radar (SAR). It starts with the definition of some SAR terminology. It then dwells on real-aperture radar mapping, unfocussed SAR and focussed SAR theory. The analysis is very useful to those wishing to learn about the background theory of SAR. Doppler theory in the context of SAR, chirp-pulse SAR for pulse compression and resolution enhancement are discussed. One section is devoted to step-frequency SAR. Range curvation and range walk effects are also analyzed. The discussion on speckle noise is particularly useful and illuminating. A design example is given. SAR processing is also discussed, with a very interesting subsection devoted to optical processing, which could be thought of as the precursor to optical computing. The Chapter ends by discussing Doppler beam sharpening. The Chapter should definitely be mastered by practioners of SAR.

Inverse SAR (ISAR), the reverse of SAR, where the target is moving and the radar is stationary, is discussed in Chapter 7. A section is devoted to comparing SAR and ISAR. Then ISAR is explained in terms of range-Doppler imaging. Target aspect rotation, image projection plane, chirp-pulse radar, stepped-frequency radar, range offset and range walk, motion correction, are subsequently discussed. Focussing methods, and different processing methods are presented. A design example is given, and a comparison is made between chirp-pulse and stepped-frequency radar. The chapter ends by discussing radar target imaging range. This is a rather long chapter with much technical details, probably due to the importance of ISAR in target surveillance and identification.

Chapter 8 starts by discussing the shortcomings of ISAR and introduce the monopulse radar as a remedy. The wideband monopulse radar could produce a 3D image of the target but providing an image in the two orthogonal cross ranges and a third slant range. The range performance of the radar is analyzed, and a stepped-frequency alternative is discussed. According to the author, the monopulse radar is still in its research stage.

Chapter 9 discusses target imaging with noncoherent radar systems. The transmit signals of noncoherent radar are usually high-power pulses produced by a pulsed magnetron.

To overcome the resulting noncoherence, a frequency-agile local oscillator is used to achieve coherent-on-receive radar. Another way is to transmit precisely controlled stepped-frequency magnetron pulses. The response of such a radar to single fixed-point targets and to range-extended targets is discussed. The effects of range profile distortion, magnetron frequency control, intra-pulse FM, and cross-range distortion are analyzed.

Chapter 10 dwells on the surveillance applications of HRR, such as electronic counter-countermeasures (ECCM), low-flyer detection, low-probability-of-intercept radar (LPIR), reduced target fluctuation loss, and small-target detection in clutter. In low-flyer detection, the effect of sea and land clutter is important. LPIR in the context of spread spectrum, RF absorption, and signal matching is discussed. Fluction loss and mitigation for surveillance radar is also presented. The chapter ends by a brief discussion of small target detection.

The book reflects the overall wide-ranging knowledge of the author in this field. It is an excellent contribution to this field, as there is no other book with similar range of coverage and content. It will be a useful reference for practioners of this field. I recommend it highly for a reference collection.

Reviewed by Weng Cho Chew
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Electromagnetic Fields in Multilayered Structures : Theory and Applications

by A.K. Bhattacharyya
Artech House,1994,179pp.,ISBN : 0-89006-651-5
Hard Back, US$ 69.00

This book describes an in-depth treatment of electromagnetic fields in multilayered microstrip and other planar structures. Accurate electromagnetic modelling of these structures is rapidly becoming of increasing importance in such applications as multilayered microwave/millimeterwave integrated circuit (MIC) as well as in multilayered printed antennas. A major portion of the material in this book has been published by the author and other researchers in various journals and conference proceedings. The book is primarily designed as a self-contained text for use in a graduate-level course, but it will also be useful to those engineers and scientists involved in modelling and design of microstrip antennas and MIC structures. The book contains six chapters and three appendices. About ten to fifteen practice problems are included at the end of each chapter. The problem sets cover a good balance of simple problems on basic theory given in a chapter and more difficult problems dealing with the extension of theory to various planar structures. Although the formulation for a general multilayered medium is given in the first two chapter, the rest of the book considers the application to problems with a single dielectric layer. The examples given are mostly simple canonical microstrip and slot-line structures analyzed using spectral-domain techniques. A brief summary of the contents follows.

Chapter 1: Field Equations in Layered Media

The chapter begins with a brief review of time harmonic Maxwell's equations. The problem of a layered medium is then decomposed into TM_z and TE_z fields for which the corresponding vector potentials are defined. The governing wave equations and boundary conditions for TM and TE fields are then given. The chapter ends with an interesting discussion on structural inability of a layered medium to support isolated $TE_{x,y}$ and $TM_{x,y}$ modes.

Chapter 2: Solution for Field Equations

Field equations in the spectral (Fourier) domain are given. For a planar electric current source, a transmission line analogy is then used to derive TM and TE field expressions in terms of line voltage on an equivalent multi-sectional transmission line. Duality is applied to derive the fields corresponding to a planar magnetic current source. The chapter ends with a development of an equivalent transmission line model for a vertical (z-directed) current source.

Chapter 3: Current sources over a grounded dielectric structure

Two canonical problems of magnetic and electric current line sources over a grounded dielectric slab are solved in this chapter. Pole and branch point singularities are discussed and the expressions for radiation and surface-wave fields are derived. A discussion of sources with a circular shaped geometry, for which the two-dimensional Fourier transform reduces to a single Hankel transform integral, ends the chapter.

Chapter 4: Characteristics of Space and Surface Wave Fields

This chapter presents a detailed treatment of space and surface wave fields. Proofs of orthogonality between surface wave modes as well as between space and surface wave fields are presented in a straightforward manner. A procedure based on reciprocity is given for determining the unknown surface wave fields generated by an arbitrary source. The procedure is then applied to a circular magnetic current ribbon.

