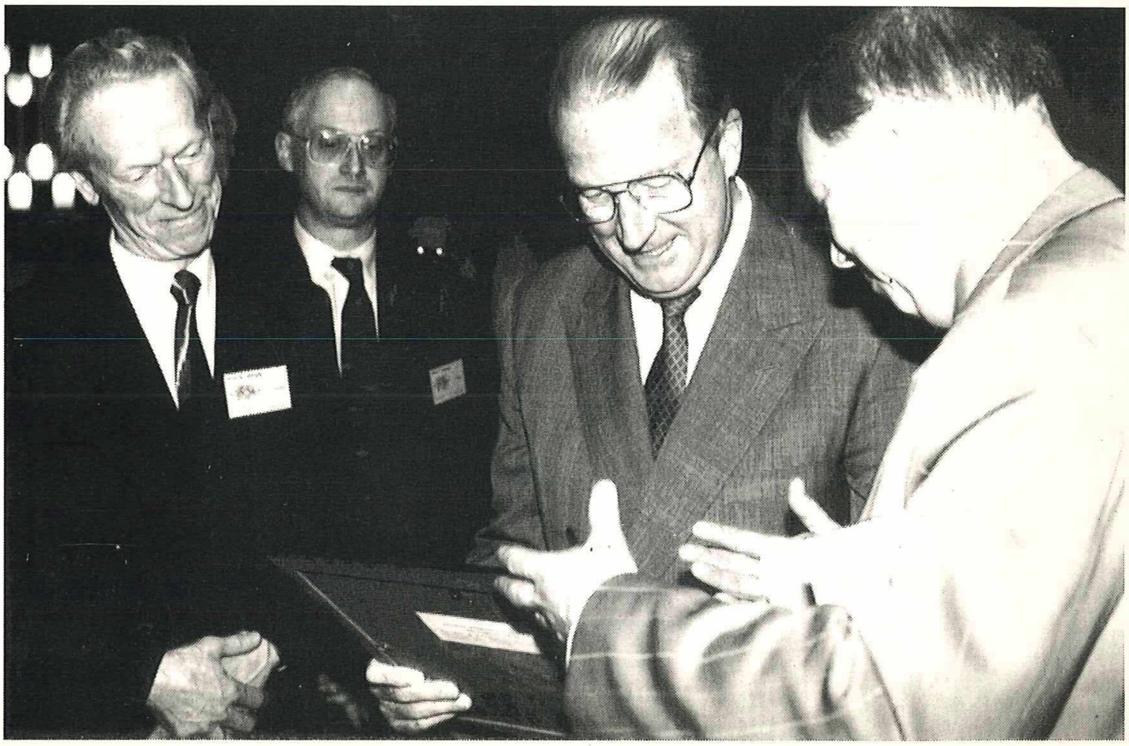
# The Radio Science Bulletin

ISSN 1024-4530

INTERNATIONAL
UNION OF
RADIO SCIENCE

UNION
RADIO-SCIENTIFIQUE
INTERNATIONALE

U.R.S.I.



**No 273**
**June 1995**

Publié avec l'aide financière de l'UNESCO

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

---

**Front cover :** President P. Bauer presents a framed photograph, taken during the first General Assembly of URSI in Laken (Belgium) in 1919, to His Majesty King Albert II of Belgium at the occasion of the symposium "Space and Radio Science". From left to right : Prof P. Delogne (Chairman of the Technical Programme Committee of this symposium), Prof. P. Lagasse (URSI Secretary General), His Majesty King Albert II, Dr. P. Bauer (URSI President).

---

**EDITOR-IN-CHIEF**
URSI Secretary General
Paul Lagasse
University of Gent
Dept. of Information Technology
St. Pietersnieuwstraat 41
B-9000 Gent
Belgium
Tel+ : 32 (9) 264 33 20
Fax: + 32 (9) 264 42 88
e-mail: rsb@intec.rug.ac.be

**EDITORIAL ADVISORY BOARD**
Pierre Bauer
(URSI President)
Peter J.B. Clarricoats
(URSI Vice-President on Publications)
James R. Wait

**PRODUCTION EDITORS**
Inge Heleu & Peter Van Daele

**EDITOR**
Paul Delogne
Université Catholique de Louvain
Telecommunications and Remote Sensing
Place du Levant 2
Bâtiment Stévin
B-1348 Louvain-la-Neuve
Belgium
Tel: + 32 (10) 47 23 07
Fax: + 32 (10) 47 20 89
e-mail: delogne@tele.ucl.ac.be

**ASSOCIATE EDITORS**
Steven Dvorak, Robert D. Hunsucker
D. Llanwyn Jones, Ari Sihvola
Piotr Sobieski, W. Ross Stone
Rudolf Treumann, Peter Van Daele
Luc Vandendorpe, James H. Whitteker

***For further information about URSI, please contact :***
The URSI Secretariat, c/o University of Gent (INTEC)
Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium
Tel. + 32 (9) 264 33 20, Fax + 32 (9) 264 42 88
e-mail: inge.heleu@intec.rug.ac.be

***For contributions to "The Radio Science Bulletin" :***
e-mail: rsb@intec.rug.ac.be

The International Union of Radio Science (URSI) is a foundation Union (1919) of the International Council of Scientific Unions as direct and immediate successor of the Commission Internationale de Télégraphie Sans Fil Scientifique (TSFS) which dates from 1913.

RSB_273_1995_06.pdf.

# From the President

Dear URSI Correspondent,

As you know, the death of Professor Takanori Okoshi, Vice-President of our Union, represents a great loss to the URSI Community. We still have in mind his outstanding contributions to the success of the Kyoto General Assembly in 1993, as well as the efficiency with which he assumed various responsibilities as a member of the Board of Officers.

In view of the numerous tasks to be discharged by the Board, including the preparation of the next General Assembly, I proposed at the last meeting of the Board (Brussels, 28-29 April) to apply Article 51 of the Statutes, which reads as follows : "A vacancy which occurs in the Board of Officers can be filled by the President after consultation with the Board of Officers and the Member Committees. An Officer appointed in this way holds office until the end of the next Ordinary General Assembly ; he can then be elected to the Board even if the Officer whom he replaced was not eligible for re-election."

With the agreement of the Board Members, and together with Professor E.V. Jull, Past President of the Union, I consulted Dr. Y. Furuhama, President of the Japanese Committee, who was present in Brussels, attending the 75th Anniversary Symposium, about the vacancy which had occurred in the Board. Upon his return to Japan, Dr. Furuhama sent me a letter, warmly recommending Professor Hiroshi Matsumoto as a candidate for Vice-President for the rest of this triennium. This was received with satisfaction by the Board Members, who consider this proposal as extremely promising.

All the URSI Member Committees were consulted concerning this proposal and all those committees who replied are very much in favour of this proposal. On 20 June Professor H. Matsumoto was nominated Vice-President of URSI up to the Lille General Assembly.

We enclose a short curriculum vitae of Professor H. Matsumoto for your information.

Our heartiest congratulations to Vice-President Matsumoto!

P. Bauer
URSI President

## Short curriculum vitae of Professor H. Matsumoto

Hiroshi Matsumoto was born in Nara, Japan, in 1942. He received the degrees of Bachelor of Engineering in 1965, Master of Engineering in 1967, and Doctor of Engineering in 1973, each from Kyoto University, Japan.

Upon completion of the Master's course in 1967, he was appointed Research Associate in the Department of Electronics, Kyoto University, and he served in this capacity until 1974. During 1974-82 he was Associate Professor at the Ionosphere Research Laboratory, Kyoto University, and during 1982-87 he was Associate Professor at the Radio Atmospheric Science Center (RASC), Kyoto University.

Since 1987 he has been Professor at RASC, and since 1992 its Director. He has held visiting research positions at NASA Ames Research Center and Stanford University in the USA, and a Visiting Professorship at the Institute for Space and Aeronautical Sciences (ISAS), the National Institute for Fusion Science, and the Communications Research Laboratory (CRL) in Japan.

Professor Matsumoto's main research interests include theoretical and computer-simulation studies of nonlinear wave-particle interactions in space plasmas, analysis of satellite observations of plasma waves in space, development of microwave power transmission systems for the Solar Power Satellite and other terrestrial applications, and laboratory experiments on plasma waves generated in a space simulation chamber.

He has published more than 150 scientific papers and edited three books in the field of space plasma and radio waves. He has served as Editor of J. Geoelectricity and Geomagnetism, Geophysical Research Letters and Associate Editor of J. Geophysical Research.

As for URSI activities, Prof. Matsumoto has served in the capacities of Vice-Chairman and Chairman of Commission H during 1983-87, and Associate Coordinator for the Scientific Programme of the Kyoto General Assembly. He is currently Coordinator of the Scientific Programme of the next Lille General Assembly.

# Editorial

Dear URSI Correspondents,

After a transient due to merging with the Radioscientist, the Radio Science Bulletin now progressively reaches steady state. Thanks to Dick Dowden for his pioneering work and to the Secretariat team for taking over ! All inputs to the Bulletin now come in some electronic format. We are daily experiencing the intricacies and inconsticencies of the emerging communication society. The next issue will contain instructions to authors on preferred electronic document formats.

The URSI 75th anniversary celebration has been very successful according to expressed opinions. By lack of place a detailed report on this memorable event has been delayed to the next issue of the Bulletin. Meanwhile we continue the publication of the Space and Radio Science Symposium papers with the remarkable contribution of Hiroshi Matsumoto. In parallel we maintain the Bulletin as the scientific forum for topics of interest to the whole URSI community by welcoming additional contributions. Yours is expected soon !

Paul Delogne

# Letter to the editor

## THIRTY-FIVE IS ENOUGH: A NEW CONSTRAINT FOR LINEAR, BIANISOTROPIC MEDIA

W.S. Weiglhofer
A. Lakhtakia

As materials scientists investigate ever more exotic materials for potential applications in electrical, electronic and optical devices, a better understanding of the electromagnetics of complex materials is of increasing importance. This was the major motivation for us to re-examine (based on findings by E J Post some decades ago) some of the very basics of the formulation of electromagnetic material relations of general, so-called bianisotropic, linear media.

At a specialist conference, held in Perigueux, France, during May 1994, we first reported on a new development concerning the constitutive relations of linear, homogeneous bianisotropic materials (see The Radioscientist, News, Vol. 5, No. 2, p. 47, June 1994).

The uniformity constraint — as it has become known — comes about as a consequence of the requirement of mathematical consistency of Maxwell's equations and the constitutive relations due to the covariant nature of modern electromagnetic theory. Essentially, the 36 constitutive parameters of a homogeneous bianisotropic medium must fulfil one algebraic equation. Thus the number of independent parameters cannot exceed 35.

Two points are worth stressing here: first, the consequences of the constraint are only felt by bianisotropic or bi-isotropic media. Isotropic media or anisotropic media (such as cold magnetoplasmas or ferrites) remain unaffected. Secondly, it is not a reciprocity condition.

If, however, certain specializations of bianisotropic media are considered, the constraint can amount to the condition of reciprocity. Indeed this happens for bi-isotropic media which have received much recent attention as generalizations of the well known chiral media (which occur abundantly in nature and have also been manufactured). Thus, the most striking consequence of the uniformity constraint is that the existence of nonreciprocal bi-isotropic materials is incompatible with modern electromagnetic theory. It may be added that there is at present no experimental evidence that nonreciprocal bi-isotropic media have ever been seen.

A short overview of the events of the recent year concerning the uniformity constraint and related issues, containing detailed references to the literature, can be found in a paper by the authors of this letter: 'Brief review of a new development for constitutive relations of linear bianisotropic media', IEEE Antennas and Propagation Magazine, Vol. 37, No. 3, in press, June 1995.

Werner S Weiglhofer, Dept. of Mathematics, University of Glasgow, Glasgow G12 8QW, Scotland, United Kingdom (e-mail: werner@maths.gla.ac.uk)

Akhlesh Lakhtakia, Dept. of Engineering Science and Mechanics, Pennsylvania State University, University Park, PA 16802-1401, USA

# In Memoriam

## Hannes Alfvén
## 1908 - 1995

Nobel Laureate Hannes Alfvén died on April 2 in his home in Djursholm, Sweden, after a fulfilling life and outstanding scientific achievements.

Born on May 30, 1908, in Norrköping, Sweden, Hannes Alfvén had a family background of highly gifted personalities, including a famous composer, Hugo Alfvén (his uncle). A couple of youthful experiences at home and in school had an important influence on his intellectual development and his professional career. One was that at a very early age he was fascinated by Camille Flammarion's book on Popular Astronomy, which kindled a lifelong interest in astronomy and astrophysics. The other was that he joined the school's radio club and built radio receivers. At that time there was no nearby radio station, and the one in Stockholm was too weak to be received with primitive equipment in his home town of Norrköping. The most promising one was a strong station in Aberdeen, Scotland, and Hannes Alfvén has described the fascination he felt, when some faint notes of music emerging out of the atmospheric noise could be identified as coming from Aberdeen.

After high school he continued his studies at the University of Uppsala, where he studied mathematics, mechanics and physics. The title of his doctoral thesis (in 1934 at the age of 26) was "Ultra Short Electromagnetic Waves" and he has himself characterized his doctoral work as a direct continuation of his radio club activities.

Very early Hannes Alfvén became interested in the acceleration of charged particles to very high energies, and especially to the extreme energies of the cosmic rays. In 1933 he published, in Nature, a paper on the origin of cosmic radiation, dismissing earlier theories on the grounds that they do not "seem to be in accordance with the latest experimental results". All of his later work is permeated by the principle that cosmic phenomena must agree with results from laboratory experiments on Earth (because the same laws of Nature should apply everywhere).

In 1940 Hannes Alfvén was appointed Professor of Electromagnetic Theory and Electric Measurements at the Royal Institute of Technology, Stockholm. There, his vigorous scientific activity led to a rapid expansion in his field of research and to the creation of a number of new professorships and departments in the School of Electrical Engineering. As a result of the rapid evolution his own professorship also changed, first to Electronics in 1946 and then to Plasma Physics in 1963. The three departments that most directly trace their origin to his work now constitute a separate entity within the Royal Institute of Technology, the *Alfvén Laboratory*, founded in 1990.

In 1967 Hannes Alfvén accepted a professorship at the University of California, San Diego and moved to La Jolla, but every year he spent the time "from the Vernal Equinox until the Autumnal Equinox" in Sweden in very active scientific interaction with his colleagues at the Royal Institute of Technology. His annual return was always something to look forward to. His annual migration between California and Sweden, as well as his intense scientific activity, continued well beyond his formal retirement in 1973.

Hannes Alfvén's scientific work reveals a profound physical insight and an astounding intuition, which allowed him to extract results of great importance and generality from specific problems by physical reasoning and with only a minimum of mathematics. An important key to his success seems to have been the fresh perspective that he got by approaching astrophysical problems from an electromagnetic point of view, a fruit of his youthful fascination with electronics (a heritage from the school's radio club) as well as astronomy. When his landmark book Cosmical Electrodynamics was published in 1950, he was referred to as an "electrical engineer in Stockholm" (in a review written by T.G. Cowling).

His most well-known discovery, of what we now call *Alfvén waves*, is in many ways typical of his approach. It grew out of a specific problem, namely that of sunspots and the sunspot cycle. At that time electromagnetic theory and fluid dynamics were both well established but separate, and "everyone knew" that electromagnetic waves could not propagate in an electrically conducting medium. But as an "electrical engineer" Hannes Alfvén realized that the magnetic fields observed in the sunspots must derive from electrical currents in the plasma itself, and that these must give rise to forces that affect the fluid motion, which in turn induces electric fields. As a result there exists a kind of waves, now universally called Alfvén waves, that involve hydrodynamics as well as electromagnetism and which propagate with *less* damping the *higher* the conductivity. He formulated his discovery in an admirably simple and clear mathematical form in a Letter to Nature published in 1942 (Existence of Electromagnetic-Hydrodynamic Waves, Nature, *150*, 405-406, 1942).

Incredible as it may seem to us today, it took years before this discovery was taken seriously. A common argument among his critics was that if such waves existed, Maxwell would have discovered them. As Hannes Alfvén tells it, he received letters from colleagues asking whether he had not understood that his paper about a new kind of waves was nonsense, and few people believed in his results. Again according to Hannes Alfvén, the breakthrough came in 1948, when after a seminar by Hannes in Chicago, Enrico Fermi nodded his head and said "of course such waves could exist", and again according to Hannes Alfvén's own account, the prestige of Enrico Fermi was such that "the next day every physicist nodded his head and said 'of course'".

Hannes Alfvén's early work on cosmic rays led him to proposing, already in 1937, that there exists a *galactic magnetic field*, but this proposal was generally dismissed, because space was believed to be a vacuum incapable of carrying electric current. Much later the existence of a galactic magnetic field was established, but without recognition of Hannes Alfvén's original proposal.

Turning his attention to the Earth's magnetic field and the phenomenon of the aurora he found the established way of calculating particle orbits to be impractical, especially in the energy range relevant to auroras. He therefore developed, as a tool, the *gyro center approximation* for the motion of charged particles in electric and magnetic fields, which has become an invaluable tool throughout the field of plasma physics.

Using his gyro center approximation Hannes Alfvén developed the concept of a *ring current* in the Earth's magnetic field. He tried to publish this result, but it was rejected by the leading journal at that time, Terrestrial Magnetism and Atmospheric Electricity, on the grounds that it did not agree with generally accepted theories.

His suggestion, in 1958, that *magnetic-field aligned electric fields*, perhaps in structures called *electric double layers*, exist above the ionosphere and cause the downward acceleration of auroral primary electrons was considered outrageous, because such fields should be "shorted out" in a collisionless plasma. His view has, however, been vindicated by massive evidence from space measurements that such fields exist and are important, although their precise nature and role are far from well understood.

Some of Hannes Alfvén's ideas are still not accepted or controversial. One example is the concept of a special kind of *partial corotation*, (at a velocity equal to 2/3 of the Kepler velocity), which he introduced to explain the structure of the Saturnian ring system and from which he successfully predicted that Uranus would prove to have a ring system. Another example is *symmetric cosmology*, which implies that the Universe may consist of equal amounts of plasma and antiplasma, separated by thin boundary layers, where intense annihilation takes place but remains unobservable, because the low density and spatial smallness of the boundary regions makes the resulting radiation too weak to be detected at the Earth. These regions are analogous to the Leidenfrost layer formed under a drop of water on a hotplate.

Hannes Alfvén has taken an active interest also in important matters outside science, especially matters related to the long term fate of mankind, such as environment, population growth and disarmament. During a period of several years in the 1970's he was President of the Pugwash movement. This is an activity initiated by Albert Einstein and Bertrand Russell and named after a small Canadian fishing village, where the first meeting was held and where the Einstein-Russell Manifesto was generated. In this movement, eminent scientists from both of the superpowers as well as Western Europe, Japan and the third world meet annually, not as representatives of their countries but as concerned individuals.

Returning to Hannes Alfvén's scientific achievements, it is worth emphasising that he has contributed to the progress of science not only by his own work but also by the extraordinary inspiration that he has given to his many students as well as to colleagues all over the world. His death has left many of us with a feeling of great loss but also of deep gratitude for all that he has meant as a scientist and as a friend.