Chapter 5: Analysis of microstrip antennas and arrays

Spectral-domain analysis of printed antennas is presented by way of two examples. In the first example an edge admittance model is used to derive the input impedance of a circular microstrip patch, while in the second example the moment method is applied to determine the current on an aperture-coupled microstrip dipole antenna. Next a very clear explanation of scan blindness in microstrip array antennas is presented, followed by a detailed analysis of blindness in an infinite array of magnetic line sources The chapter ends with the analysis of a printed strip screen polarizer.

Chapter 6: Analysis of planar transmission lines

In the first part of the chapter, spectral-domain static analyses of single and coupled microstrip lines are presented. Stationary formulas are used to derive the capacitance per unit length of the lines leading to corresponding effective dielectric constants and characteristic impedances. In the second part of the chapter, full-wave spectral-domain analyses of microstrip line and slot line are presented and dispersive characteristics of printed transmission lines are discussed.

Appendices

The mathematical topics covered in the three appendixes are: the saddle point method of integration, the singularity extraction technique, and the branch point and branch cut of a multiple-valued function.

In conclusion, this book emphasizes the spectral-domain formulation of planar structures in multilayered media. Taken on balance, it is well suited as a main or a supplementary text for an introductory graduate-level course. One important and related topic not covered in this book is the spatial-domain mixed potential integral equation (MPIE) method, which is the primary technique for analysis of arbitrary shaped microstrip structures. After mastering the topics covered in this book, however, it would not be too difficult for a motivated student to study MPIE method and apply it to various microstrip or other planar antennas and transmission lines.

Reviewed by Ahmad Hoorfar
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Villanova University, Villanova, PA 19085, USA

Uniform Stationary Phase

by V. A. Borovikov

The Institution of Electrical Engineers, 1994, 233 pp., ISBN 0 85296 812
Hard Back, $95.00

This is a very readable book for anyone with a standard background in the classical mathematics customarily assimilated by those with applied interests. The Introduction contains a very clear exposition of a method for determining the number of terms to be retained in an asymptotic expansion before it begins to diverge. The Fresnel integral is used as the example.

The first three chapters then treat one dimensional integrals. The first chapter contains an exposition of nonuniform asymptotic expansions including the case in which the stationary point is also a branch point. The second chapter develops uniform asymptotic expansions for situations in which two critical points (combinations of stationary points, poles and branch points) coalesce. The approach of critical points to a boundary or to infinity is also treated. In chapter three the methods are extended to consider the merging of three critical points and again the approach to the boundary is examined. Here the less commonly encountered Piercy integral, analogous to the Airy integral but containing a quartic term in the phase, occurs.

In chapter four the techniques developed in the earlier chapters are extended to two dimensional integrals and the case of stationary points near smooth and corner points of boundaries are treated.

In chapter five the techniques are applied to various problems in scalar wave propagation. The examples treated are the uniform asymptotic expansions for the integrals that arise in diffraction by a wedge and a slit, the cylindrical wave reflection from a plane interface, reflection from a concave surface, radiation from an aperture and diffraction by two wedges.

Chapter six presents a treatment of the various special functions that occur in the previous developments. What many may find to be an extremely useful appendix on the numerical evaluation of these special functions by means of expansion in Tschebyscheff polynomials is also included.

In the reviewer's opinion, the book is definitely to be recommended to anyone who is involved with these types of calculations.

Reviewed by George L. Lamb, Jr.
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Annual Report from IUWDS

1. Introduction

The International Ursigram and World Days Service (IUWDS), a joint service of URSI, IAU and IUGG and a permanent service of the Federation of Astronomical and Geophysical Data Services (FAGS), provides rapid information to the world community to assist in the planning, coordination and conduct of scientific and other work affected by the sun-earth environment.

Three basic mechanisms have been selected to accomplish this program. Firstly, IUWDS prepares the International Geophysical Calendar each year. This calendar gives a list of "World Days" which scientists are encouraged to use for carrying out their experiments. The calendar is prepared for IUWDS by the World Data Center-A for Solar Terrestrial Physics in Boulder, USA. The calendar is distributed widely to the scientific community and is also published in a number of Journals and other publications.

Secondly, there is the International Ursigram Service for assisting those who need a specific state of solar activity, earth atmosphere or magnetosphere at the time of their experiment. Both programs are designed to be very flexible and can be easily adjusted to fit the needs of the scientific community.

Thirdly, IUWDS arranges "Solar Terrestrial Prediction Workshops" bringing together scientists, solar terrestrial forecasters, and users of forecasts to advance the science of forcasting. Such workshops were held in Boulder (1979), Meudon near Paris (1984), Leura near Sydney (1989), and Ottawa (1992). Each workshop resulted in a collection of papers - the Workshop Proceedings - being published and becoming important reference material for the field.

In addition, on behalf of COSPAR, each month IUWDS summarises the status of satellite orbits around the earth and of space probes in the interplanetary medium in the Spacewarn Bulletin. Future launches are announced, actual launches are reported, new satellites receive an international designation, decays in the earth atmosphere are predicted and announced, and finally series of satellites useful for international participation are listed. This bulletin is produced by the World Data Center-A for Rockets and Satellites located at the Goddard Space Flight Center in Greenbelt, USA.

The present solar cycle proved to be very active in its early stages, both in terms of sunspot number and in the frequency of severe disturbances to the sun-earth environment. This activity, combined with the increasing sensitivity of modern technology, has emphasised the relevance and importance of the services co-ordinated by IUWDS.

2. The International Ursigram Service

The International Ursigram Service operates through a number of Regional Warning Centres (RWC) scattered all around the world. Warning Centres are located in : Beijing (China), Boulder (USA), Moscow (Russia), Paris (France), New Delhi (India), Ottawa (Canada), Prague (Czech Republic), Tokyo (Japan), Sydney (Australia) and Warsaw (Poland).