Carl-Gunne Fälthammar

# YAKOV IOSIPHOVICH LIKHTER
# 1914 - 1995

Professor Yakov Iosiphovich Likhter passed away on March 17, 1995. He was one of the patriarchs in radio wave science in the USSR (and later in Russia), and also one of the first founders of satellite VLF wave research.

Yakov Iosiphovich Likhter was born on 27 February 1914 in the Ukraine village Makarovo (Kiev region). He graduated from the Moscow University in 1940, and in March 1941 he was called up for the Soviet Red Army. Yakov Iosiphovich Likhter was at the front line from the first day of the Great Patriotic war. The Orders of the Red Star and Patriotic War medals were awarded to him for the courage shown during the war.

Yakov Iosiphovich started his scientific activity from April 1950 in the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN), and worked there for the remaining 45 years of his life. During many years he was Head of the laboratory of the Very Low Frequency Emissions of IZMIRAN in the Moscow region. During that period the laboratory became one of the leading divisions of the Institute and one of the most prominent laboratories in the country in the field of VLF wave processes. He initiated research on the natural VLF electromagnetic emissions in the near-Earth plasma by means of more than ten INTERCOSMOS satellites. Many types of new VLF phenomena were discovered and explained by Professor Ya. I. Likhter. He was also rather famous in the field of atmospheric noise statistics. More than 150 scientific papers and 4 scientific books were published by Professor Ya. I. Likhter.

After his retirement Professor Ya. I. Likhter worked as a leading scientist in IZMIRAN. Yakov Iosiphovich Likhter was the world-famous scientist, and he was a man with clear principles and great honesty. He liked the science itself, and he worked a lot. He was a very kind man and attentive to his assistants and colleagues.

Over the years he made a lot of contributions to URSI Commission E and his efforts have always been greatly appreciated. All of his friends and successors inside Russia and abroad mourn together with the family of Professor Yakov Iosiphovich Likhter over his death. But his memory will always be treasured in our hearts.

M.M. Mogilevsky and O.A. Molchanov

# URSI Accounts 1994

I am pleased to introduce the Balance Sheet of Income and Expenditure for the year ended 31 December 1994 which is reproduced below.

During the financial year, the Secretary General and the Secretariat of URSI have worked extremely hard in order to make the financial operations of URSI very transparent and with the help of computer-aided packages it is now possible to follow income and expenditure in a very efficient way. Commission Chairmen also receive statements relevant to their funds. The overall financial position of URSI is very satisfactory. During the year consideration was given to transferring the US reserves to Europe. However, it was discovered that penalties would be attached were this to take place immediately and the Board of Officers are satisfied that the existing arrangements should continue at least until the next General Assembly.

As readers will know, a decision affecting the future of the Radioscientist was made during the year and this will lead to significant financial savings in the year 1995. A one-time offset will arise from the 75th Anniversary Celebrations but the benefit to URSI certainly justified the expense, which will appear in the next Balance Sheet.

I am pleased to commend the audited accounts to URSI.

P. J. B. Clarricoats
Treasurer of URSI

## INTERNATIONAL UNION OF RADIO SCIENCE (URSI)
## BALANCE SHEET : 31 DECEMBER 1994

| | ASSETS | US$ |
|---|---|---|
| Dollars | | |
| Banque Degroof | 15,067.57 | |
| Merrill Lynch WCMA | 20,354.33 | |
| Générale de Banque | 27,663.00 | |
| Smith Barney Shearson | (49.39) | |
| | | 63,035.51 |
| Belgian francs | | |
| Banque Degroof | 2,865.69 | |
| Générale de Banque | 69,746.47 | |
| | | 72,612.16 |
| Investments | | |
| Demeter Sicav shares | 22,794.75 | |
| Rorento Units | 124,034.97 | |
| Aqua Sicav | 64,103.22 | |
| Merrill-Lynch Short Term | 30,012.85 | |
| Merrill-Lynch Global Utility | 13,492.10 | |
| Smith Barney Utilities Fund | 81,764.00 | |
| Reinvestment S.B. Utilities | 10,078.33 | |
| Smith Barney Grade Bond | 49,300.00 | |
| Reinvestment S.B. Grade Bond | 7,019.40 | |
| | | 402,599.62 |
| Other | | |
| Petty cash | | 420.81 |
| | Total Assets | 538,668.10 |
| | | ======== |
| Less creditors | | |
| IUCAF | 14,047.75 | |
| IUWDS | 6,007.88 | |
| Salary and Social Security | 3,672.53 | |
| Audit fees | 1,718.75 | |
| | | 25,446.91 |
| Balth van der Pol Medal Fund (1) | | (13,381.97) |
| | NET TOTAL OF URSI ASSETS | 499,839.22 |
| | | ======== |

The net URSI Assets are represented by :

| | | $ |
|---|---|---|
| Closure of Secretariat : | | |
| Provision for Closure of Secretariat | | 24,131.25 |
| | | |
| Scientific Activities Fund : | | |
| Scientific Activities in 1995 | 80,000.00 | |
| Young Scientists in 1995 | 30,000.00 | |
| Administration Fund in 1995 | 80,000.00 | |
| I.C.S.U. Dues in 1995 | 5,000.00 | |
| | | 195,000.00 |
| XXIV General Assembly Fund : | | |
| During 1995 : | | 30,000.00 |
| | | 249,131.25 |
| Unallocated Reserve Fund | | 250,707.97 |
| | | 499,839.22 |
| | | ======== |

**Statement of Income and Expenditure**
**for the year ended 31 December 1994**

| I. INCOME | | $ |
|---|---|---|
| Grant from ICSU Fund | | 21,200.00 |
| Contributions from Member Committees | | 175,273.38 |
| Special contributions | | 1,635.94 |
| Sales of Publications | | 106.25 |
| Royalties | | 52.84 |
| Bank Interest | | 13,108.04 |
| Gain of Exchange | | 1,110.00 |
| Other Income | | 10,078.00 |
| Total Income | | 222,564.45 |
| | | ======== |
| II. EXPENDITURE | | |
| a) Scientific Activities | | 54,668.38 |
| General Assembly 1993 - Scientific | 4,406.88 | |
| Symposia/Colloquia/Working Groups | 30,959.97 | |
| Representation at scientific meetings | 11,901.53 | |
| Grants to organizations | 7,400.00 | |
| b) Routine Meetings | | 8,800.18 |
| Bureau/Executive committee | | |
| c) Publications | | 69,623.71 |
| d) Administrative Expenses | | 59,804.53 |
| Salaries, Related Charges | 38,443.09 | |
| General Office Expenses | 6,638.54 | |
| Office Equipment | 1,695.97 | |
| Accounting and Audit Fees | 10,236.56 | |
| Bank Charges | 2,659.97 | |
| Loss on Exchange | 130.40 | |
| | | |
| e) ICSU Dues | | 7,052.00 |
| Total Expenditure | | 199,948.80 |
| | | ======== |
| | | |
| Excess of Income over Expenditure | | 22,615.65 |
| Accumulated Balance at 1 January 1994 | | 454,440.51 |
| | | |
| Balance at 31 December 1994 | | 477,056.16 |
| Appreciation of Belgian Franc | | 22,783.06 |
| | | |
| Accumulated Balance at 31 December 1994 | | 499,839.22 |
| | | ======== |

Rates of exchange :
1 January 1994 : $1 = 35,50 BF
31 December 1994 : $1 = 32,00 BF

Observation :
The account indicated with (1) is represented by :
376 Rorento Shares : market value on December 31, 1994 = $17,960

Market value of investments on December 31, 1994 ($1 = 32,00 BF) :

| | |
|---|---|
| - DEMETER SICAV : | 35,510.06 |
| - RORENTO UNITS (2) : | 310,470.81 |
| - AQUA-SICAV : | 74,605.06 |
| - M-L SHORT TERM : | 25,800.00 |
| - M-L GLOBAL UTIL. : | 14,858.00 |
| - SMITH BARNEY UTIL. : | 77,302.42 |
| - SMITH BARNEY GRADE : | 48,145.13 |
| | 586,691.48 |

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

APPENDIX

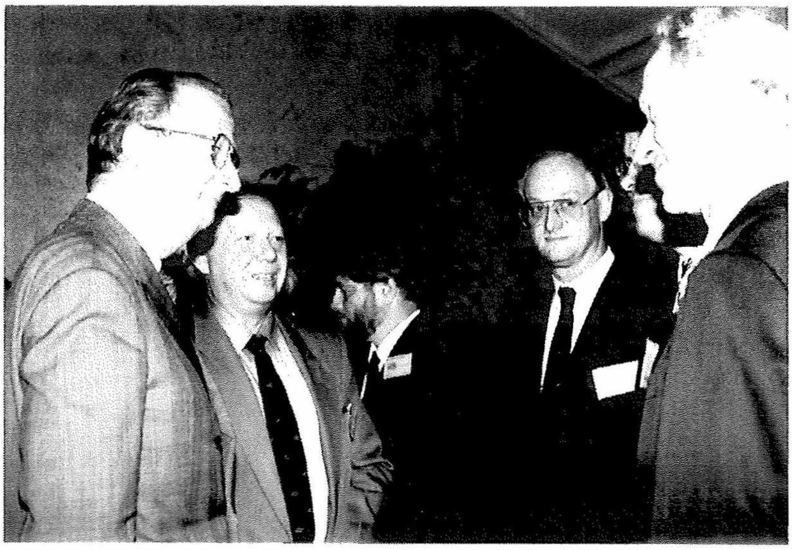
## Detail of Income and Expenditure

| | | $ |
|---|---|---|
| I. INCOME | | |
| Special Contributions | | |
| Commonwealth Science Council | | 1,635.94 |
| Other Income | | |
| Reimbursement YS Adimula | 8,503.00 | |
| Profit on Sale Merrill-Lynch Fund | 1,575.00 | |
| | | 10,078.00 |
| II. EXPENDITURE | | |
| Symposia/Colloquia/Working Groups : | | |
| COSPAR C4, Hamburg | 400.00 | |
| COSPAR IRI, Hamburg | 400.00 | |
| ESGAP, Aussois | 2,800.00 | |
| Com. F. Specialist meeting, Lawrence | 2,000.00 | |
| EMC'94, Rome | 2,500.00 | |
| CPEM'94, Boulder | 3,000.00 | |
| Solar Terrestrial Physics, Sendai | 800.00 | |
| MMET'94, Kharkov | 1,000.00 | |
| Physics & Eng. (sub)mm, Kharkov | 2,150.00 | |
| Beacon Satellite, Aberystwyth | 1,345.78 | |
| ISAE'95, Bali | 1,300.00 | |
| EMC'94, Wroclaw | 2,500.00 | |
| APT MEETING, Urumqi | 2,000.00 | |
| JINA '94, Nice | 532.38 | |
| SUZDAL, Uppsala | 1,631.81 | |
| IGARSS'95, Firenze | 5,000.00 | |
| ISSTA'96, Mainz | 1,600.00 | |
| | | 30,959.97 |
| Grants to Organizations : | | |
| COSPAR | 400.00 | |
| ICTP-ITU-URSI | 3,000.00 | |
| FAGS | 2,000.00 | |
| IUCAF | 2,000.00 | |
| | | 7,400.00 |
| Publications : | | |
| KLM Transmail Services | 27,771.56 | |
| The Radio Sc. Bulletin (No 268, 269, 270) | 28,034.56 | |
| Bulletin No 267 (December ''93) | 4,064.19 | |
| Modern Radio Science + Review of R.S. | 5,814.65 | |
| Proceedings General Assembly | 3,938.75 | |
| | | 69,623.71 |

**75th ANNIVERSARY**

# URSI - 75 Years Space and Radio Science Symposium

*On 26-27 April, 1995 our Union celebrated its 75th Anniversary in Brussels, Belgium with the "Space and Radio Science Symposium". In the September issue of the "Radio Science Bulletin" a more extensive report on this important event will be published. The proceedings of this Symposium can be bought from the URSI Secretariat.*



*At the occasion of the "Space and Radio Science Symposium", Prof. Paul Delogne - Chairman of the Technical Programme Committee of the Symposium (on the right) - and Prof. Paul Lagasse - URSI Secretary General (second from the right) - are introduced to His Majesty King Albert II of Belgium by Dr. Pierre Bauer, URSI President (second from the left).*

*Dr. Pierre Bauer, URSI President, during his speech at the Opening Ceremony of the Symposium "Space and Radio Science".*

*The Symposium, held in the prestigous Academy House in Brussels, was attended by a large number of participants, from all over the world. The photograph shows (first row, from left to right): Prof. W.E. Gordon (Honorary President of URSI), Prof. J. Van Bladel (Chairman of the Local Organising Committee), His Majesty King Albert II of Belgium, Prof. P. Delogne (Chairman of the Technical Programme Committee), Prof. P. Lagasse (URSI Secretary General), Prof. E.V. Jull (URSI Past President) and Prof. J. B. Andersen (URSI Vice President).*

75th ANNIVERSARY

URSI - 75 Years
Space and Radio Science
Symposium

# MICROWAVE POWER TRANSMISSION FROM SPACE AND RELATED NONLINEAR PLASMA EFFECTS

H. Matsumoto

## Abstract

We first present a brief historical review of the development of technology and scientific research related to the transmission of electrical energy via radio waves. The idea of radio power transmission was first conceived by Tesla about a century ago. However, the first practical use of radio waves was for transmitting intelligence and information, and not for transmitting electrical power per se. At the close of World War II, engineers and scientists re-examined the original Tesla idea of transmitting electric power to a distant place via radio, as high-power microwave technology became available. These efforts in 1960's resulted in the idea of the Solar Power Satellite (SPS) which was proposed by P. Glaser in 1968. The NASA/DOE concept of the SPS was extensively developed in the late 1970's. After reviewing the history of microwave power transmission and related theoretical/experimental studies from the beginning of this century up to 1980, we will discuss recent research on microwave power transmission after 1980. Our focus will be on related experiments conducted in the 1980's and 1990's, including those on ground-to-ground microwave energy transmission, ground-to-aircraft power transmission, and rocket-to-rocket power transmission. The rocket experiment we discuss was conducted to examine a possible nonlinear resonant interaction of intense microwaves with the ionospheric plasma. The result of the rocket experiment is further studied in detail by particle model computer simulations, and the results are explained in terms of nonlinear plasma effects. Such problems of interaction between the microwave power beam and the ionosphere must be resolved before space-to-ground and space-to-space power transmission can be realistically developed.

*Prof. Hiroshi Matsumoto is with the*
*Radio Atmospheric Science Center*
*Kyoto University, Uji*
*Kyoto 611, Japan*
*Tel: + 81 (774) 33 2532* *Fax: +81 (774) 31 8463*

## 1. Introduction

On the occasion of the 75th Anniversary of URSI, it is appropriate to re-examine the historical traces of radio utilization for transmitting electric power without wires to a distant destination. Today, radio waves are mainly used for transmitting intelligence and information. However, the threat of the lack of energy resources, especially for electrical energy, is increasing as a result of the population explosion and rapid industrialization over the globe. Therefore, considering that the energy problem on our mother planet Earth, and the crisis of the Earth's environment have become urgent issues for mankind, we need to re-examine the use of radio waves for transmission of clean electrical energy from one place to another, especially from space to the ground, without wires.

There exists a good review paper by W. C. Brown [1] on the history up to 1980 of power transmission by radio waves. We briefly describe, in Section 2, the historical footprints of radio power transmission from a century ago to 1980. In the late 1970's, the NASA/DOE sponsored extensive studies on the Solar Power Satellite (SPS). The NASA/DOE SPS studies program contained an evaluation of the impact of a microwave power beam on the plasma environment of the ionosphere. Section 3 reviews the theoretical studies on Ohmic heating of the ionosphere, the thermal self focusing instabilities caused by the SPS microwave power beam and the related ionospheric heating experiments by ground-based heating facilities. Following these studies, the present author conducted a further study of microwave action on the ionospheric plasma, focusing on the nonlinear resonant scattering of the microwave power beam by magnetized ionospheric plasma. Section 4 presents a theoretical study of the nonlinear resonant interaction of a high-power microwave beam with ionospheric plasma, and a rocket experiment called MINIX (Microwave-Ionosphere Nonlinear Interaction eXperiment) which was conducted to test the theoretical estimate of nonlinear resonant interactions. Extensive computer simulations of nonlinear resonant interactions were carried out by the present author and his colleagues to interpret the MINIX result in terms of nonlinear wave-wave-particle interactions. Section 5 describes the computer simulation and its theoretical interpretation.

In Section 6 we outline two recent microwave-driven airplane experiments: SHARP in Canada and MILAX in Japan. The recent experiment on microwave power beam steering using an active phased array system developed in Japan is described as well. In Section 7 a brief account of a recent rocket experiment and recent ground-to-ground power transmission is given. In Section 8 we conclude with a summary and discussion for future plans of research and development on microwave power transmission (MPT).