In its own geographic area, each RWC collects all the data and reports available concerning the state of the sun-earth environment. In some cases, these come from observatories operated directly by the Regional Warning Centre. In many cases, they are gathered from regional scientific institutes and universities.

These data and reports are coded according to the IUWDS code book and distributed daily, on request to users and to other RWCs. Data exchange is generally via a daily, or more frequent, message sent either by electronic mail, facsimile transmission or by telex. Electronic transfer of data is also used to relay larger image files.

Information transmitted through the IUWDS network is analysed by Regional Warning Centres which produce a number of "summary" reports and forecasts. The "Geoalert", a forecast of solar-geophysical conditions for the next few days, is a particularly important one of these reports. Each RWC prepares its own forecast ("Geoalert") and sends it to the World Warning Agency (WWA) in Boulder each day. The WWA then issues a Geoalert which is distributed worldwide each day at 0300 UT through the IUWDS network. Many RWCs also relay the WWA Geoalert to users within their own region.

3. Publications

The International Geophysical Calendar is distributed free of charge throughout the world. The present distribution is approximately 2000 copies produced at a nominal cost.

The Spacewarn Bulletin is also distributed free of charge throughout the world and the information is now available through an electronic bulletin board system.

The Geoalerts and the abbreviated Calendar records are published monthly in "Solar and Geophysical Data" produced and distributed by World Data Center-A for Solar Terrestrial Physics in Boulder, USA.

The daily Geoalerts and Ursigram messages, distributed daily by telex, are "real-time" information. These are obsolete after a few days and only a summary is printed as the "IUWDS Alert Periods" in the Solar-Geophysical Data Books published by World Data Center-A. However, the production and distribution of Ursigrams is a very important part of the current expenses of the RWCs. This expense is borne by the host institutions.

The IUWDS Code Book has been updated and reprinted in a loose leaf format. Further updates occur on a regular basis as new codes are introduced or existing ones are changed. The updates are supplied to RWCs for distribution as required.

4. Recent IUWDS Activities

4.1. The 1996 Solar Terrestrial Predictions Workshop

IUWDS has sponsored four previous predictions workshops - Boulder in 1979; Paris in 1984; Sydney in 1989; and Ottawa in 1992. The purpose of the meetings is to bring together scientists who study the solar terrestrial environment, forecasters who predict conditions, and the users of forecasts. By getting these people together IUWDS expects to improve the quality of forecasts and their value to the user community.

A fifth predictions meeting was held in January 1996 in Hitachi, Japan. This meeting was arranged by the local IUWDS Regional Warning Centre operated by the Japanese Communications Research Laboratory. The meeting brought together 137 people from 18 nations, participating in an interesting program of talks, poster sessions, and group discussions. As with previous meetings, the Workshop focused on several "Working Groups" representing important elements of solar terrestrial forecasting. For this meeting, the working groups were Solar/Interplanetary Predictions; Magnetospheric/Geomagnetic Predictions; Ionospheric Predictions; and Radiation/Space Applications.

As with previous meetings, papers from the Workshop are being collected into a publication - the Workshop Proceedings. This serves as valuable reference material for all of those people interested in the solar terrestrial environment and its prediction. The proceedings from the Japanese meeting are expected to be available late in 1996 and will be circulated widely in the scientific and user community.

4.2. IUWDS Steering Committee Meeting

Along with the Hitachi Workshop, two meetings of IUWDS Warning Centres were held. The first was a two-day workshop, especially for forecasters, in which each RWC presented a report of its activities and its plans for the coming years. There were also sessions devoted to the manner in which IUWDS data exchange should evolve in this era of the World Wide Web. This "forecasters" meeting took place before the main workshop and provided useful input to it.

A meeting of the IUWDS Steering Committee took place during the Hitachi Workshop. The meeting discussed possible changes to the format of the Predictions Workshop as well as the best timing and venue for the next meeting. A long standing topic of discussion within IUWDS is the need for the name of the organisation to be changed to better reflect its position as an international group providing space environment services. A new name has been selected and will be adopted once approval has been obtained from the organisations to which IUWDS is affiliated.

4.3. Campaigns to Improve Forecasting

One issue that arose strongly at the Hitachi meeting was the idea of arranging campaigns to challenge, and hopefully improve, the quality of solar terrestrial forecasting. Such campaigns may be either retrospective or prospective and would link forecasters and scientists in applying models to the forecasting process. Much remains to be resolved about how campaigns would be arranged and funded, and how results would be collected and reported. To review this options, a science advice group was established and this group will report during 1996.

4.4. The Evolution of IUWDS Data Exchange

IUWDS Warning Centres have traditionally used coded information which is exchanged between centres and used as input to computer models to predict conditions in the space environment. Different centres have a greater, or lesser use, for coded data and there is a trend towards the exchange of more detailed information, often in the form of images. The Warning Centres agreed that coded data would remain important for some time. However, there will be no further editions of the IUWDS code book produced in hard copy. Instead the code book is available in electronic form on the IUWDS Home Page on the World Wide Web.

The explosive growth of the World Wide Web presents both a challenge to, and an opportunity for, IUWDS data exchange. Solar terrestrial data, useful for forecasting purposes, is now freely available from non IUWDS sources, and the concept of a "regional" warning centre may be less meaningful as forecasts are increasingly provided on the Web.

Options for the integration of IUWDS services range from simply referencing each other up to the production of a full "world" service on the Web. The agreed option was for partial integration so that the strengths of each centre (such as understanding the needs of local customers) are preserved. However, where integration is possible it will improve the service available to customers. Various centres have particular expertise which can integrated into the products of other centres to the benefit of all.

4.5. IUWDS Home Page

IUWDS now has a home page on the Web and this contains information about IUWDS and its Warning Centres, copies of the IUWDS code book, and references to the home pages of IUWDS centres. The page is a good way to navigate the Web to obtain space environment services.

4.6. IUWDS Brochure to be Produced

With the issue of the new name resolved IUWDS will produce a brochure which can be used to promote its activities. Copies of the brochure will be distributed to each Warning Centre and will be available at international scientific meetings.

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Annual Report from IUCAF

1. Introduction

IUCAF, the Inter-Union Commission on Frequency Allocations for Radio Astronomy and Space Science, was formed 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 bodie for frequency allocations. IUCAF

2. Membership

During 1995 the composition of IUCAF was:

URSI	W.A. Baan	U.S.A.
	R.J. Cohen	United Kingdom
	H.C. Kahlmann	The Netherlands
	J.B. Whiteoak	Australia
IAU	R. Sinha	India
	A.R. Thompson	U.S.A.
	M. Ishiguro	Japan
	B.A. Doubinsky	Russia
COSPAR	D. Breton	France
	A. Gasiewski	USA

Ex Officio Advisers:
Director ITU Radio Bureau : Robert Jones, Canada
Chairman ITU Radio Board : M. Miura, Japan

Changes to the membership of IUCAF for 1995 are :
Dr. B.J. Robinson retires from IUCAF in March 1995 after serving as Chairman for eight years. Dr. J.B. Whiteoak has been appointed by URSI from March 1995. Dr. W.A. Baan has been selected Chairman of IUCAF, from March 1995.

IUCAF continues to maintain its network of Correspondents in 35 countries to interact with national authorities responsible for radio frequency management.

IUCAF recognizes the great efforts made by Dr. Brian Robinson during his tenure as Chairman of IUCAF. Dr. Robinson led IUCAF successfully in dealing with the local and global issues facing the passive users of the spectrum. Dr Robinson has great concern for the transmissions from the rapidly growing number of satellites and the danger they pose for the passive services. The coordination between IUCAF and the administration of the Russian GLONASS global positioning system has been accomplished under his guidance. Dr. Robinson has also established a network of IUCAF Correspondents that provide a liason with the passive users community of many countries. Thank you Brian Robinson.

3. Scientific Meetings

During the period of January 1995 to January 1996, IUCAF Members or Correspondents took part in the following meetings:

- COMMSPHERE'95, International Symposium on Future Telecommunications and the Electromagnatic Spectrum held in Eilat, Israel January 22 to 26, 1995 [IUCAF Doc. 409]
- The second and third meetings of the ITU Task Group on Spurious Emissions TG1/3 in Paris (April) and Sunnyvale, CA (September) [IUCAF Doc. 410, 411, and 412]
- The Annual Meeting of the Committee on Radio Frequencies of the National Research Council (U.S.A.) held in Washington, DC in April, 1995
- Two meetings of the Committee on Radio Astronomy Frequencies of the European Science Foundation held in Grenoble France in April and in Porto, Portugal in September, 1995.
- The World Radiotelecommunication Conference 1995 held from October 18, 1995 to November 19, 1995 in Geneva, Switzerland. [IUCAF Doc. 413 and 414]
- The 15th Annual Meeting of the Frequency Coordination Group SFCG-15 in Bangalore, India from December 6 to 15, 1995 [IUCAF Doc. 418]

The following major questions were dealt with in the above mentioned meetings:

3.1. COMMSPHERE'95

At COMMSPHERE'95, IUCAF actively participated in the special session on Radio Astronomy and the Mobile Satellite Service. Drs. Baan, Cohen, Kahlmann, and Posonby, presented papers on behalf of IUCAF in a session on frequency coordination with the Radio Astronomy Service. The session was led by Dr. Roy Booth (URSI) from Sweden. Although one objective of the meeting was to facilitate a dialogue between radio astronomy and MSS people, its was extremely difficult to do so. Although the radio astronomers attended all MSS sessions, it was very discouraging to see that critical members of the MSS community did not want to hear the message of the radio astronomy community.

3.2. Little LEO MSS Systems

Little LEO systems are Low Earth Orbits (LEO) Mobile Satellite Systems (MSS) that operate below 1000 MHz. An article written by Drs. Govind Swarup (former IUCAF Member) and Ramesh Sinha (IUCAF Doc 411 and TG 1-3/38) points out the danger that these systems pose for operations of the Radio Astronomy Service in allocated bands below 1 GHz. The trigger for this concern was the "advance publication" at the ITU of a satellite paging system called IRIS. The published technical parameters suggest that a non-optimally designed spread spectrum system will produce significant out-of-band/adjacent band emission in the radio astronomy bands. In investigating the actual design of this particular (Belgian) satellite, Prof. Paul Delogne acted on behalf of the radio astronomy community. He contacted the manufacturer of the satellite system and found, during various contacts, that the designers of the system have been taking extreme care to reduce the out-of-band emissions of the satellite. A paper on the design of the transmission system has been published by P. Delogne and C. Van Himbeeck, SAIT Systems (URSI Radio Science Bulletin, 1995, 275, 23). The publication of this design will be very helpful in showing design engineers that systems with desirable out-of-band characteristics can be built.

3.3. Coordination with Mobile Satellite Service Operators

Coordination with the Mobile Satellite Service operating in the 1610-1626.5 MHz band and the Radio Astronomy Service has become a very important issue during the year 1995. Two issues play a role in this coordination: 1) co-Primary sharing between the RAS in the 1610.6-1613.8 MHz band and the MSS Earth-to-space link in the whole band, and 2) coordination between the secondary MSS space-to-Earth link and the RAS.