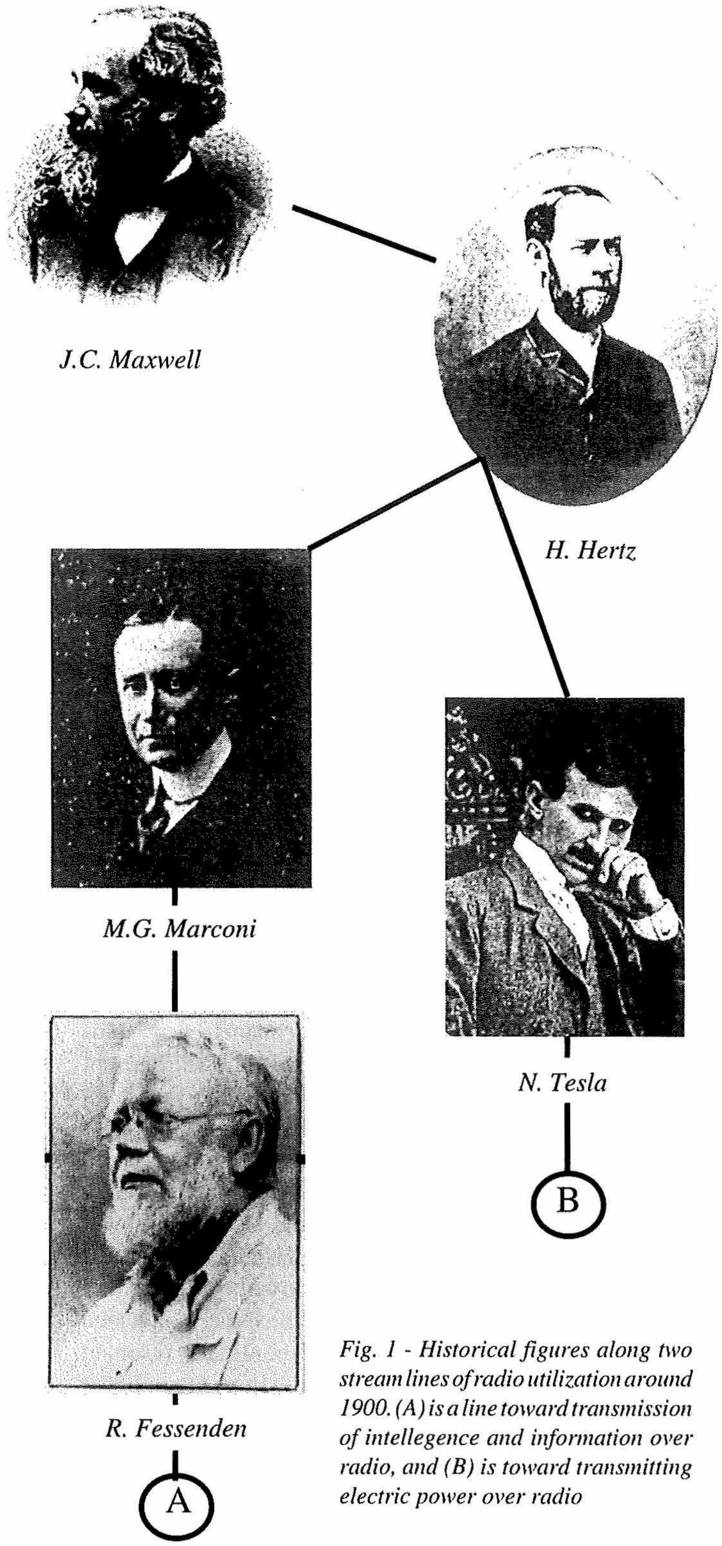



*Fig. 1 - Historical figures along two stream lines of radio utilization around 1900. (A) is a line toward transmission of intellegence and information over radio, and (B) is toward transmitting electric power over radio*

## 2. History of microwave power transmission before 1980

In, 1864, James Clerk Maxwell [2] predicted the existence of radio waves by means of mathematical model. Twenty four years later, in 1888, bolstered by Maxwell's theory, Heinrich Hertz [3] first succeeded in showing experimental evidence of radio waves by his spark-gap radio transmitter. This experiment stimulated Marchese Guglielmo Marconi [4], who first achieved signal transmission by means of radio waves over 10 m in 1895, and over the Atlantic Ocean in 1901. It was Reginald Fessenden [5] who first succeeded in transmitting continuous wave (CW) for voice telecommunications [6]. Thus, the road to modern radio telecommunication was opened up around the turn of the century. Modern radio utilization has been directed into the area of radio telecommunications for transmission of "intelligence and information" over rather weak radio waves. This is one main stream of radio utilization stemming from the Maxwell-Hertz-Marconi-Fessenden work. However, another stream of work was directed toward a different radio wave application. The second stream of radio utilization was an effort to transmit electrical energy by radio to a distant place. These two streams are illustrated in Figure 1.

The idea of radio power transmission was first conceived and experimented on in 1899 by Nikola Tesla [7, 8]. He attempted to distribute ten thousand horse-power under a tension of one hundred million volts. He said "This energy will be collected all over the globe preferably in small amounts, ranging from a fraction of one to a few horse-power. One of its chief uses will be the illumination of isolated homes". He actually built a gigantic coil which was connected to a high mast of 200-ft with a 3 ft-diameter ball at its top (see Figure 2). He fed 300 kW power to the Tesla coil resonated at 150 kHz. The RF potential at the top sphere reached 100 MV.

From the turning point of the century on, however, radio has been used mainly for transmitting intelligence and information, and very few attempts have been made to transmit electrical energy over radio following Tesla's work.

The reason for a lack of interest in radio power transmission in the first half of this century is clear. People were waiting for the invention of a high-power microwave device to generate electromagnetic energy of reasonably short wavelength, since efficient focusing toward the power receiving destination is strongly dependent on the use of technology of narrow-beam formation by small-size antennas and reflectors. In 1930's much progress in generating high-power microwaves was achieved by invention of the magnetron and the klystron. Though the magnetron was invented by A. W. Hull [9] in 1921, the practical and efficient magnetron tube gathered world interest only after Kinjiro Okabe [10] proposed the divided anode-type magnetron in 1928. It is interesting to note that H. Yagi and S. Uda[11], who are famous for their invention of Yagi-Uda Antenna, stressed a possibility of power transmission by radio waves in 1926, thereby displaying profound insight into the coming microwave tube era in

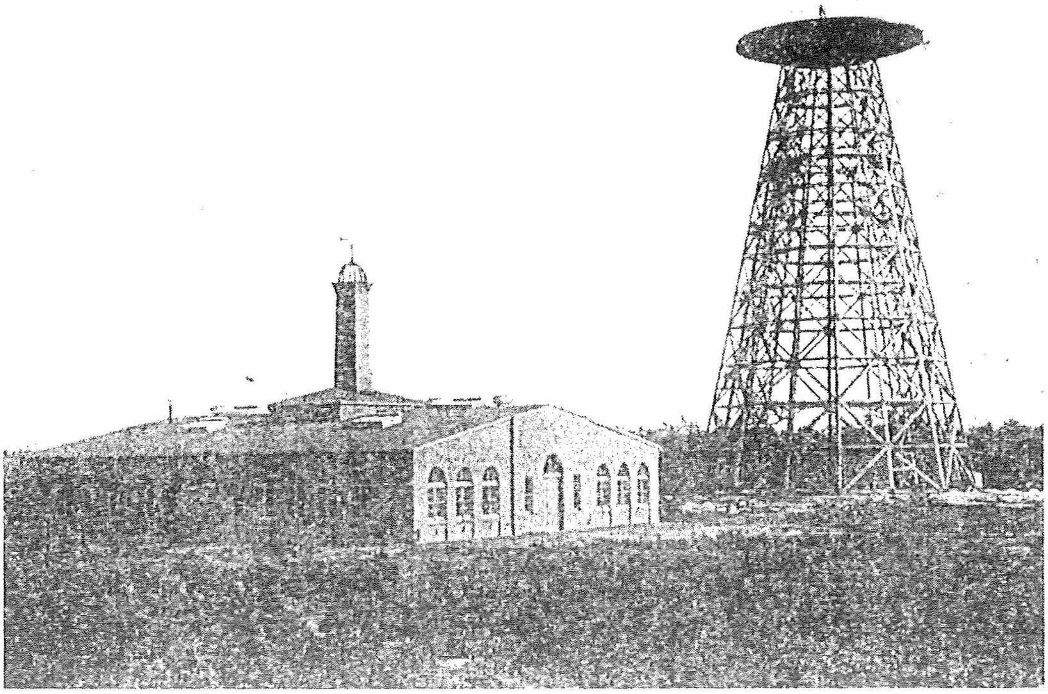


*Fig. 2 - Tesla's experimental laboratory in Colorado Springs with power plant and transmitting tower [from N. Tesla, 1905]*

Japan. Microwave generation by the klystron was achieved by the Varian brothers [12] in 1937 based on the first idea by the Heil brothers in Germany in 1935.
During World War II, development of radar technology accelerated the production of high-power microwave generators and antennas. A CW high power transmission over a microwave beam was investigated in secrecy in Japan. The project, the "Z-project", was aimed at shooting down air-bombers by a high-power microwave beam from the ground, and involved two Nobel winners H. Yukawa and S. Tomonaga [13]. Figure 3 shows a 100 kW magnetron developed at that time, and an introduction of the Japanese Magnetron appeared in "Electronics" of USA immediately after World War II. However, the technology of the high-power microwave tube was still not developed sufficiently for the practical continuous transmission of electric power. Further, no power device was available to convert a microwave energy beam back to DC power until the 1960's.
The post-war history of research on free-space power transmission is well documented by William C. Brown [1], who was a pioneer of practical microwave power transmission (see references in [1]). It was he [14] who first succeeded in demonstrating a microwave-powered helicopter in 1964, using 2.45 GHz in the frequency range of 2.4 - 2.5 GHz reserved for the ISM (Industrial, Scientific and Medical) applications of radio waves (see Figure 5 in [1]). A power conversion device from microwave to DC, called a rectenna, was invented [15, 16, 17] and used for the microwave-powered helicopter. The first rectenna (shown in Figure 3 in [1]) was composed of 28 half-wave dipoles terminated in a bridge rectifier using point-contact semiconductor diodes. Later, the point contact semiconductor diodes were replaced by silicon Schottky-barrier diodes which raised the microwave-to-DC conversion efficiency from 40 % to 84 %[1], the efficiency being defined as the ratio of DC output to microwave power absorbed by the rectenna. The highest record of 84% efficiency was attained in the demonstration of microwave power transmission in 1975 at the JPL Goldstone Facility [18]. Power was successfully transferred from the transmitting large parabolic antenna dish to the distant rectenna site over a distance of 1.6 km. The DC output was 30 kW [18] (see Figure 9 in [10]).
An important milestone in the history of microwave power transmission was the three-year study program called the DOE/NASA Satellite Power System Concept Development and Evaluation Program, started in 1977. This program was conducted for the study of the Solar Power Satellite (SPS), which is designed to beam down the electrical power of 5 to 10 GW from one SPS toward the rectenna site on the ground.
The extensive study of the SPS ended in 1980, producing a 670 page summary document [19]. The concept of the SPS was first proposed by P. E. Glaser [20] in 1968 to meet both space-based and earth-based power needs. An artist's SPS concept is shown in Figure 4. The SPS will generate electric power of the order of several hundreds to thousands of megawatts using photo-voltaic cells of sizable area, and will transmit the generated power via a microwave beam to the receiving rectenna site. Among many technological key issues which must be overcome before the SPS realization, microwave power transmission (MPT) is one of the most important key research issues. The problem contains not only the technological development of microwave power transmission with high efficiency and high safety, but also scientific analysis of microwave impact onto the space plasma environment. We discuss this in the following three Sections.

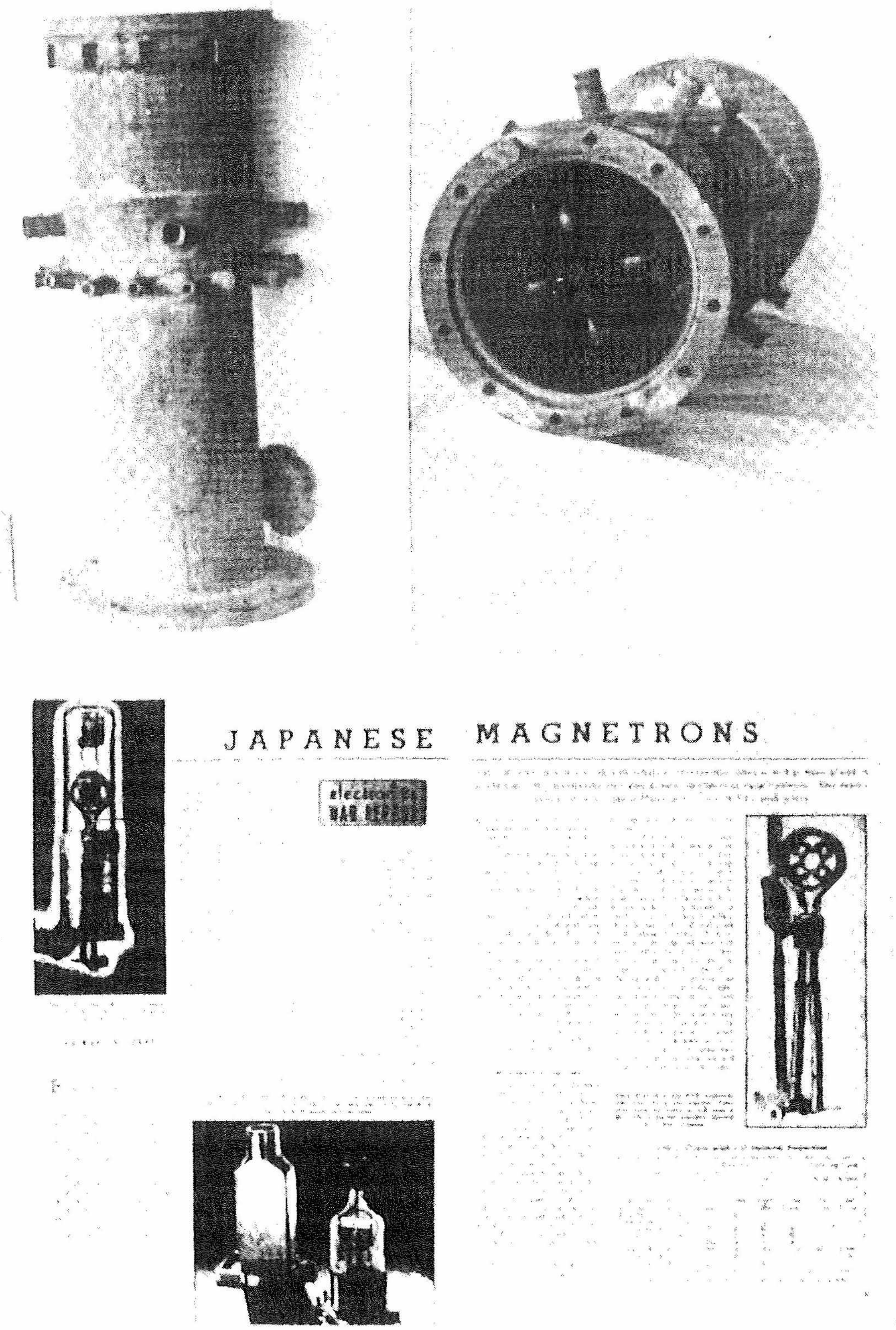



*Fig. 3 - A 100 kW magnetron developed during World War II in Jaspan and a copy of an article appeared in US "Electronics" based on the onformation collected by US GHQ after the end of World War II*

## 3. Review of ohmic heating of the ionospere and thermal self-focusing instability by SPS and a related ionospere heating experiment

The SPS studies program, carried out in the latter half of 1970's under the sponsorship of the US NASA/DOE, contained research on the effects associated with the propagation of intense microwave beams through the ionosphere. Two main effects were pointed out.

The first is the resistive (Ohmic) heating effect due to collisional damping of microwaves. Though the fraction of wave energy absorbed by the ionospheric plasma is very small, the resultant Ohmic heating can significantly modify the local ionospheric thermal balance [21, 22]. The electron temperature is determined by a balance between heating and cooling processes. The heating by microwaves is proportional to square of the electric field of the microwave $E^2$, to square of the ratio of the local plasma frequency and the microwave frequency, $(f_p < f)^2$ and to the collision frequencies $\nu_{ei}$ and $\nu_{en}$ where $\nu_{ei}$ and $\nu_{en}$ are the collision frequencies of electrons with ions and neutral particles, respectively. The collision frequency $\nu_{en}$ increases as the electron temperature increases. Thus Ohmic heating by intense microwaves can be self-amplifying, and thereby result in thermal runaway [22, 23]. Calculation of the balance between the enhanced heating and cooling losses through vibrational excitation of $N_2$ and $O_2$ shows that the electron temperature will be raised several-fold for a microwave power density of 23 mW/cm$^2$ . It is also found that the electron density in the E-layer will be increased by 10 - 20 % due to a decrease in the temperature-dependent recombination rate of $O_2^+$ and $NO_2^+$ , while in the D-layer increase in the attachment rate to $O_2^+$ will cause up to a 50 % reduction in the electron number density [21, 23]. As the ionospheric heating efficiency varies inversely as the square of the radio frequency, ionospheric heating equivalent to that by the SPS microwave beam can be achieved at lower radiated power by heating at a lower frequency. With this idea, experimental tests of the enhanced electron heating theory were carried out by the Rice University Group lead by W. E. Gordon [24], using the 430 MHz radar system at the Arecibo Observatory. A series of underdense $(f_{heater} < f_p)$ HF ionospheric modification experiments using the Platteville high power HF (5-10 MHz) heating facility at Colorado were conducted to simulate the effects of the SPS microwave beam, while monitoring potential impact upon telecommunication system performance [25, 26]. It was concluded that there is no significant difference between the telecommunication system performance of the OMEGA system (VLF), the LORAN system (LF) and the AM broadcast system (MF) between the times when the heating facility was operating and when it was not. Thus, the impact of the SPS intense microwave beam on the performance of VLF, LF and MF telecommunication systems would be minimal [25].

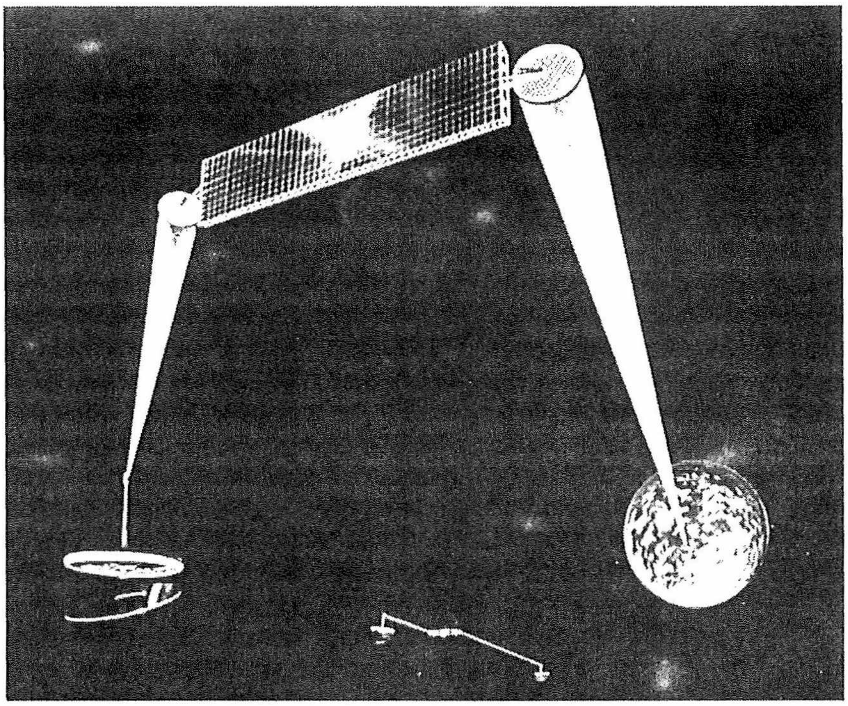


*Fig. 4 - Artist concept of Solar Power Satellite. The power station will transmit electric power to the Earth and possibly to Space Factory, Space Farms and Space Cities in addition*

The second potential effect of the SPS microwave beam onto the ionosphere, studied extensively in the late 1970's, is the phenomenon of thermal self-focusing [27, 28, 29]. Thermal self-focusing takes place as a result of a positive feedback loop. Small natural density fluctuations in the ionosphere cause a spatial variation of the refractive index thereby giving rise to a slight focusing and defocusing of the microwave. This slight inhomogeneous (differential) heating of the ionospheric plasma results in a temperature gradient driving the plasma from the focused region and thereby amplifying the initial density fluctuations. The self-focusing instability will eventually reach a hydrodynamic equilibrium creating large-scale ionospheric irregularities. A self-focusing experiment was conducted at the Arecibo Observatory using intense HF electromagnetic wave under the overdense condition $(f_{heater} < f_p)$ [30]. The experimental result showed clear self-focusing striations and large-scale structuring of the ionosphere. However, it is noted that these experiments were all conducted under the overdense condition and not the underdense condition.

The two main effects described above are caused basically by the non-resonant heating of the plasma by the intense electric field of the SPS microwave. Resonant interactions of the microwave beam with the ionospheric plasma are another interesting research area. Parametric excitation of ionospheric plasma waves was studied for multiple-frequency electromagnetic radiation. The interaction between two high frequency microwaves and a multiple of the ionospheric resonant frequency (such as the electron plasma frequency) was studied [31, 32] utilizing a model of an up-going pilot microwave signal operating at a frequency slightly separated from the downcoming power beam, and beat waves generated within the finite width of the main downcoming energy beam.

The US government suspended the NASA/DOE program study partly due to budget problems and partly because of the apparent recovery from the oil shock in the 1970's, although the NASA/DOE final report concluded that "no factors that would preclude the SPS research and development are found in the light of the highly potential future energy crisis".

## 4. Theory and rocket experiment (MINIX) on nonlinear plasma wave excitation by microwave power beam in the ionosphere

Most of the experiments conducted in the 1970's on the potential impact of the SPS microwave onto the ionosphere were conducted by the ground-based heating facility using much lower frequency than the SPS microwave frequency of 2.45 GHz. Therefore, the realistic resonant interaction of the SPS microwave with natural resonance frequency bands of the order of several MHz to several kHz may not have been adequately estimated. The resonant interaction naturally involves electrostatic waves which can be detected much more easily by in-situ measurement than by ground-based radar diagnostics. Based on such idea, an in-situ rocket experiment of radiating an intense 2.45 GHz microwave into the ionospheric plasma was proposed by the present author in the early 1980's in Japan. The project was named MINIX which stands for Microwave Ionosphere Nonlinear Interaction eXperiment.

The plasma response to the injected microwave power beam was monitored by diagnostic sensors and receivers onboard the rocket. Preceding the MINIX experiment, Matsumoto [33, 34] numerically evaluated the growth rate of the resonant instabilities of electron plasma waves and ion acoustic waves as a result of Raman and Brillouin scattering of the SPS intense microwave under model ionospheric plasma parameters. The growth rate of Langmuir waves as a result of the Raman scattering of the microwave is given [34] by

$$\gamma_e = -\frac{1}{2}\left[\Gamma_e + \Gamma_2 - \sqrt{(\Gamma_e + \Gamma_2)^2 + \frac{\Pi_e^2}{\omega^2} k^2 v_0 \sin^2 \varphi}\right] \quad (1)$$

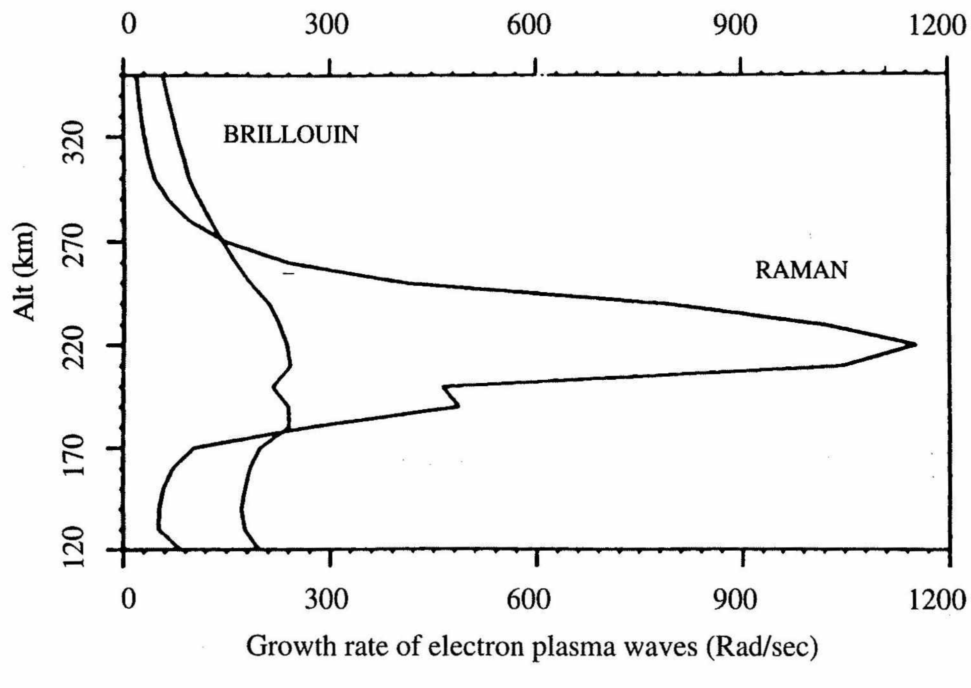



*Fig. 5 - Growth rates of Langmuir waves excited by the Roman scattering of the SPS microwave, and fo ion acoustic waves excited by the Brillouin scattering of the SPS microwave. The microwave field $E_0$ is assumed to be 220 V/m (from [33]).*

where $\Pi_e$ is the electron plasma frequency and $G_e$ is the damping rate of Langmuir waves; the latter includes two terms resulting from the Landau damping and collisional damping. The quantity $G_2$ represents a collisional damping of the back-scattered microwave with a frequency of

$$\omega_2 = \sqrt{\Pi_e^2 + c^2 (k - k_0)^2}$$

$v_0 = eE_0 / (m_e \omega_0)$ is the sloshing velocity of electrons by the SPS microwave, and j is an angle between k and $E_0$. The suffix o denotes the quantity associated with the SPS microwave. A similar expression for the growth rate $G_i$ for ion acoustic waves was also obtained [34] (not shown). Numerical calculation of $G_e$ and $G_i$ versus the ionospheric altitude (see Figure 5) showed that Langmuir waves are easily excited by the SPS microwave, while the growing time of ion acoustic waves is much slower. It is noted that the growth rate expression (1) gives only the initial growth rates as a result of nonlinear interaction between the three waves: the incident intense microwave, the back-scattered microwave and the excited Langmuir wave. The nonlinear coupling of the three waves should satisfy both energy and momentum conservation in the form of

$$\omega_0 = \omega_1 + \omega_2 \, , \, k_0 = k_1 + k_2 \qquad (2)$$

where $w_j$ and $k_j$ (j= 0, 1, 2) are angular frequency and wave number respectively, and the subscripts 0, 1 and 2 represent the incident microwave, the back-scattered microwave, and the excited Langmuir wave, respectively.

The MINIX rocket experiment was carried out by a Japanese sounding rocket S-520-6 of ISAS (Institute of Space and Astronomical Sciences) on August 29 in 1983 [35, 36, 37, 38]. The experiment was conducted with a mother-and-daughter rocket system. Figure 6 shows an artist's concept of the experiment, while Figure 7 represents the ground testing of the mother-daughter system with the real flight model payloads. Two sets of high power (~ 830 watts) magnetrons (reinforced versions of Toshiba Magnetron 2M172 for home use oven) were installed on the mother section of the rocket payload and were connected to the truncated waveguide antenna (see Figure 8) to radiate intense microwave with a frequency of 2.45 GHz. The DC power supply to the magnetrons was given by onboard batteries. A plasma diagnostic package was installed on the daughter unit of the rocket. It was composed of a VLF wide band receiver, an HF sweep frequency receiver, a geomagnetic aspect sensor, electron density and temperature meter, and a microwave receiver. Four rod antennas with a length of 2 m were extended out from the daughter rocket in the top plane of the daughter unit to detect plasma waves which are expected to be nonlinearly excited by the injected intense microwave. The HF sweep frequency receiver

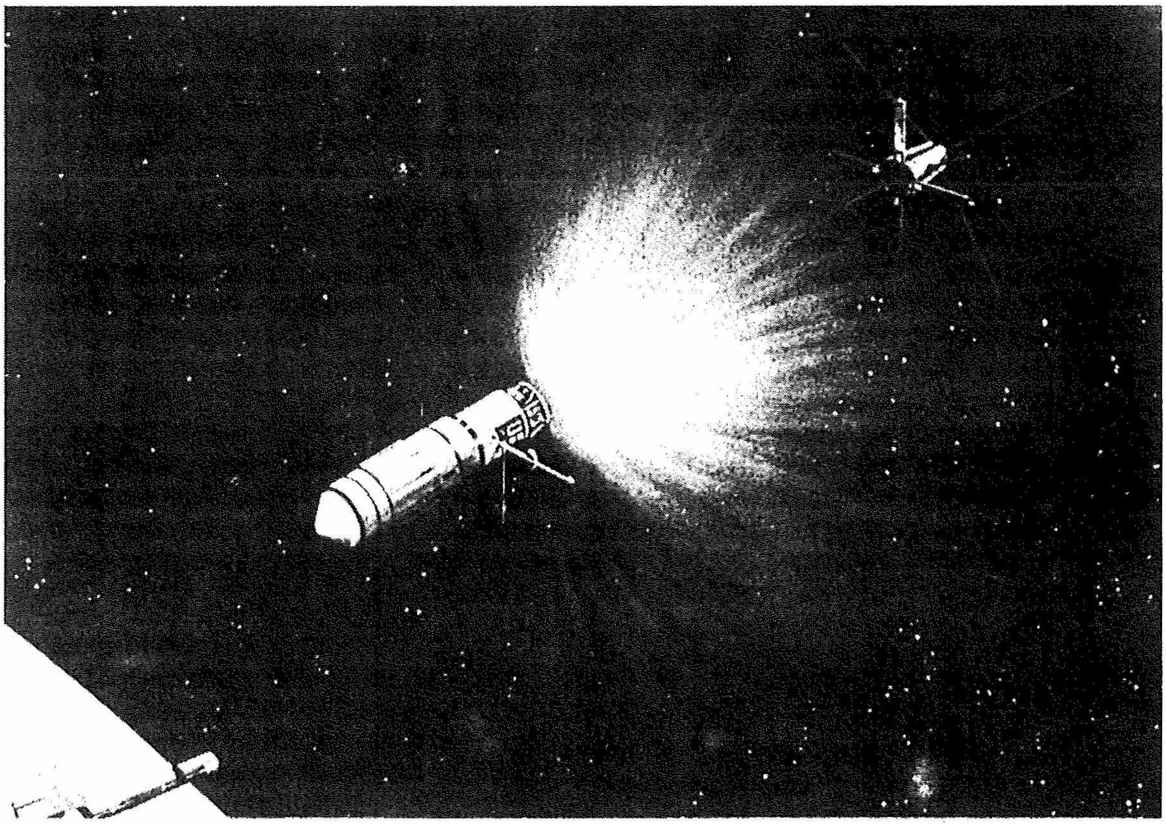


*Fig. 6 - An artist concept of the MINIX rocket experiment. A high power microwave (~ 830 watts) was radtiated from the truncated wave guide antenna toward the daughter rocket section by which the nonlinear responses of the ionospheric plasma were measured.*

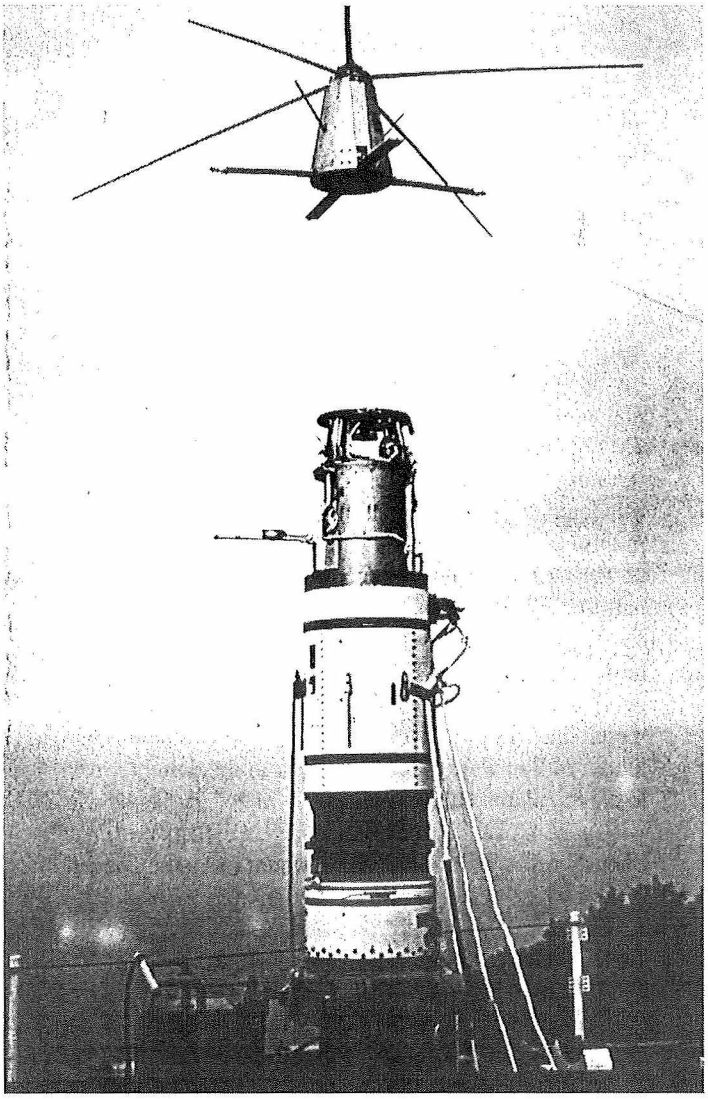


*Fig. 7 - A photograph of pre-flight test scene of the MINIX payload at launching site KSC in Japan. The daughter unit with various sensors and diagnostic packages was separated by a crane from the mother section. A truncated wave guide antenna used for the side ward transmission is seen in the mother section*

covered a frequency range from 100 kHz up to 18 MHz with a sweeping time of 250 msec. The VLF receiver covered a fre-quency range from 60 Hz up to 25 kHz. Four paddles were extended out at the bottom level of the daughter unit and were used for rectennas. The arrangement of these antennas and paddles is shown in Figure 7.

Figure 9 shows the configuration of the payload instrumentation on board S-520-6 rocket. The mother unit, which is the section below the level of separation plane in Figure 9, carried the power supply composed of the DC-battery and DC-DC converter, the microwave transmitter with a time sequencer, two sets of truncated wave guide antennas, a Langmuir probe, a wide-band telemetry set, a neutral gas plume of $N_2$ gas, and a TV monitor camera for monitoring the in-flight separation of the daughter unit. The neutral gas plume was prepared to create an artificially simulated D-layer with high collision frequency at the height of the lower F layer near the apex of the rocket orbit.

Figure 10 shows the trajectory of the S-520-6 rocket. The MINIX experimental time sequence along the orbit is also shown in the figure. The thick line parts along the orbit indicate the time interval of microwave transmission. The experiment was conducted under three different modes: The first mode (I) was devoted to the study of Ohmic heating in the ionospheric D-layer and lower E-layer. In this experimental mode, the microwave was transmitted continuously for a long duration of 10 seconds. Above the altitude of 100 km, the second mode (II) was in operation where the microwave was transmitted intermittently with a 5 sec transmission followed by a 5 sec pause-of-transmission period for the measurement of the plasma response. Under the mode (II), the microwave was radiated radially, i.e., in the direction perpendicular to the spin axis of the rocket. After the separation of the daughter unit near the apex of the orbit around 220 km altitude, the experimental mode was switched to the mode (III) where the microwave was transmitted forward in the axial direction from the truncated wave guide antenna facing the leaving daughter unit (see Figure 6), with the same ON-OFF time sequence as that in the mode II. The modes (II) and (III) were mainly prepared to detect the theoretically predicted

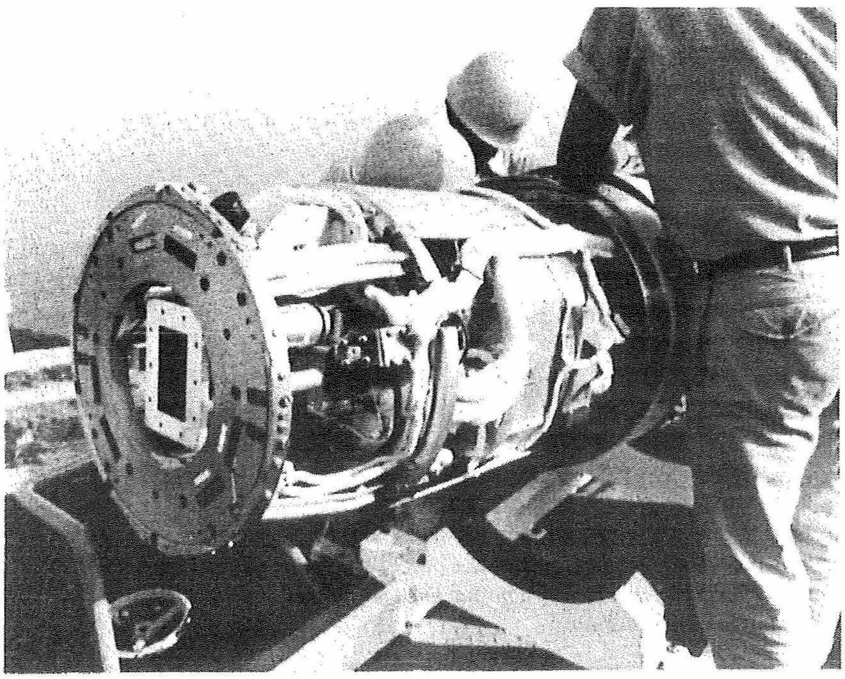


*Fig. 8 - The truncated wave guide antenna aperture used for the forward transmission of 2.45 GHz microwave onboard the MINIX payload.*

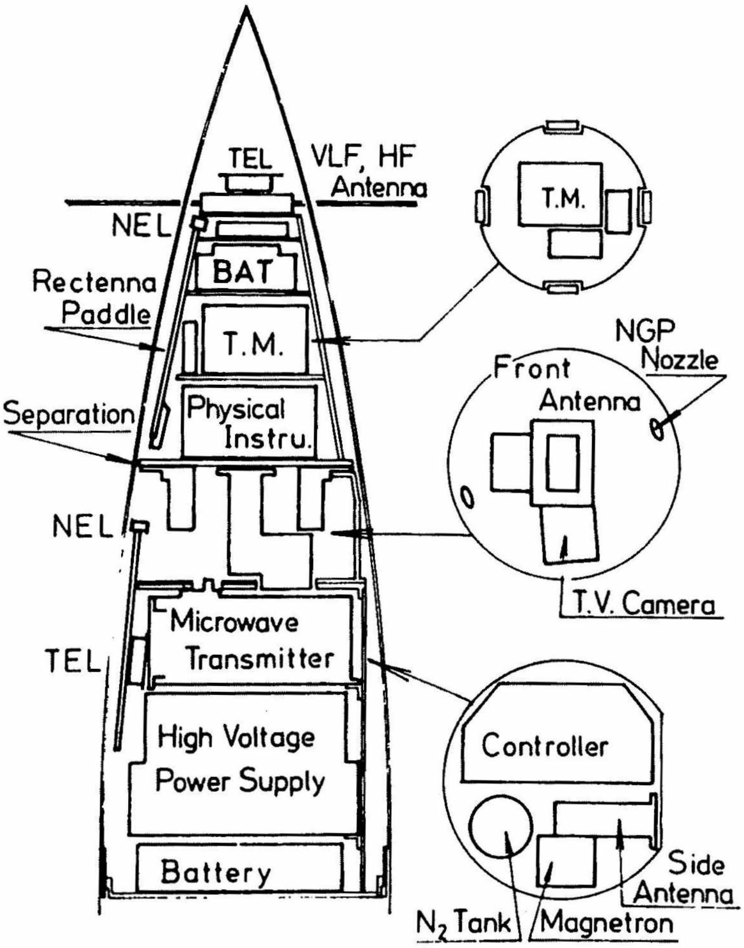



*Fig. 9 (left) - Payload configuration of MINIX rocket experiment. Mother and daughter sections are separated by spring coil during the flight in the ionosphere*

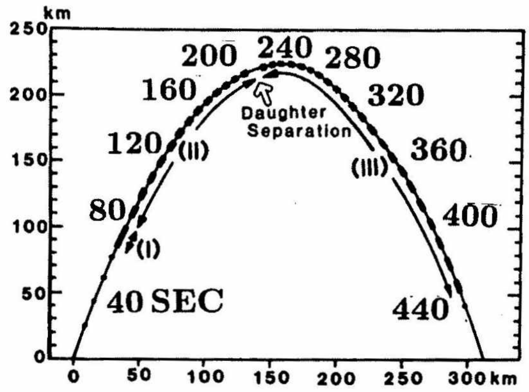



*Fig. 10 (above) - The trajectory of S-520-6 rocket and the time sequence of the MINIX along the orbit*

excitation of plasma waves through nonlinear resonant interaction of the transmitted intense microwave.