The first coordination issue, which involves handheld Mobile Earth Stations in the neigborhood of RAS observatories, has been adequately solved by using the coordination zone concept. Within such a zone the MES cannot be using a band close to the RAS band during observations. This concept has been accepted by both CORF and CRAF. On the other hand, the second coordination issue continues to be a major concern for the radio astronomers. At the moment Motorola s Iridium system is the only MSS system that intends to use the 1621.35-1626.5 MHz band for a TDMA/FDMA uplink-downlink. However, despite all promises by Motorola representatives from 1992 to 1994, Iridium cannot protect the RAS observatories for more than 4-5 hours per day. The National Radio Astronomy Observatory (NRAO) in the U.S.A. has agreed to an Memorandum of Understanding with Motorola under these conditions. However, no other observatory in existence is presently willing to sign an MoU with Motorola. On the other hand, the Iridium system is required to coordinate with the RAS not only in the U.S.A. but even in other countries, before it can start operations. At this time, it is unclear what the outcome of this issue will be, but it appears that for IUCAF the year 1996 will be dominated by such coordination efforts.

A Motorola-IUCAF coordination meeting has taken place in Arecibo for the first time. Iridium presented its case using the Arecibo Observatory as an example. The meeting remained cordial but it became clear that there is a standoff sitiuation [see IUCAF Doc. 417]. Since coordination with a satellite system is a global issue, IUCAF has proposed an open meeting between IUCAF and Iridium involving RAS representatives from other countries.

3.4. Space Frequency Coordination Group

The SFCG-15 Meeting was attended by IUCAF members Drs. Daniel Breton, Boris Doubinski, and Ramesh Sinha. A report of the issues discussed at the meeting in Bangalore has been presented in IUCAF Doc. 418 and distributed by email.

The main thrust of this meeting was the preparatory work needed on passive sensing and space research issues for WRC-97. Various Recommnedations and Resolutions were considered relating to the protection of passive Space Research and Remote Sensing. Spectrum needs and evaluation of the use of various bands resulted in new Resolutions from the meeting. The use of the Earth-Exploration Satellite bands were considered and in particular the bands around 60 GHz. An effort is currently being made among the remote sensing community to preserve the 50-66 GHz band totally for passive use and to re-allocate the Inter-Satellite Service allocation. This effort was initiated during WRC-95 when, during the last week of that meeting, the need for new ISS assignments became threatening. A wish list of desired frequency bands and ways to protect them has been generated during the SFCG-15 meeting and has since been discussed via email.

3.5 GLONASS Navigation Satellite System

Coordination between the GLONASS administration and IUCAF has been the first step towards solving the GLONASS problem. Presently the USA and Russia are finalizing the basic frequency re-arrangement plan agreed upon between IUCAF and GLONASS. The frequency shifts of GLONASS will facilitate the incorporation of GLONASS into a Global Navigation Satellite System, which will involve both GLONASS and the American GPS system. Contacts between IUCAF and GLONASS are still intact and another coordination meeting is being considered.

3.6. ITU Radiocommunication Sector Meetings

3.6.1. The World Radiocommunication Conference 1995

The first World Radiocommunication Conference WRC-95 of the new ITU has been held in October/November 1995 in Geneva. The issues discussed during this topical meeting, held at two-year intervals, related mostly to radio astronomy bands. Only one remote sensing issue appeared during the last days of the conference. A Recommendation was passed calling for studies to protect the 60 GHz band and to avoid Inter-Satellite Service allocations in this band. IUCAF was well represented with the following members and associates present at all or part of the meetings: Ananthakrishnan (Indian delegation), Baan (USA, IUCAF delegation), Doubinski (Russian and IUCAF delegation), Gergely (USA delegation), Gorgolevski (Polish delegation), Roger (Canada; IUCAF delegation), Ruf (German delegation), Sinha (India, IUCAF delegation), and Thompson (USA, IUCAF delegation).

As a result of a united team effort and thorough preparation of its delegates, the Radio Astronomy Service was very successful in increasing its protection. Two reports have been produced in relation to WRC-95: a preparatory circular on the RAS issues at WRC-95 (email IUCAF Doc. 413) and a discussion of the results of WRC-95 (email IUCAF Doc. 414). The following gains have been made at WRC-95:

a. a general footnote on protection of RAS bands below 1 GHz from out-of-band emission from Mobile Satellite stations,

b. a protection footnote and further mention for an unprotected but very prominent methanol transition,
c. a footnote calling for protection of a 15.35-15.4 GHz band from out-of-band emission from service in the bands above,
d. a footnote calling for protection from harmonic emissions of an MSS down link,
e. a mention of the paper on harmful thresholds for the RAS in the RAS article in the Radio Regulations, and
f. a call for sharing studies between the RAS and the MSS in two bands at 1600 MHz.

These results indicate significant progress for the RAS. It is evident that the ITU and WRC-95 recognize that radio telescopes are very vulnerable with regard to transmissions from satellites. It was also encouraging to see that many administrations were considerate of the needs of the passive services and willing to help the radio astronomers. Preparations have already begun for WRC-97, which will have again a number of remote sensing and radio astronomy issues on the agenda.