All of the instrumentation on board the MINIX rocket worked perfectly and provided useful data. The measurement of the variation of electron temperature showed no temperature difference between ON and OFF periods of the microwave transmission during the mode (I). It turned out later with the use of pre-launch plasma chamber data on plasma heating by MINIX transmitter [39] that the estimated maximum temperature increase due to the Ohmic heating

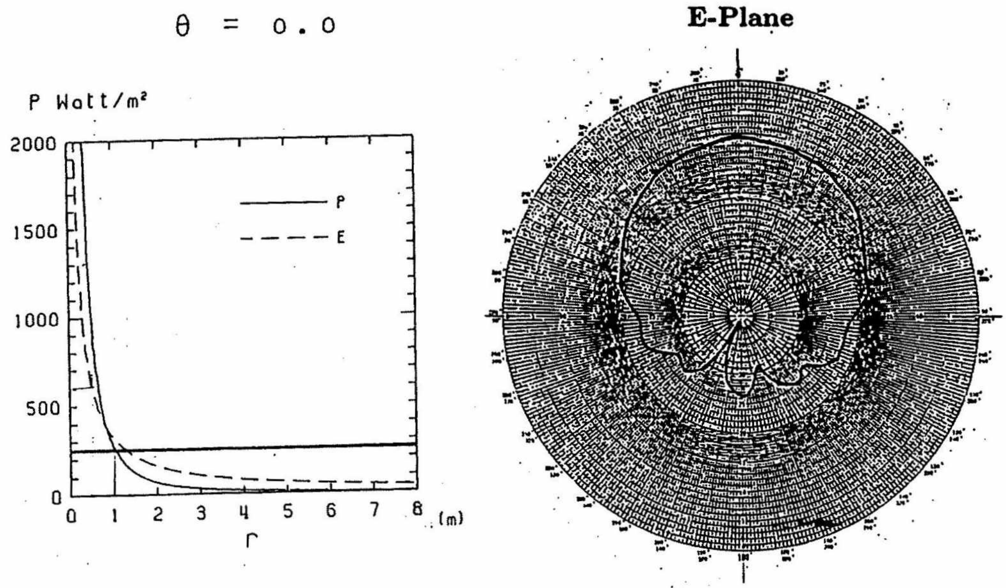



*Fig. 11 - Power density and electric field intensity of the radiated microwave as a function of distance from the MINIX truncated wave guide antenna. The right panel shows the antenna pattern of the transmitting antenna.*

for the MINIX situation is below 100 K which is lower than the detectable limit by the Langmuir probe used in the MINIX. It is also noted that the effective time of microwave exposure to the ionospheric plasma particles was too short compared to the characteristic time for the Ohmic heating. The plasma volume illuminated by the intense microwave with a power density which is comparable to or higher than that of the SPS microwave is limited to within the distance of 2 m from the center of the truncated wave guide antenna. The power density and the electric field intensity of the microwave radiated by the magnetron plus wave guide antenna system are shown in Figure 11.

The sweep frequency analyzer (SFA) in the HF range measured the spectrum of ionospheric plasma waves and broadcasting waves reaching the rocket altitude from the ground. The SFA detected strong plasma waves at certain frequency bands when and only when the microwave was transmitted. The plasma wave spectra from 100 kHz to 18 MHz are shown in Figure 12. The upper spectral curve is for the period of the microwave transmission, while the lower is for the no-transmission period. The spectra above 10 MHz are not different from each other, but those below 10 MHz show a clear difference. The shaded part shows the enhancement of the spectral components due to additional excitation of the plasma waves by the intense microwave. In Figure 12, the local electron cyclotron frequency $F_H$ and

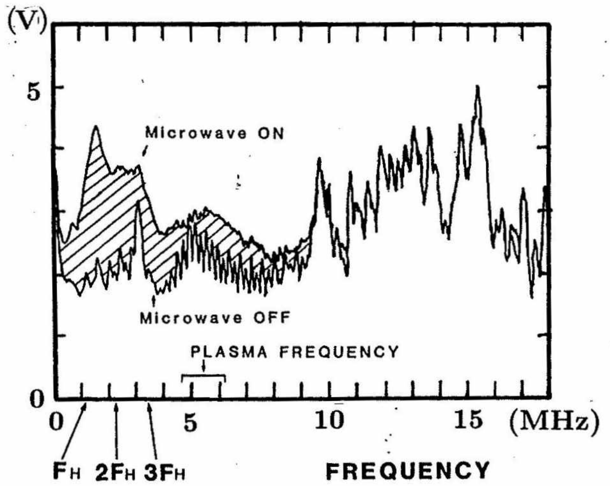



*Fig. 12 - Plasma wave spectra observed by HF wave receiver onboard the daughter unit of the MINIX rocket experiment. The upper spectral line is for the time when the intense 2.45 GHz microwave is transmitted into the ionospheric plasma. The lower spectral line is for the time when the microwave is not transmitted. The spectral peaks above 10 MHz are due to the broadcasting waves reaching from the ground.*

its harmonics and the local electron plasma frequency are indicated on the horizontal frequency axis. The error bar in the electron plasma frequency was due to the ambiguity in determining the number density and temperature from the Langmuir probe. The enhancement in the spectral intensity is seen in two different characteristic frequency ranges. One is seen at odd half harmonics of the local electron cyclotron frequency in the range from 1.5 MHz to 3.5 MHz. The frequency range of these waves did not change with altitude as the local electron cyclotron frequency is almost constant in the orbit range of the rocket. Taking into account the observed frequency range and discrete peaks at odd half cyclotron frequencies, we explained these waves in terms of electron cyclotron harmonic (ECH) waves. The other enhancement is seen above the local electron plasma frequency ranging from 5 MHz to 8 MHz. The frequency range shifts upward with the altitude of the rocket, and accordingly with the increasing plasma density in the E- to F-layers of the ionosphere. We explained the enhancement of this frequency above the local electron plasma frequency in terms of Langmuir waves due to the excitation by the intense microwave through Raman scattering.

The VLF wide band receiver could not pick up the expected ion acoustic wave through Brillouin scattering. This was not surprising because the theoretically calculated [34] growth rate of the ion acoustic waves is not large enough to make these waves grow to the observable amplitude within a short time illuminated by the microwave at a fixed point of the ionosphere. The illuminated time was about 1 msec, which is calculated by the size of the plasma volume illuminated by the intense (E > 200 V/m) microwave, while the theoretically calculated growing time is longer than 10 msec.

The result of the MINIX on nonlinear plasma wave excitation due to intense 2.45 GHz microwaves was not much different from what had been predicted by the theoretical calculation. A similar but more complicated expression of the growth rate of the electron cyclotron waves including upper hybrid waves was obtained based on the nonlinear kinetic theory of resonant three-wave coupling[40, 41]. It is expressed as

$$\gamma_{ECH} = \sqrt{|\beta_1\beta_2|}E_0 \qquad (3)$$

where $E_0$ is the intensity of the incident intense microwave, and $b_1$ and $b_2$ are the coupling coefficients defined by

$$\frac{dE_1}{dt} = i\beta_1 E_2^* E_0 \qquad (4)$$

$$\frac{dE_2}{dt} = i\beta_2 E_0 E_1^* \qquad (5)$$

where $E_1$ and $E_2$ are the electric field of the backscattered microwave and the excited electron cyclotron wave. With a lengthy calculation and by use of the resonant condition (2), we obtain the final complicated expression of $b_1$ and $b_2$ (eqs. (80) - (93) in [41]) which contains both tensor elements of the linear dispersion relation and the integral containing resonant terms at higher harmonics of electron cyclotron frequencies. Numerical calculation of the growth rate shows that the electron cyclotron harmonic waves are also excited by the intense microwave under ionospheric conditions.

Despite the qualitative agreement with these theoretical predictions, the MINIX result showed the following features which are not consistent with the above theory. The first point is that the observed spectrum of the excited Langmuir waves are not monochromatic, nor quasi-monochromatic, but of broad-band nature in contrast to the monochromaticity predicted by theory based on the resonance condition (2). The second point is that the intensity of the electron cyclotron waves is higher than the Langmuir wave intensity. The second point clearly contradicts the theoretical prediction. The saturation level of the nonlinearly excited plasma waves (both Langmuir and ECH waves) through the nonlinear resonant three wave-coupling is proportional to the growth rate divided by the product of the coupling coefficients $b_0 b_1$. The theory shows that the saturation level of the Langmuir waves should be larger than that of the ECH waves. However, the amplitude of the Langmuir waves excited by the microwave in the MINIX was smaller than that of the ECH. Thus, these two experimental features are not well explained by the conventional nonlinear resonant three-wave coupling theory. In the next section, we will describe our attempt to overcome this contradiction by the help of computer simulations.

## 5. Computer Simulation of Nonlinear Interaction of Microwave Power Beam with Space Plasma

Traditionally, methods of scientific research have involved a mutual interplay between experiment and theory. Experiment attempts to collect "factual" information through repeated or controlled measurements. Theory, on the other hand, tries to order accumulated factual knowledge and thereby propose a new paradigm of description of physical processes. New theoretical descriptions and new experiments challenge each other in turn. Such feedback between theory and experiment is generally on-going. However, as in the case of MINIX, theory and experiment sometimes show a gap which cannot be easily overcome because of difficulties of repeated experiments and/or a limit to the applicability of theory for highly nonlinear and complex processes. In order to fill such a gap, a third new approach become available with the advent of modern high speed computers. This third approach is called computer simulation or computer experiment. The basic idea of computer simulation is to simulate the physical behavior of complicated natural systems by solving an appropriate set of mathematical equations based on an accepted and fundamental physical mathematical model. As one can easily change the set of the mathematical equations as well as the boundary and initial conditions, the computer simulation can be a perfectly controlled experiment. The main advantage of computer simulations is that complicated physical systems including nonlinearity and/or strong inhomogeneity can be dealt with as easily as simpler, linear and homogeneous systems can be treated. The International Union of Radio Science (URSI) has played a significant role of accelerating the establishment of this third research tool in Radio Science, especially in the field space plasma wave studies through its activities in Commission H [43].

In order to understand the MINIX result and the nonlinear interaction of the intense microwave power beam with the ionospheric plasma (which contradicts the nonlinear resonant three wave coupling theory) we performed a series of computer simulations. The computer code used for this purpose is a particle-model simulation code called KEMPO [43]. KEMPO solves Maxwell's equations and simultaneous equations of motion of several tens of thousands to several millions of super-particles. The one-dimensional version of the KEMPO code is now available in the public domain [42]. As the MINIX result showed that there exist two different electrostatic (ES) plasma waves with two different propagation angles relative to the geomagnetic field, we have set up two different simulation models. One is the case where all of the incident intense microwave (or the "pump" electromagnetic (EM) wave in terms of nonlinear resonant three-wave coupling), the back-scattered microwave (or the back-scattered "idler" EM wave ) and the excited ES plasma wave are assumed to propagate along the external magnetic field $B_0$. The other model assumes that they propagate in a perpendicular direction to $B_0$. The former and the latter cases are referred to as the "parallel case" and the "perpendicular case" hereafter. The energy and momentum conservation relation expressed by Eq.(2) can be graphically shown by a parallelogram in the *w-k* diagram. Figure 13 is one example of the parallelogram in the perpendicular case. The common simulation

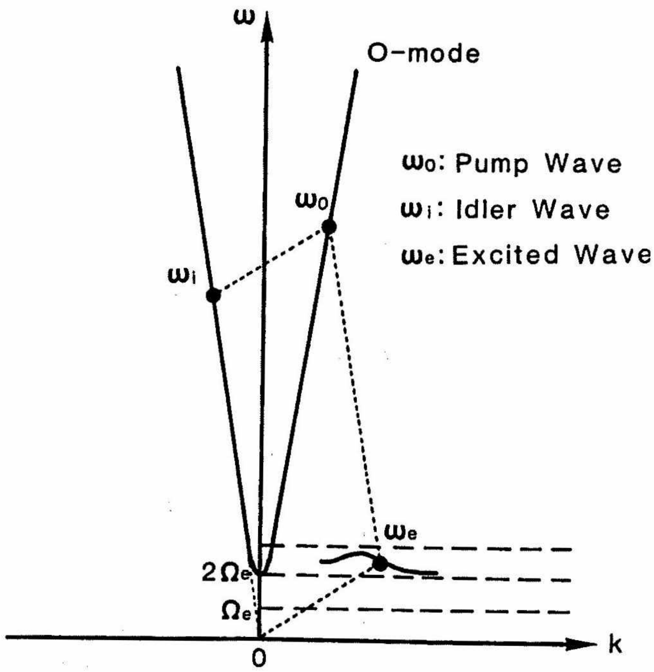



*Fig. 13 - A parallelogram in the ω-k diagram showing the resonant interaction between two electromagnetic waves (microwaves) and electron cyclotron harmonic (ECH) wave.*

parameters for both cases are listed in Table 1. Figure 14 shows an example of a temporal variation of the excited ES wave intensity, and that of the kinetic energy of electrons for both the parallel and perpendicular cases. The upper and lower panels correspond to the parallel and perpendicular

<Plasma Parameters>

| | | |
|---|---|---|
| Speed of Light | c | 50 |
| Electron Plasma Angular Frequency | $\Pi_e$ | 2.0 |
| Electron Cyclotron Angular Frequency | $\Omega_e$ | 1.0 |
| External Magnetic Field Strength | $B_{ext}$ | 1.0 |
| Charge to Mass Ratio of Electrons | $q_e/m_e$ | -1.0 |
| Total Number of Electrons | $N_p$ | 32768 |
| Parallel Thermal Speed of Electrons | $v_{th\parallel}$ | 1.0 |
| Perpendicular Thermal Speed of Electrons | $v_{th\perp}$ | 1.0 |
| Dielectric Constant | $\varepsilon_0$ | 1.0 |

<System Parameters>

| | | |
|---|---|---|
| Time Step | $\Delta t$ | 0.01 |
| Grid Spacing | $\Delta x$ | 1.0 |
| Number of Grids | $N_x$ | 2048 |

<Parameters of Injected EM Wave>

| | | |
|---|---|---|
| Angular Frequency | $\omega_0$ | 18.5~23.4 |
| Wave Number (Mode Number) | $k_0$ | 15~19 |
| Wave Magnetic Field Strength | $B_\omega$ | 0.5 |

*Table 1 - Numerical parameters for simulations presented in Figure 14*

cases, respectively. In the parallel case, an L-mode EM wave is adopted as the pump. The L-mode wave couples with a back-scattered L-mode EM wave and a Langmuir wave (LW). This coupling is referred to as L-L-LW coupling. A similar result is obtained (not shown) for R-R-LW wave coupling with the R-mode pump wave. In the perpendicular case, an X-mode EM wave is used as the pump. The X-mode pump wave is scattered producing a back-scattered X-mode EM and the ES ECH wave through the X-X-ECH coupling. A similar result is obtained for the O-O-ECH coupling (not shown). The ECH wave excited by the X-mode EM wave, shown in the lower panel, is one of the multiple harmonic modes of ECH waves. It is the upper hybrid mode that shrinks to the upper hybrid oscillation when its wave number tends to zero. As seen in Figure 14, both the LW and ECHW grow exponentially in the early phase. The numerically measured growth rates of the LW and ECHW are $g_{LW} = 0.07$ and $g_{LW} = 0.04$, respectively.

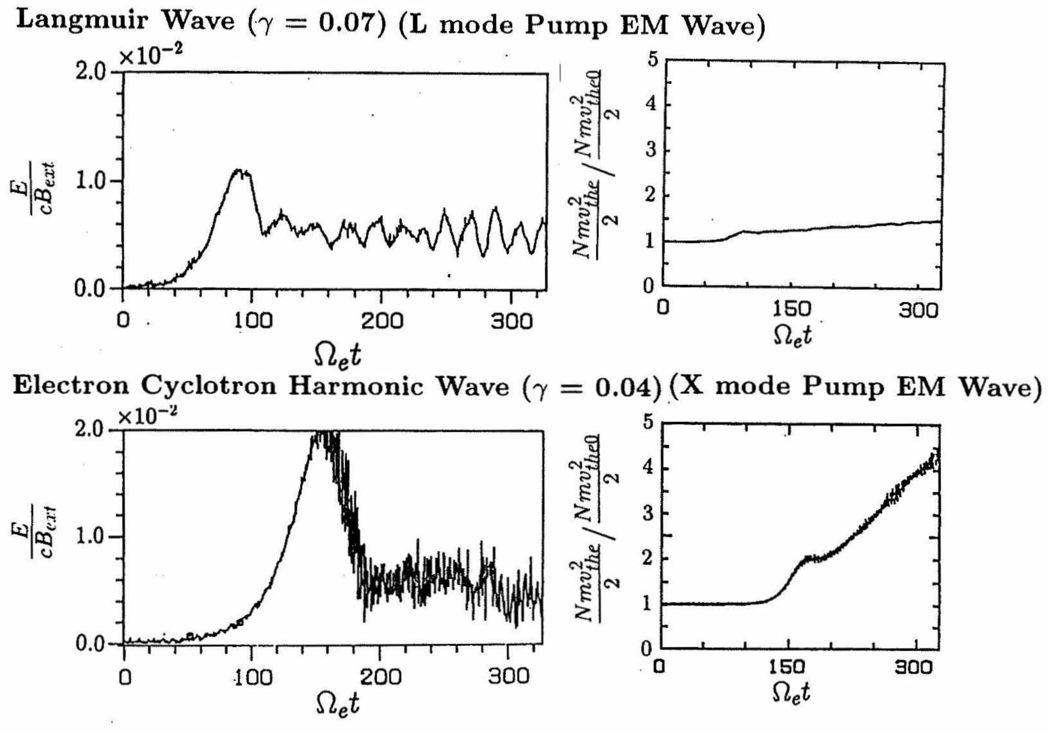



*Fig. 14 - The left column shows time evolution of the electric field of electrostatic (ES) plasma waves excited nonlinearly by the pump electromagnetic (EM) waves. The right column shows the corresponding time history of particle thermal energy. The upper and lower panels are for the parallel and perpendicular cases, Langmuir Wave is excited by an L-mode EM pump wave while ECH Wave is excited by an X-mode EM pump wave in the perpendicular case.*

These growth rates agree well with the theoretically predicted value of the growth rate based on the nonlinear resonant three-wave coupling theory.

In contrast to a good agreement of the growth rates of both LW and ECHW, the saturation levels of the LW and of the ECHW contradict the theoretical prediction as seen in Figure 14. The LW saturation level is almost half of that of the ECHW. The simulation result does not agree with theory, but agrees well with the result of the MINIX rocket experiment. Thus, the computer simulation could reproduce the inconsistency between the rocket experiment and theory. One of the merits of computer simulations is that one can make the diagnostics as detailed as one wishes from the information stored in memory. In particular, compared with rocket experiments, one can extract detailed information on particle dynamics which is normally very difficult to measure with a sufficient time resolution. On the right panels in Figure 14, plotted are the time history of the particle kinetic energy in the simulations. In both the Langmuir wave and ECHW cases, the particle thermal energy increases exponentially according as the electric field E grows exponentially, until the electric field reaches the saturation. This initial exponential increase of the kinetic energy, however, does not actually cause the thermalization of electrons, but reflects the sloshing motion synchronizing with the electric oscillation of the ES wave. However, at the time of the wave saturation, those particles begin to be thermalized through phase-mixing. The rise in the particle thermal energy and the fall in the electric field intensity after the saturation show that the particles start to extract energy from the ES wave and are heated.

Examination of the thermal energy increase helps us to understand why the saturation levels of the electric field of the ES waves are much lower than those estimated by theory, and why the measured Langmuir wave intensity is lower than that of the ECHW. To confirm the result of the first single simulation on the growth rate and saturation levels, we ran a series of simulations with different frequencies of the pump EM wave. The simulation parameters for the simulation series are listed in Table 2. The result is shown in Figure 15. The solid and dashed lines show theoretical values of the LW and ECHW, respectively. Those of the LW and ECHW observed in the simulations are plotted by square and circular symbols, respectively. The agreement of the growth rates (Figure 15(a)) between theory and simulations were confirmed by this series of simulations. On the other hand, the saturation levels observed in the series of simulations are much lower than the theoretical prediction shown in Figure 15(b). The larger gap between the theory and simulation for the Langmuir wave compared to the ECH wave results in the reversal of the saturation levels thereby contradicting the theoretical prediction. The saturation at lower intensity or at earlier time of interaction for the Langmuir waves turns out to be the result of the breakdown of the resonant condition (Eq.(2)). As seen in Figure 14, the plasma is heated by the nonlinearly growing ES wave leading to heating of the plasma. Therefore, the fact that the earlier saturation than predicted by the three-wave coupling theory should be related to the plasma heating. We then examined the change of the dispersion characteristics as a function of the electron temperature. The result shows that the dispersion relation of the Langmuir waves has higher susceptibility to the change of the electron temperature. Figure 16 shows the change of the dispersion relation in the *w-k* diagrams when the electron temperature is doubled. As indicated in the figure, the increment of the frequency Dw, which represents the frequency mismatching, is larger for the LW than for the ECHW. The frequency mismatching given by $Dw = w_0 - w_1 - w_2$ influences the growth of the excited ES wave through [44],

$$\gamma = \sqrt{|\beta_1 \beta_2| E_0^2 - \Delta\omega^2} \qquad (6)$$

<Plasma Parameters>

| | | |
|---|---|---|
| Speed of Light | c | 50 |
| Electron Plasma Angular Frequency | $\Pi_e$ | 2.0 |
| Electron Cyclotron Angular Frequency | $\Omega_e$ | 1.0 |
| External Magnetic Field Strength | $B_{ext}$ | 1.0 |
| Charge to Mass Ratio of Electrons | $q_e/m_e$ | -1.0 |
| Total Number of Electrons | $N_p$ | 32768 |
| Parallel Thermal Speed of Electrons | $v_{th\parallel}$ | 1.0 10$^{-4}$ |
| Perpendicular Thermal Speed of Electrons | $v_{th\perp}$ | 1.0 10$^{-4}$ |
| Dielectric Constant | $\varepsilon_0$ | 1.0 |

<System Parameters>

| | | |
|---|---|---|
| Time Step | $\Delta t$ | 0.01 |
| Grid Spacing | $\Delta x$ | 1.0 |
| Number of Grids | $N_x$ | 2048 |

<Parameters of Injected EM Wave>

| | | |
|---|---|---|
| Angular Frequency | $\omega_0$ | 5.0 ... 22.5 |
| Wave Number (Mode Number) | $k_0$ | 33 ... 109 |
| Wave Magnetic Field Strength | $B_\omega$ | 0.5 |

*Table 2 - Numerical parameters for a series of simulations presented in Figure 15*

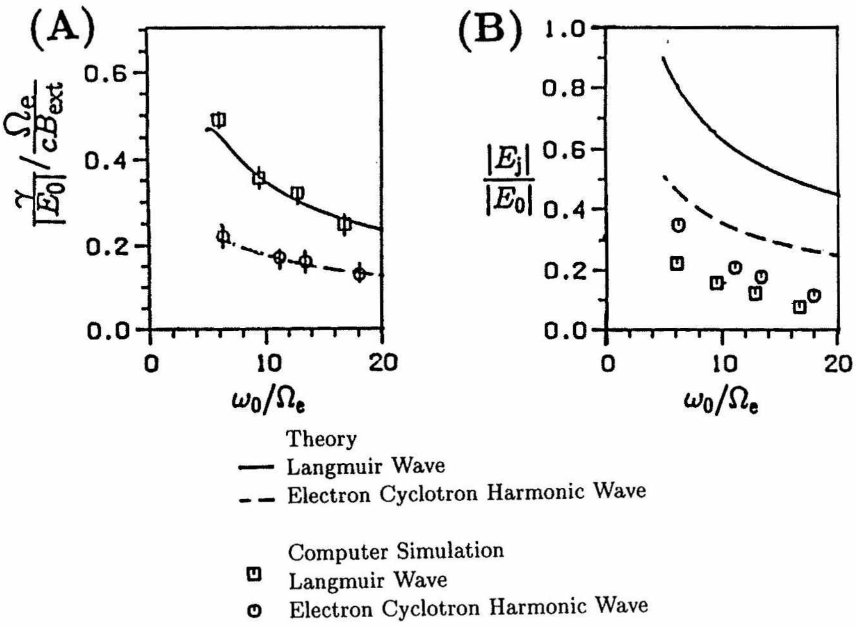



*Fig. 15 - Comparison of the growth rates of the ES waves and their saturation levels between theory (indicated by lines) and computer simulations (indicated by symbols). The solid line and square symbols are for Langmuir Wave. The dashed line and circular symbols are for the ECHW.*

Therefore, the change of the dispersion relation, or the breakdown of the resonance condition for three-wave coupling due to plasma heating explains why the Langmuir waves reached saturation earlier and thereby stayed at a lower intensity than ECHW.

Another discrepancy concerning the nonlinear excitation of plasma waves by the microwave power beam revealed by the MINIX rocket experiment was the broad band nature of the excited Langmuir waves. The excited Langmuir waves did not show the line spectrum as predicted by the theory (Eq. (2)), but showed a broad spectrum. This can be understood in the light of the results of the computer simulation. The previous example of the simulation shows an effective plasma heating by the excited ES waves which self-quenches the wave-amplitude of the ES waves. This means that the frequency and wave number of the triplet ($w_0$, $w_1$, $w_2$) and ($k_0$, $k_1$, $k_2$) changes in time so that a new triplet automatically satisfies Eq. (2) for the heated plasma. A schematic illustration of this interpretation is given in Figure 17. Such sequential shift of the resonance frequency can explain the broad band nature of the observed Langmuir waves in the MINIX. Concerning the ECHW, another type of nonlinear three-wave coupling is possible for the electron cyclotron harmonic waves, as illustrated in Figure 18. In this case, multiple triplets ($w_0$, $w_1$, $w_2$), ($w_0$, $w_3$, $w_4$), ($w_0$, $w_5$, $w_6$) can satisfy the energy and momentum conservation simultaneously as a result of multiple branches of the dispersion relations in the $w$-k diagram. This feature can explain the MINIX multiple spectral peaks of the ECHW with a spacing of the order of the local electron cyclotron frequency.

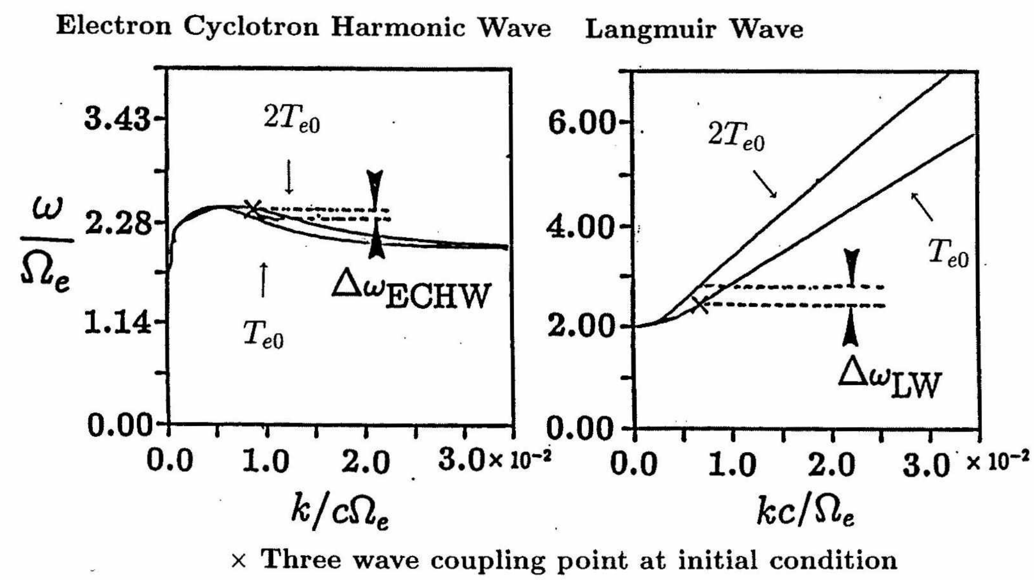



*Fig. 16 - Comparison of the change of the dispersion characteristics of LW and ECHW due to doubling of the electron temperature. The quantity Dw gives a measure of the frequency mismatching from the resonant condition of the nonlinear three-wave coupling.*

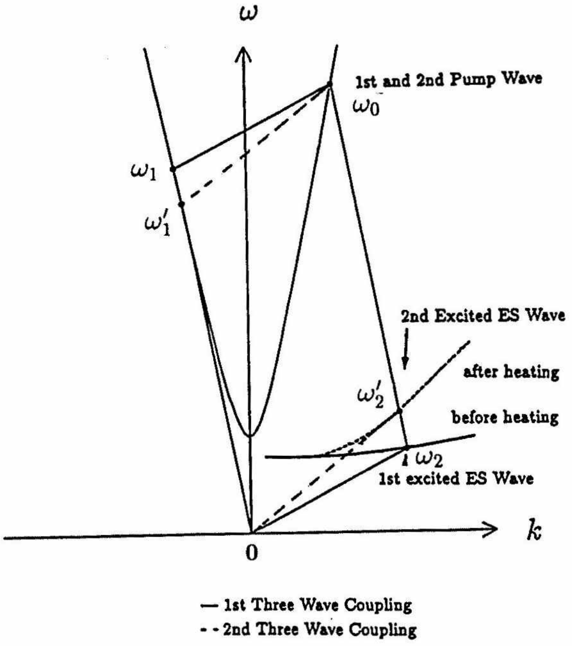



*Fig. 17 - A schematic illustration of the change of resonance condition of the three-wave coupling involving Langmuir Waves. Due to the change of electron temperature, a new triplet ( $\omega_0$, $\omega_1$', $\omega_2$') is found automatically, thus leading to the frequency broadening.*

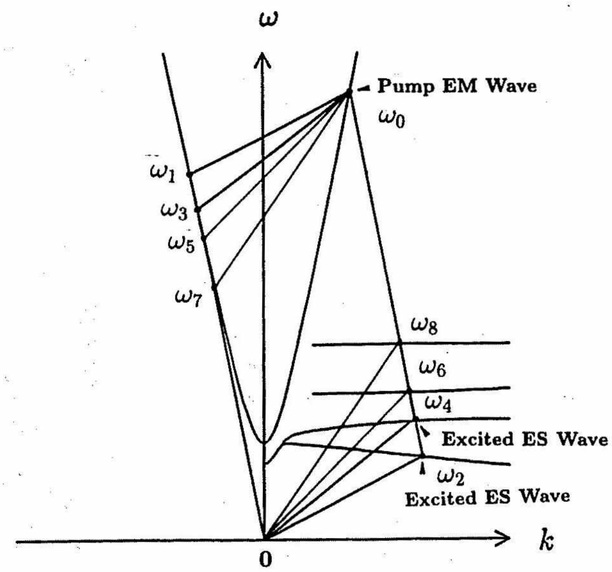
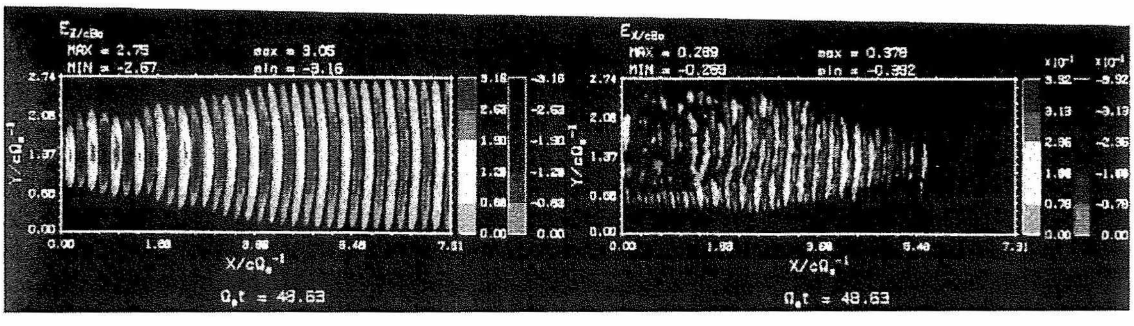



*Fig. 18 - A schematic illustration of simultaneous nonlinear three-wave coupling by one EM pump wave feeding energy and momentum into multiple ECH waves.*

As discussed above, even a simple one-dimensional computer simulation based on the particle model of the plasma turns out to be sufficiently effective to fill a gap between theory and experiment. Moreover the simulation solves an apparent discrepancy between the simple nonlinear theory and rocket experiment. Extending the simulation model from 1-D to 2-D, we are able to study the nonlinear interaction more realistically. Figure 19 is an example of such a 2-D simulation. Snap shots are shown of the spatial intensities of the pump wave (left upper panel), of the excited ES plasma waves (right upper panel) and of the thermal velocity of the plasma. The pump EM wave is



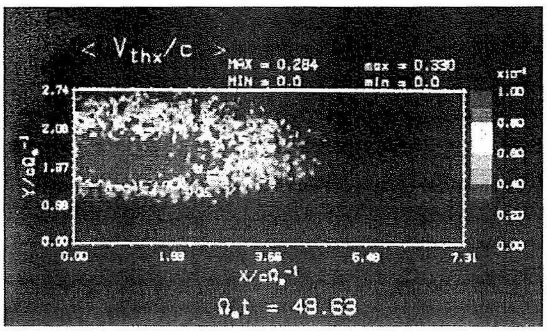
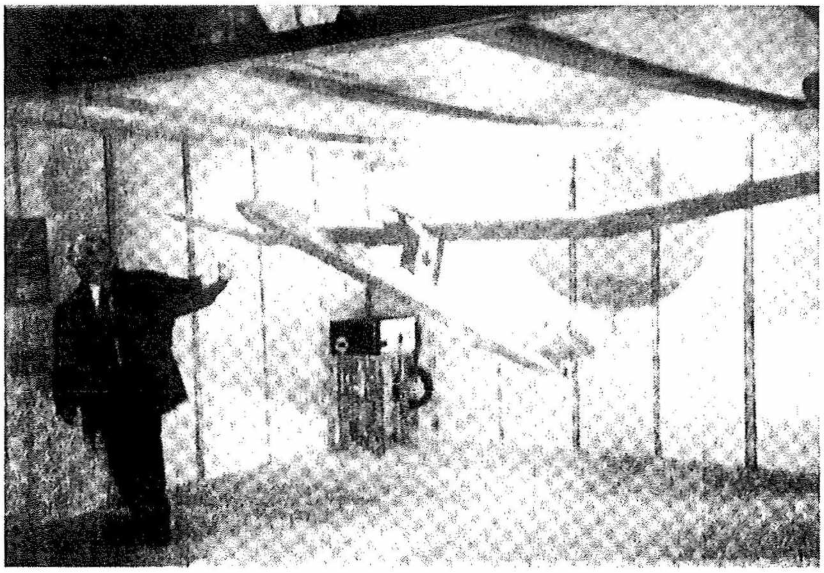




*Fig. 19 - A set of the result of two-dimensional computer experiment by KEMPO on the nonlinear effects caused by the injected intense EM wave. The upper left panel shows the intensity contour of the electric field of the pump EM wave injected from the left boundary. The upper right panel shows the intensity of the excited ES waves. The lower left panel shows the spatial distribution of thermal speed of the plasma. It is interesting to note that the plasma electrons are heated in a region where the ES waves are intense.*

radiated from the left boundary by an array of current sources placed on the left boundary, thus reproducing the spatially inhomogeneous intensity distribution of the MINIX microwave power beam. The ES waves shown in the upper right panel have already been damped in the vicinity of the antenna where the plasma is heated effectively.

The microwave power beam used for the future SPS has to pass through the magnetosphere and the ionosphere. In addition to the Ohmic heating and large-scale thermal instabilities discussed in Section 3, nonlinear excitation of electrostatic plasma waves is highly possible taking into account the theory, computer simulation and the rocket experiment MINIX. Though the power absorbed by these ES plasma waves and resultant plasma heating is very small, the impact of the microwave power beam onto the ionospheric plasma is not negligible. Nevertheless knowing the plasma wave characteristics excited by the microwave power beam as well as the physical plasma process involved in the excitation, we should be able to avoid possible interference to the HF communication network.