3.6.2. ITU Task Group 1/3 on Unwanted Emission

During WARC-92 in Torremolinos, Spain, a resolution 66 had been passed calling for studies on reducing spurious and out-of-band emission. As a result ITU-R Study Group set up a Task Group 1/3 to study this issue and generate recommendations for WRC- 97. TG 1/3 has met a total of three times. The first meeting was during the WP 7D meeting in Geneva, Nov. 1994, attended by various IUCAF members. TG 1/3 nr.2 was held in April, 1995 in Paris with IUCAF representatives Jim Cohen and Eric Gerard in attendance. TG 1/3 nr. 3 was held in September, 1995 in Sunnyvale, CA with IUCAF representatives Willem Baan and Richard Thompson in attendance. The next meeting of TG 1/3 will be in Paris on April 1-5, 1996 and follows the meeting of ITU Working Party 7D at Nan ay Observatory on March 25-29, 1996. A total of four IUCAF documents have presently been submitted to TG 1/3 (Doc. 410, 411, 415, and 416; see below).

The initial decision made by TG 1/3 is to concentrate first on spurious emission and address the issue of out-of-band emission later. The purpose of TG 1/3 is indeed to generate recommendations on limits of spurious emissions, keeping in mind the needs of the passive services. However, tighter standards on transmission equipment would also raise the production cost of the equipment and would be objectionable to the manufacturers in various countries. Two standards are being discussed in this context: the USA/Canada/China standards and the CEPT/European standards, which are typically 17 - 43 dB tighter than these of the first group. The radio astronomers are attempting to get the second standard adopted possibly over a time scale of ten years. Present technology would allow for such a transition. In general, the radio astronomers at these meetings face a difficult task because they are out-numbered by far by the commercial representatives.

3.7. Adverse Environmental Impacts on Astronomy

The activities of this ICSU Working Group are being monitored by IUCAF members by means of occasional meetings and regular email correspondence.

4. Remote Sensing Concerns

During the SFCG-15 meeting concerns and needs of the remote sensing community were discussed mostly in preparation for WRC-97. A wish-list of remote sensing frequencies was circulated after SFCG-15 in electronic form. The only controversial item was the wish to locate cloud radars at 95 GHz, which would give a 3 dB advantage over a radar in the active remote sensing band at 78 GHz. This plan requires a frequency swap with other services at 95 GHz. On the other hand, radio astronomers are concerned about such a swap because the 95 GHz spectrum is presently very clean and heavily used for astronomical molecular line research. A down-looking radar with inadequate filtering could destroy access to this spectral region. Discussions between radio astronomy and active remote sensing representatives are in progress. IUCAF is actively participating in these discussions on the remote sensing agenda items for WRC-97.

5. Relations between Members and Correspondents

Much of the regular contact between IUCAF members and these of CORF and CRAF is conducted via electronic mail. This facilitates a rapid distribution of information and an easy exchange of ideas. Many of the IUCAF documents are being distributed only in electronic form. Contacts with scientists in countries with not as strong traditions of radio astronomy and remote sensing need regular attention. In an attempt to keep all Correspondents current, contact is being made with all Correspondents in order to set up an email exploder network aimed at effectively and rapidly disseminating information.

The IUCAF membership is well aware of the relatively small number of scientist participating in spectrum management activities. With the increasing pressure on the radio spectrum, new participants will be recruited. IUCAF members are making radio scientists and engineers aware of the current and future problems at all radio observatories; consequently IUCAF hopes for their much needed support and participation in spectrum management activities.

Plans are being made to invite directors of prominent observatories to attend WRC-97 as part of the IUCAF delegation. Such participation will make the directors accutely aware of the arduous efforts required to preserve and protect the spectrum intended for passive use.

In addition, efforts are being made to increase the awareness of scientific spectrum issues among the spectrum managers in developing countries. Plans are being made to organize a small conference to inform these spectrum managers on WRC-97 related science issues.

6. Publications and Reports

- IUCAF 408 - Annual Report for 1994 of IUCAF (Robinson)
- IUCAF 409 - Report on the International Symposium on Future Telecommunication and the Electromagnetic Spectrum, COMMSHERE-95, Eilat, Israel (Baan)
- IUCAF 410 - Reply to Chairman, TG 1-3 Questionaire TG 1-3/21 (Apr 95; Baan)

- IUCAF 411 - Spurious Emission from LEO Satellites, TG 1-3/38 (Aug 95; Swarup and Sinha)
- IUCAF 412 - Report of TG 1-3 Meetings in Paris and Sunnyvale (email; Cohen, Baan)
- IUCAF 413 - Radio Astronomy Issues at WRC-95 - A position Statement from IUCAF and IAU Comm. 40 (Aug 95; email; Baan)
- IUCAF 414 - Radio Astronomy Issues at the World Radiocommunication Conference WRC-95 (email; Baan), including IUCAF input document on the importance of the 6.7 GHz methanol line WRC-95 Doc. 129.
- IUCAF 415 - USTG 1-3/13 The Effect of Category-A Spurious Emission Limits on the Radio Astronomy Service (Thompson)
- IUCAF 416 - USTG 1-3/14 Spurious Emission Levels Desired for the Protection of the Radio Astronomy Service from Terrestial Services (Baan, P. Perillat, M. Davis from Arecibo Observatory)
- IUCAF 417 - Visit by Iridium Delegation to Arecibo Observatory (Jan 96; email; Baan)
- IUCAF 418 - Report on the SFCG-15 Meeting in Bangalore, India (Dec 95; email; Sinha)
- IUCAF 419 - Final Acts of WRC-95 - Frequency Table and Footnotes related to the Radio Astronomy Service (Dec 95; email; Sinha)
- IUCAF 421 - Annual Report 1995 of IUCAF (Baan)

7. Organisational Matters

Finances: Generous support from URSI, IAU, and COSPAR has enabled IUCAF to make travel grants to its Members and Correspondents to ensure adequate participation at important conferences. During 1995 IUCAF was able therefore to participate actively in meetings of the Radiocommunication Sector at WRC-95, the meetings of TG 1-3, the COMMSPHERE'95 conference, and SFCG-15 of the Space Frequency Coordination Group.