## 6. Application of Microwave Power Transmission to Microwave-Driven Airplane



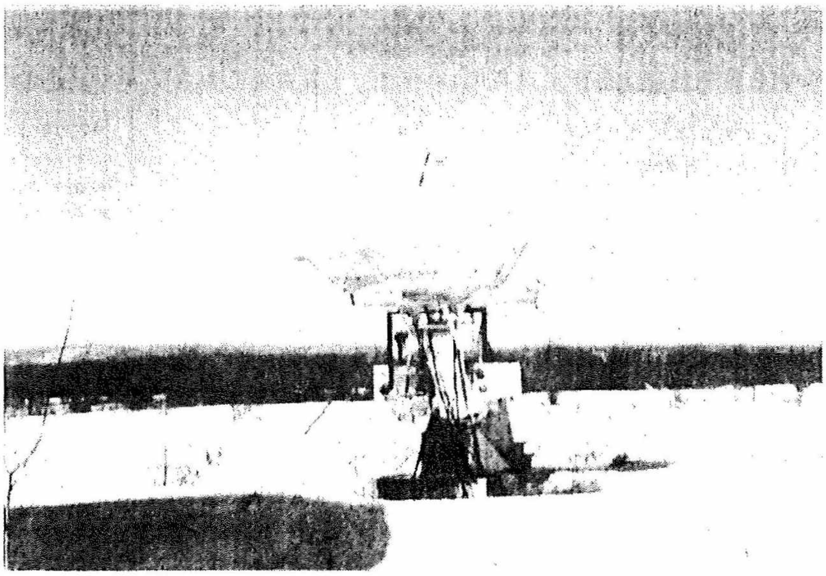
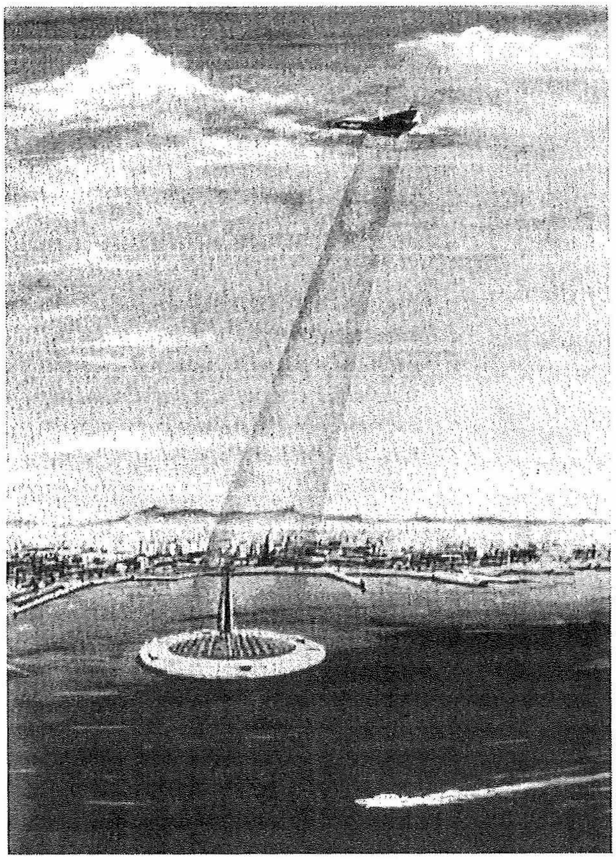


*Fig. 20 - A 1/8-scale SHARP Airplane and a parabolic antenna which will be used for 1/4-scale SHARP experiment.*

In the late 1980's, a program to develop a long endurance high altitude platform called SHARP (Stationary High Altitude Relay Platform) was proposed in Canada [45]. The idea is to float an unmanned light-weight airplane for a long period, circling at an altitude of about 21 km for the purpose of relaying radio communications signals over a wide area. To maintain the platform floating for weeks or months, a fuel-less airplane powered by microwave energy transmitted from the ground was proposed and experimented on [46]. On September 17, 1987, a 1/8-scale prototype SHARP flew on beamed microwave power for 20 minutes at an altitude of about 150 m. Figure 20 shows a photo of the prototype SHARP with a 4.5 m wingspan. The microwave beam was transmitted by a 4.5 m diameter parabolic antenna transmitting 10 kW microwave with a frequency of 2.45 GHz. Two water-cooled magnetrons each with 5 kW output power were used. The parabolic antenna mechanically tracked the airplane which flew inside a 50 degree cone. The power density at the airplane altitude was 400 W/m$^2$. A dual polarization rectenna with two orthogonal linearly-polarized dipole arrays was developed. The rectenna diodes used in the first flight were Silicon Schottky diodes (HP2835). Its power handling capability was 1 W/element, and its microwave-to-DC conversion efficiency was about 70% [46]. The rectenna received sufficient power to feed 150W to the electric motor of the 4.1 kg weight SHARP airplane [46].

A similar project was carried out in Japan in the early 1990's. The project was called Stratospheric Radio Relay Systems (SRRS), and was studied by a working group under the Ministry of Posts and Telecommunications of Japanese government [47]. The objectives of the SRRS are similar to those of Canadian SHARP. In the SRRS, it is planned to launch five such unmanned airplanes over Japan as depicted in Figure 21, so that these five platforms can cover most of areas where communication demands are heavy. In parallel with the SRRS working group, a microwave-driven airplane experiment was planned and conducted successfully on August 29, 1992 by a joint team organized by the present author [48]. The team members were from Kyoto University, Kobe University, Communications Research Laboratory, Nissan Motor Co. Ltd., Fuji Heavy Industries Ltd. and Toshiba Co. The



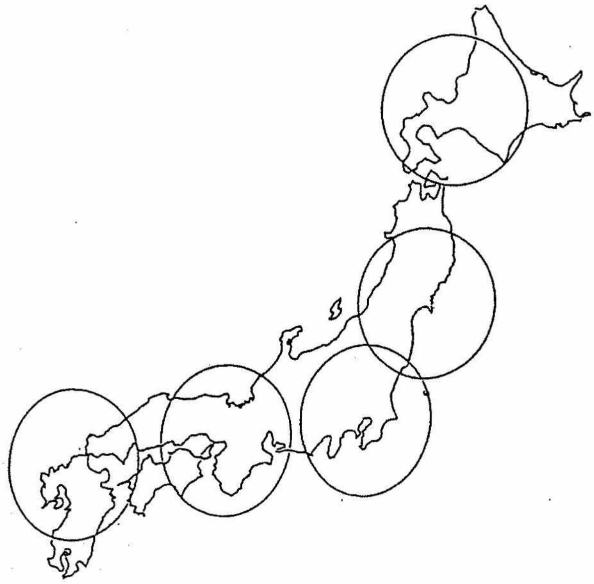


*Fig. 21 - A schematic illustration of Stratospheric Radio Relay System (SRRS). Five SRRS's will cover most of the heavy communication demands in Japan.*

experimental project was called MILAX meaning MIcrowave Lifted Airplane eXperiment, and was partly sponsored by ISAS of Japan. The MILAX airplane is a balsa-based light-weight (~ 4 kg) airplane with a 2.5 m wingspan and has a shape as shown in Figure 22. The MILAX flew successfully for 40 seconds (or 400 m distance over a straight course for car driving test) at an altitude of about 15 m. The testing scenery is shown in Figure 23. Because of the limits of the maximum microwave power (~ 1 kW) and of the aperture of the transmitting antenna (~ 1.2 m) , the flight altitude had to be as low as 15 m in order to guarantee the power density of 200 $W/m^2$ at that altitude. The microwave power beam was radiated toward the fuel-free MILAX airplane by an active phased array antenna.

The MILAX active phase array transmitter was composed of five-stage Gallium-Arsenic (GaAs) semi-conductor amplifiers (see Figure 24), 4-bit digital phase shifters and circular microstrip antennas (see Figure 25). The transmitter is divided into 96 sub-arrays, each consisting of 3 antennas, one phase-shifter and one GaAs amplifier. Each sub-array can supply 13 W microwave output resulting in the total radiation capability of 1.25 kW. The frequency used in the MILAX was 2.411 GHz in the ISM frequency band. The transmitter system was installed on the roof of a transmitter car (see Figure 25).

Six rectenna subarrays, each consisting of 20 rectennas are installed on the flat-bottom of the MILAX airplane. Prior to the development of the MILAX rectenna, several rectenna

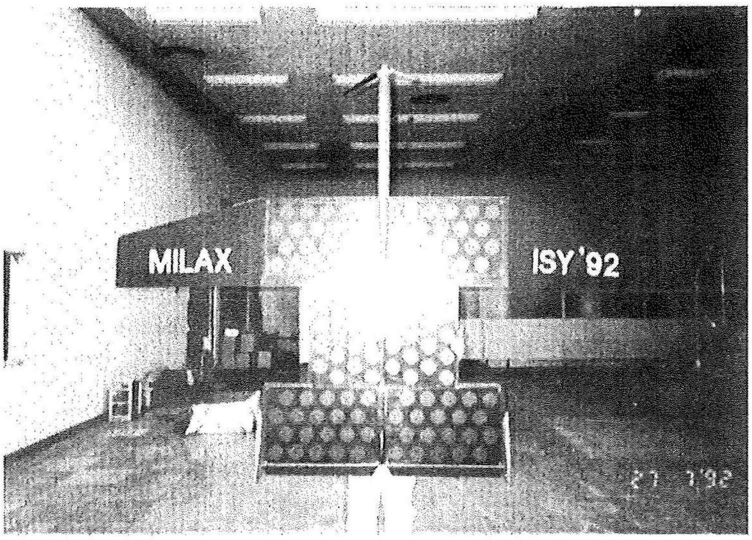



*Fig. 22 - An outlook of MILAX airplane (Bottom side). Circular patches are microstrip antenna used for the antennas.*

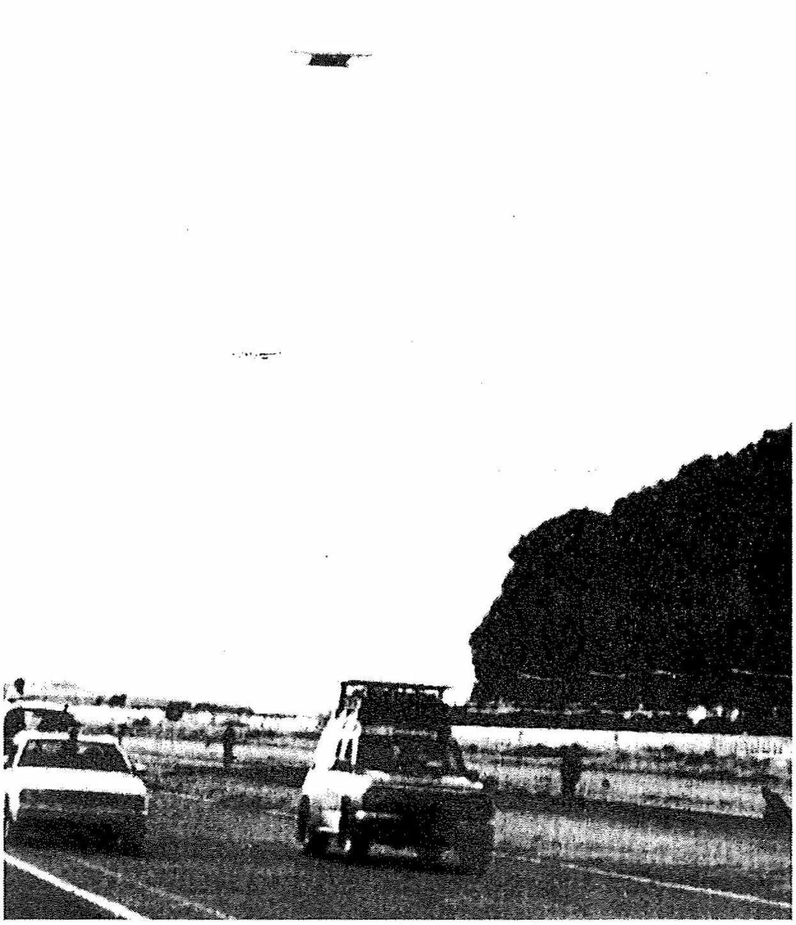


*Fig. 23 - MILAX demonstration flight. The MILAX airplane flew only by the microwave power transmitted from the transmitter car running panelled to the airplane. The MILAX was conducted on Aug. 29, 1992 at Oppama driving test course of Nissan motor Co, Japan.*

researches had been done in Japan [49, 50, 51]. Based on these studies, the receiving antennas used for the MILAX rectenna were not of the dipole-type, like these used in the JPL/Goldstone Ground-to-Ground Power Transmission Experiment and in the MINIX and SHARP, but were of a new type of microstrip circular patch antennas. The circular patch antennas have the advantage of a non-resonant nature at integer multiple harmonic frequencies, thereby having the capability of suppressing spurious radiation from the rectennas. The disadvantage of heavier weight as compared to dipole antennas was overcome by introducing a paper honeycomb structure [52], as shown in Figure 26. The diodes used for the MILAX rectenna are eight HP5082-2350 Schottky diodes in 2-series / 4-parallel combination. The power handling capability was 1 W per element, and the microwave-to-DC conversion efficiency was about 52% [52].

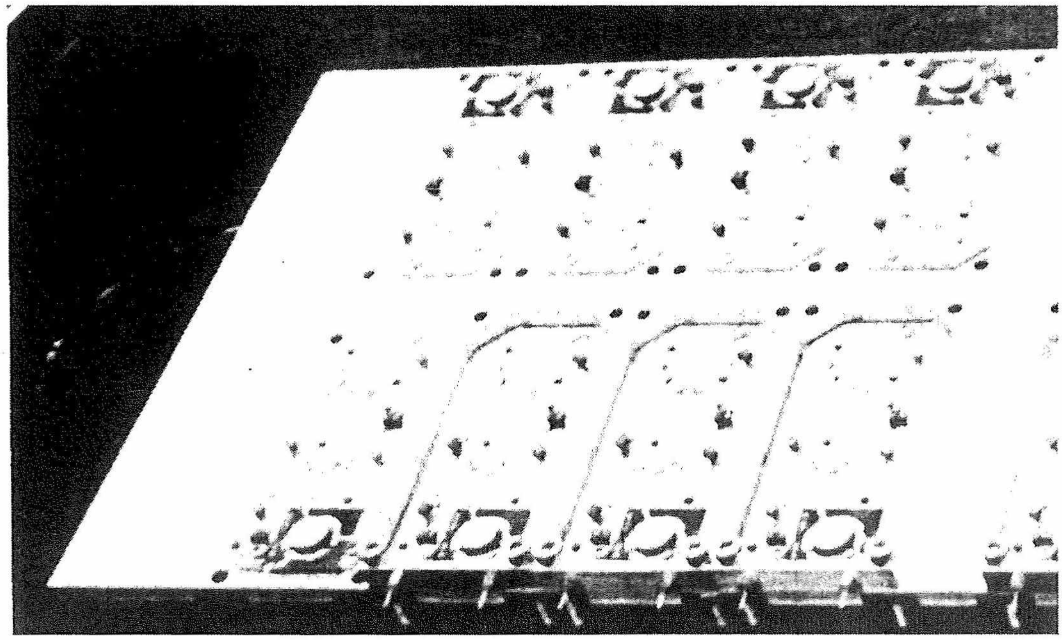


*Fig. 24 - GaAs-based semiconductor amplifiers used in the MILAX. Each amplifier supplies 13 W microwave output.*

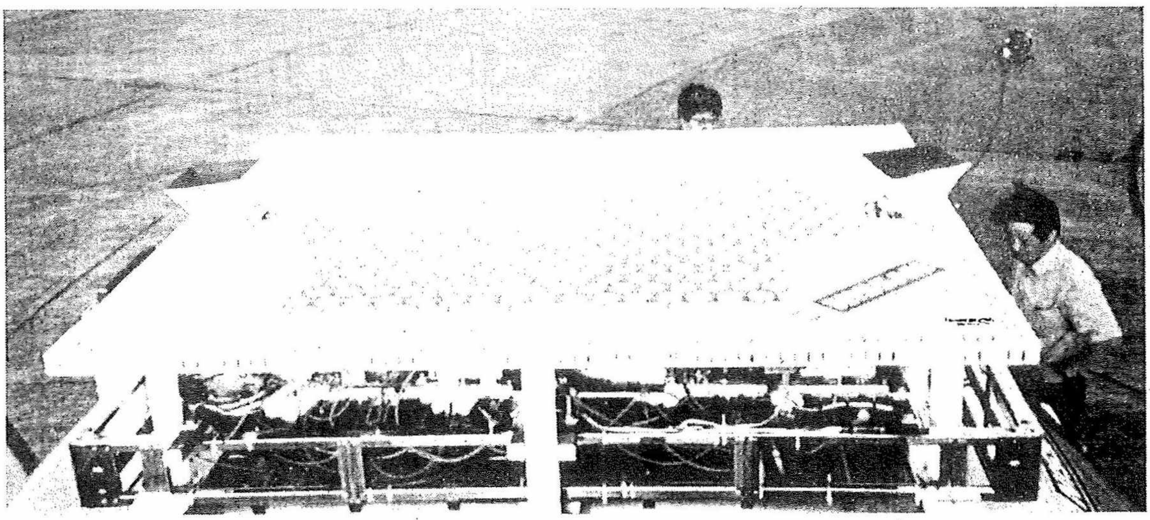


*Fig. 25 - A view of the transmitting antenna array installed on the roof of a transmitter car. The antennas were of circular microstrip type.*

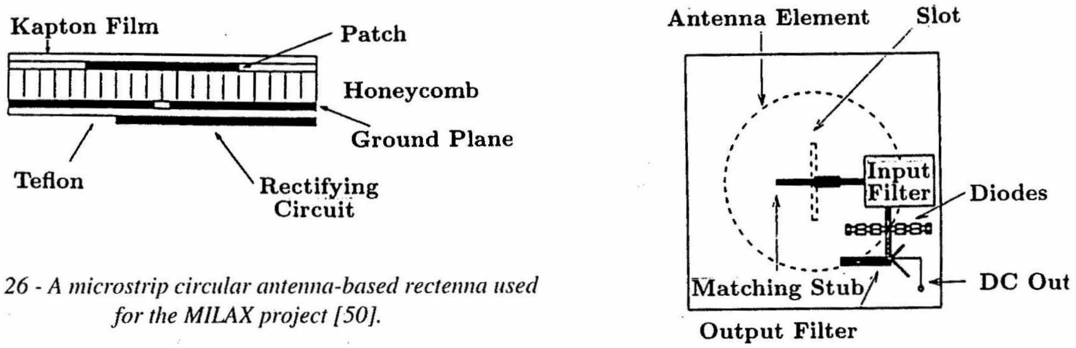



*Fig. 26 - A microstrip circular antenna-based rectenna used for the MILAX project [50].*