It is increasingly important that IUCAF representatives attend key meetings. Already the IUCAF Members are often outnumbered by representatives advocating commercial use of the spectrum. Since the coordination problems are more global, IUCAF has an important role to play in preserving the cleanliness of the bands allocated for passive and active scientific use. Such global efforts require an increased travel budget and the continues support of URSI, IAU, and COSPAR is essential. In addition, IUCAF Members and Correspondents have obtained substantial financial support from their home institutions.

Secretariat: IUCAF has no formal Secretariat. The business is conducted from Arecibo Observatory, Puerto Rico, USA and is generously supported by the NAIC, the National Astronomy and Ionosphere Center, which provides secretarial support and access to all means of electronic communication. NAIC is operated by Cornell University under a cooperative agreement with the National Science Foundation of the United States of America.

8. Future Plans

Several long term problems are on the IUCAF agenda. For many years the passive services have been the only users of the mm-wave frequency bands. Radio astronomy and remote Earth sensing have been using the allocated and non-allocated bands at frequencies up to 900 GHz. This situation is changing rapidly with the advances of solid state detector technology. For instance, collision avoidance radars are being planned for all future cars which operate at 75 GHz or higher. Since much of this technology is aimed at the consumer market, lower quality, low cost and mass production will dominate this market. In addition, radar systems and inter-satellite communication will cause problems for the passive services. Within Working Party 7D and at IUCAF instigation, suggestions have been made to establish "radio quiet zones" for the mm-wave observatories around the world. Such zones would help protect the observatories from terrestial interference. Little progress has been made in this aspect, but IUCAF will actively promote such local solutions for the mm-wave observatories.

IUCAF is presently making strong efforts to get the remote sensing community involved. In general, the remote sensing and radio astronomy communities are quite separated and do not interact sufficiently, although their techniques are much the same.

9. Conclusion

Continued vigilance is required to ensure that the protection of the passive services is not eroded. The advances made during WRC-92 and WRC-95 will benefit the passive services in the future, but the influence of the commercial interests becomes increasingly strong at the ITU and government levels. IUCAF and the scientists involved in local spectrum management are experiencing strong opposition against any attempts to improve the status or the protection of passive bands when those commercial interests are affected.

The passive services have long been in the forefront of receiver and antenna technology and presently enjoy extremely low system temperatures and high sensitivity. This also makes the passive services more vulnerable to outside interference. Coordination and protection efforts at the local level are imperative for all observatories worldwide. It is encouraging to see that some observatories spend significant efforts on interference detection and mitigation, and that there is a good balance between local, regional, and international spectrum management efforts for the passive services.

During WRC-95 there was increased recognition of the problems caused for the passive services by spread spectrum emissions from satellites. This problem will become more severe in the years to come as the number of large satellite systems is mushrooming in order to serve global telecommunication needs. In particular, the coordination between IUCAF and the Radio Astronomy Service on one side and the Mobile Satellite Service on the other will be of paramount importance. IUCAF has a critical role to play in the telecommunication race, which is becoming more global every day.

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Report from SCOR

1. Introduction

The 32nd Executive Committee meeting of SCOR took place at Cape Town, South Africa, during the week of November 14-16, 1995. After the completion of the meeting, Professor Gjessing, URSI Representative for SCOR, had contacts with the executive director of SCOR, Dr Elizabeth Gross, regarding subjects of potential interest to URSI. In the following a consentrated set of topics will be summarized.

2. The current membership of SCOR Council and Committees

Executive Committee

President	Prof. I.N. McCave	UK
Past-President	Prof. J-O Stromberg	Sweden
Secretary	Prof. B.J. Rothschild	USA
Vice-Presidents	Prof. S. Krishnaswami	India
	Prof. Wang Pinxian	China
	Prof. T. Healy	New Zealand
Ex-officio	Dr. Y. Lancelot (CMG)	France
	Dr. F. Grassle (IABO)	USA
	Prof. B. Hoskins (IAMAP)	UK
	Dr. R. Muench (IAPSO)	USA
Co-opted	Dr. R.A. Clarke	Canada

Secretariat
Executive director Dr. Elizabeth Gross
Department of Earth and Planetary Sciences
The Johns Hopkins University
Baltimore MD 21218, USA
Tel. : 410-516-4070, Fax : 410-516-7933

The XXIII General Meeting of SCOR will take place at the Southampton Oceanographic Center, England, late September 1996.

3. Special SCOR activities of potential interest to URSI

Over some period URSI has, as we well know, directed some attention to the sea surface. This activity has centered around specific commission F Remote Sensing challenges such as :

- Scatterometer for estimation of surface wind and sea state.
- Radiometers for assessment of sea surface temperature and also sea state.
- SAR systems in satellites (such as Seasat and ERS1) for the study of ocean current structure.
- Radar Altimeter for assessment of ocean waves, swells and storm surges.

Reviewing the SCOR activities, emphasis is placed on items that may contribute to URSI challenges.

As an example, it would be interesting to compare notes not only in regard to results of sea surface remote sensing by radio waves and results from models (data assimilation schemes), but also between remote sensing results from URSI (such as ERS1 SAR) and the results from ocean acoustic tomography from SCOR.

In the following some of the key items, from the viewpoint of URSI, will be listed.

3.1 Working Group 96 : Acoustic Monitoring of the World Ocean

Terms of Reference :

- To study the existing methods of large-scale acoustic tomography of the ocean and identify those which can benefit from international collaboration.
- To evaluate the opportunities for international collaboration in the use of acoustic techniques for monitoring global climate change in the ocean.
- To assess other methods and theories relating to investigation of the ocean by means of observations of sound propagation over long distances.
- To prepare a report to SCOR on the scientific prospects for largescale acoustic tomography.

Chair :
Dr. David Farmer, Institute of Ocean Sciences
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E-mail : dmf@ios.bc.ca

Members :

Leif Bjorno	Denmark
Geoff Brundrit	South Africa
Yves Desaubies	France
Nikolai Dubrovsky	Russia
Andrew Forbes	Australia
Harley Hurlburt	USA
Walter Munk	USA
Iwao Nakano	Japan
Mark Slavinsky	Russia
Zhang Renhe	China

Corresponding Members :

Victor Akulichev	Russia
Leonid Brekhovskikh	Russia
Art Baggaroer	USA
Z Klusek	Poland
Alexander Voronovich	Russia
Guan Dinghua	China

Executive reporter :
Dr Robin Muench USA

3.2 SCOR Working Group 101 on Influence of sea state on the atmospheric drag coefficient

A workshop was held in Vienna on Z3 August 1991 to discuss the current state of knowledge of the influence of sea state on the aerodynamic drag coefficient between the atmosphere and the ocean. About twenty people attended and concluded that the influence of swell and wind waves on the drag coefficient was uncertain and that further critical experiments were required.

The flux of momentum, however, is important in air sea models used both for climate studies and operational forecasts. The advent of wave sensing satellites will make the forecasting of sea state more exact. Our understanding of the flux of other quantities across the air sea boundary, such as heat or carbon dioxide are expected to be enhanced by knowing the nature of the momentum transfer.

Terms of Reference :

- To hold a workshop on the relationship between momentum flux to the sea and the sea state.
- To encourage the execution of critical experiments.
- To prepare a report to SCOR on the most like expression relating momentum flux to sea state.

Co-Chairs :
Professor Jan S. F. Jones,
National Committee for Oceanic Sciences,
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3.3 SCOR Working Group 193. The role of wave breaking on upper ocean dynamics

Even to the casual observer, wave breaking is a widespread phenomenon on the wind driven sea surface. Wave breaking contributes unique characteristics to the boundary layers on either side of the air-sea interface, yet despite its fundamental character and strong influence on upper ocean dynamics and air-sea interaction processes, reliable prediction and quantification on the occurrence and dynamical consequences of wave breaking remains an elusive goal. The IUTAM Breaking Waves Symposium held in Sydney in July 1991 revealed a very strong scientific interest in this area, and there was a strong consensus expressed during the panel discussion for the need to co-ordinate future theoretical and observational research efforts.

The SCOR workshop offers an excellent platform for coordinating a critical mass of leading modellers, theoreticians and experimentalists to highlight the shortcomings of our present scientific knowledge and propose future research directions, with the goal of advancing our ability to develop more realistic predictive models for upper ocean. dynamics, that reliably reflect the influence of wave breaking.

Terms of Reference :

- To hold a workshop to review the present status of our knowledge of wave breaking on the wind driven sea surface and quantification of its dynamical implications for upper ocean dynamics.
- To examine the implications of existing modelling an observational data, and formulate strategies for future incisive modelling and experiments.
- To prepare an authoritative report to SCOR on the status of our present understanding of wave breaking and its importance on upper ocean processes, and a projection of the needs for future theoretical and observational research directions on breaking ocean waves.

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3.4 SCOR/IOC Scientific Steering Committee on Global Ocean Ecosystem Dynamics GLOBEC (with ICES and PICES) 1992

Terms of Reference :

- To identify the scientific issues and detailed goals and objectives for an international study of Global Ocean Ecosystem Dynamics Research and Monitoring (GLOBEC) with a focus on secondary
- To develop a detailed scientific plan for GLOBEC and to guide the modelling and technological developments required to understand the mechanisms by which ocean physics contributes to the variability of secondary production.
- To recommend to the sponsoring organizations the necessary actions to be taken to implement the scientific plan and to co-ordinate and manage the resulting activities.

- To collaborate, as appropriate, with other related programs and planning activities, such as the IGBP, the International Geosphere-Biosphere program, the Joint Global Ocean Flux Study, the World Ocean Circulation Experiment, the IOC/FAO program on Ocean Science and Living Resources, and the emerging Global Ocean Observing System.
- To report regularly to SCOR and IOC and to related bodies on the state of planning and accomplishments of GLOBEC.

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3.5 Scientific Steering Committee for the Joint Global Ocean Flux Study (with IOC) 1987

Terms of Reference :
- To identify the fundamental scientific issues and detailed goals and objectives for an international Joint Global Ocean Flux Study.
- To develop a scientific plan and to establish requirements for carrying it out.
- To recommend the necessary actions to be taken to implement the plan and co-ordinate and manage the resulting activities.
- To collaborate, as appropriate, with other related programmes and planning activities.
- To report regularly to SCOR and IGBP on the state of planning and accomplishments of JGOFS.

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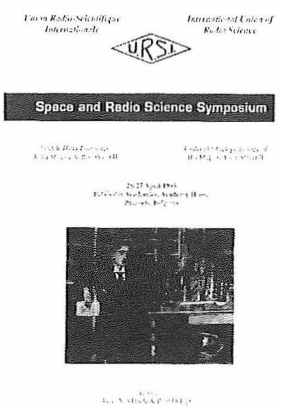

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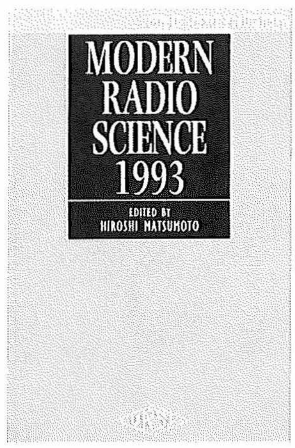

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