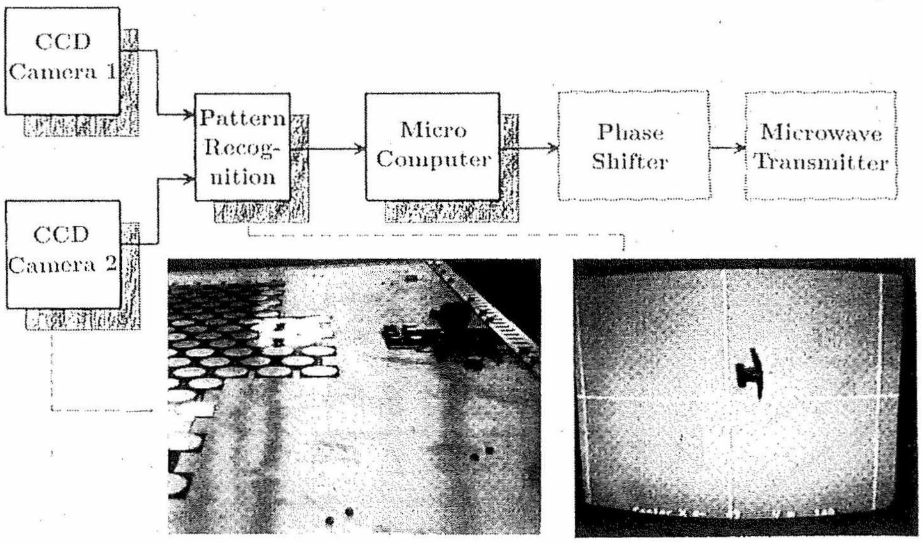



*Fig. 27 - A computer-controlled beam steering system for microwave power transmission toward the MILAX airplane. The image of the airplane is captured by two CCD cameras installed on the roof of the transmitter car. Then the computer recognizes the airplane location and height by a pattern recognition software. According to the information on height and location, the computer controls the phase shifters of the microwave amplifiers of the active phased array.*

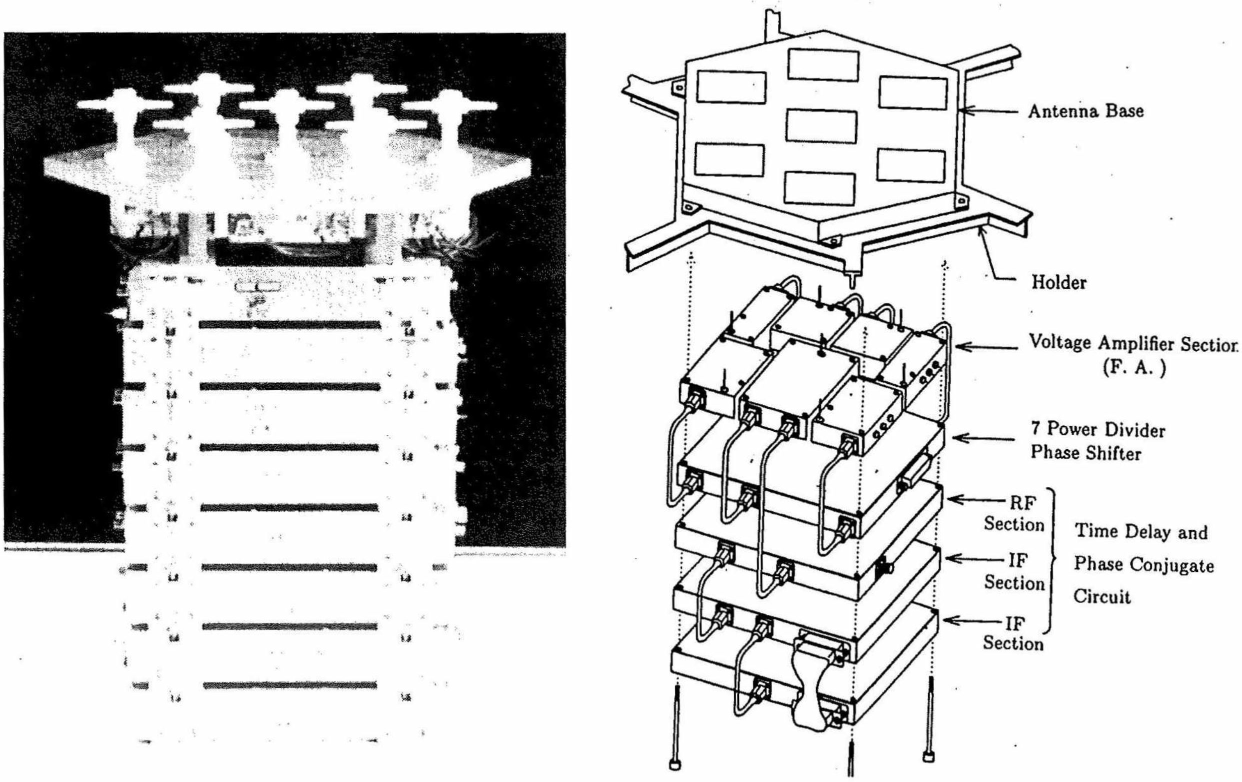



*Fig. 28 - A 90 W microwave power transmitter unit composed of seven dipole antennas, seven GaAs semiconductor amplifiers and retrodirective phase conjugate circuits.*

The main reason of the adoption of the active phased array in place of a conventional parabolic antenna is its higher steerability of the microwave power beam. The power beam can be controlled and steered electronically in contrast to the mechanical control of a parabolic antenna. In the MILAX, we monitored the location of the MILAX airplane by two CCD cameras which were installed on the edge of the roof-transmitter antenna looking upward. In Figure 27, a system of identifying the location of the airplane is shown. A micro-computer, after recognizing the pattern of the airplane image and calculating the x-y coordinates and the altitude of the airplane, sends the control signals to the phase shifters of the microwave amplifiers so that the microwave beam is accurately directed toward the airplane. This system worked perfectly in the MILAX.

Though we adopted computer-control for steering the microwave power beam in the MILAX due to time and budget limitations, we have also attempted to develop the retro-directive beam control system. Figure 28 shows a photograph of a 90 W microwave power transmitter with the use of the retro-directive control method [53]. Seven dipole antennas are connected to semi-conductor microwave

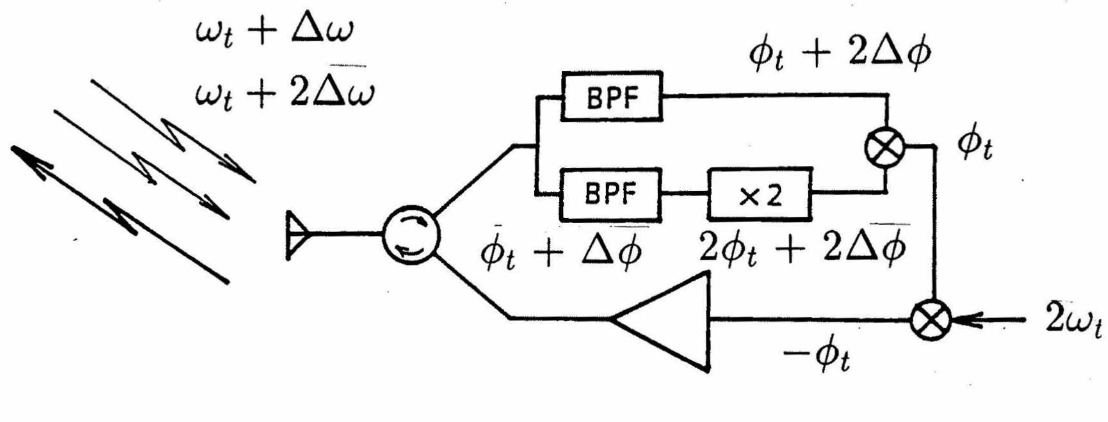
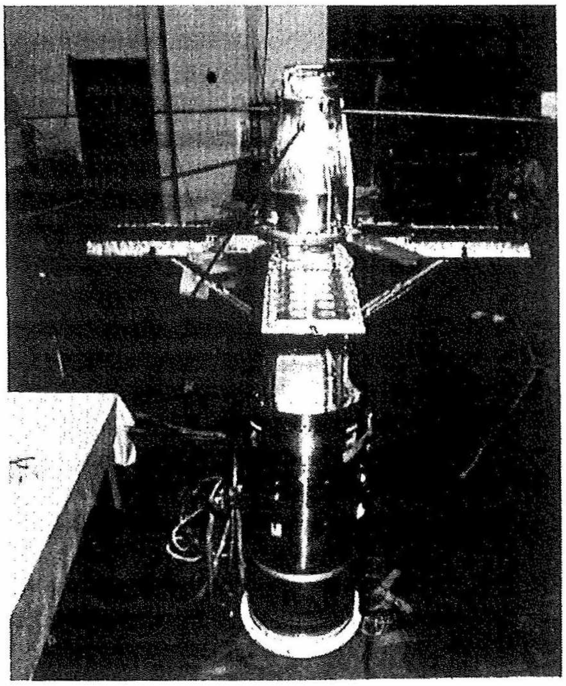



*Fig. 29 - A new phase conjugate circuit used for the 90 W unit in Figure 28. Two pilot signals with asymmetric frequencies of $\omega_0 + \Delta\omega$ and $\omega_0 + 2\Delta\omega$ are used.*



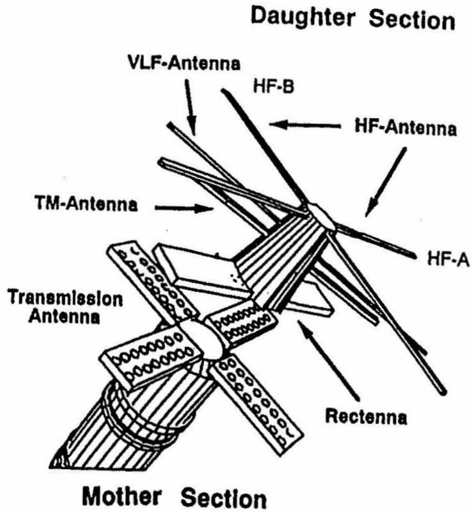



*Fig. 30 - Picture and illustration of the payload section of the ISY-METS rocket experiment. Four deployed paddles mount 16 transmitting microstrip antennas each. The daughter unit carried diagnostic packages and rectennas with various sensors.*

amplifiers. The 90 W microwave power transmitter has capability of transmitting the microwave power beam automatically in the direction of incoming pilot signals. A unique feature of the developed unit shown in Figure 28 is that it uses a new phase conjugate circuit (PCC) using asymmetric two pilot frequencies. The PCC used for the unit is shown in Figure 29. As we use two asymmetric pilot signals $w_0 + Dw$ and $w_0 + 2Dw$ instead of $w_0 \pm Dw$, we need no division of the phase $f_t$ of the pilot signal after the first mixer. Therefore we can determine the phase $f_1$t uniquely without the ambiguity of $\pi$ radians.

## 7. Other Recent Experiments on Microwave Power Transmission in Japan

On Feb. 18, 1993, a second rocket experiment of microwave power transmission between mother and daughter units was carried out by the S-520-16 sounding rocket [54, 55]. The rocket experiment was given the name of ISY-METS meaning Microwave Energy Transmission in Space during the International Space Year. The ISY-METS had objectives of investigating nonlinear effects of the high power microwave onto the ionospheric plasma in more or less a similar way to that of the MINIX. In this sense, the ISY-METS is an advanced version of the MINIX. However, it has another mission to verify a newly developed active phased array microwave transmitter which had been modified from that used in the MILAX in the space plasma environment. The total power of approximately 800 W was transmitted from the microstrip array antennas mounted on four deployed paddles. The configuration of the transmitting antenna paddles and the sensors extended outward from the daughter unit are shown in Figure 30. The phase of the transmitted microwave from each antenna on the deployed paddle was controlled by the same 4-bit digital phase shifter as used in the MILAX. The phase shifters were controlled

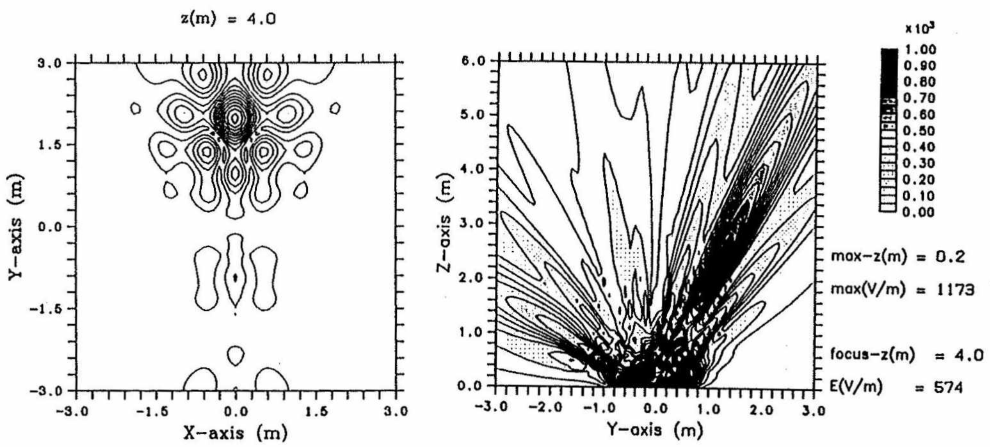
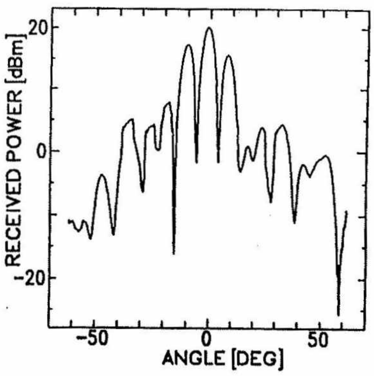



*Fig. 31 - Computed power concentration map in the x-z and x-y plane, where the contour of the ISY-METS transmitting antenna is placed at x = 0, y = 0 and z = 0 in the x-y plane. In the specific example, the power-concentration point is set at (x, y, z) = (0 m, 2 m, 4 m)*



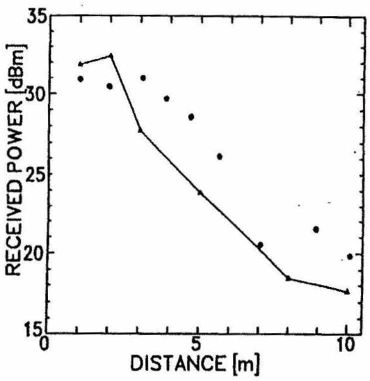




*Fig. 32 - Antenna pattern of the ISY-METS microwave power transmitter (left), and the measured power (right) at power-concentrated points at distances from 0 m to 10 m. The solid line and dots represent the values measured in the pre-flight radio anechoic chamber, and in the flight in space, respectively.*

by an onboard computer providing a variable transmitted power density and direction of the microwave beam. Figure 31 shows an example of power concentration at a point of approximately 4.5 m away from the center of the transmitting antennas. Such power-concentrated points were determined by the computer using pre-set parameters and the onboard real-time data of the relative direction the daughter unit.

Figure 32 shows a data set during a pre-flight test in the radio anechoic chamber. The left panel shows the antenna pattern of the microwave transmitter. The right panel shows the measured power at concentrated points which were varied from 1 m to 10 m from the transmitting antenna. The measured data are shown by the solid line in the figure. The dots in the same figure are the power density measured onboard the ISY-METS rocket during the flight; these measurements and agreed well with the pre-flight test values [55].

Two types of rectennas were installed on the daughter unit. One was developed by a research group at Texas A&M University, while the other was by the CRL group. The former used an orthogonally placed pair of three dipole antennas, as used in the MILAX. The structure and configuration are found in Figure 9 and Figure 10 in [55]. The initial results of the ISY-METS rocket experiment are now under analyses and will be published in detail elsewhere.

Other applications of microwave power transmission have recently gathered interests in Japan in the practical world in addition to the academia. One of them is a small-scale ground-to-ground power transmission without wires toward a distant place where wired power distribution networks are either unavailable not or very poorly available. In order to collect fundamental data on microwave power transmission under varying weather conditions, the Kansai Electric Power Company Inc. began a collaborative field experiment with Kyoto University and Kobe University. Figure 33 shows a photo of the experimental site showing a parabolic antenna with a 3 m diameter driven by a 5 kW magnetron and a rectenna array of a size of 3.5 m x 3.2 m placed 42 m away from the parabolic transmitting antenna. The rectenna array was built by Kyoto University and is composed of 2304 rectenna elements. A preliminary test started in October, 1994 and is still being conducted to collect fundamental data on the characteristics of power transmission and reception by the system.

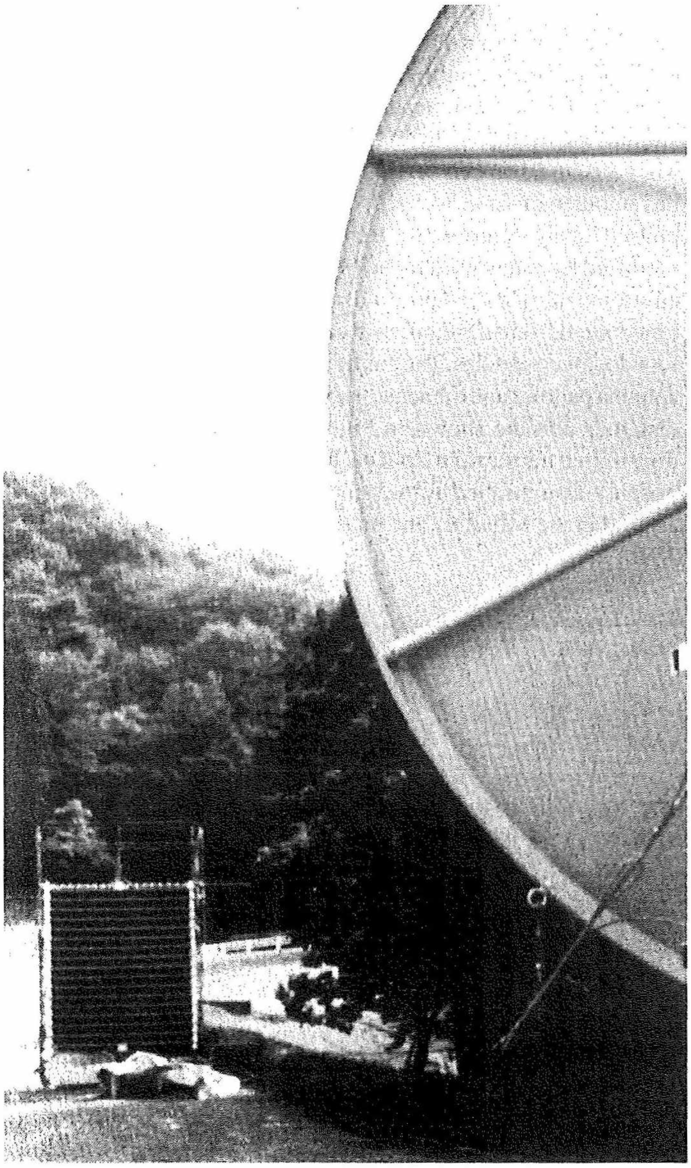


*Fig. 33 - A photo showing a field experi-ment of MPT at Yamazaki Experimental Site of Kansai Electric Power Company Inc (KEPCI). The experiment is a joint collaborative research between Kyoto University, Kobe University and KEPCI ($K^3$ project).*

## 8. Discussion and Conclusion

The Tesla idea of wireless power transmission was revived by the NASA/DOE SPS studies program in the 1970's. Following the pioneering work on microwave power transmission by W. C. Brown, many engineers and scientists have conducted the related research and developed applications stimulated by the SPS studies program in the US, former Soviet Union, France, Germany, Japan and other countries. However, even after the SPS boom subsided following the suspension of the SPS research in the US in 1981, both fundamental academic research and application-oriented developments and experiments in microwave power

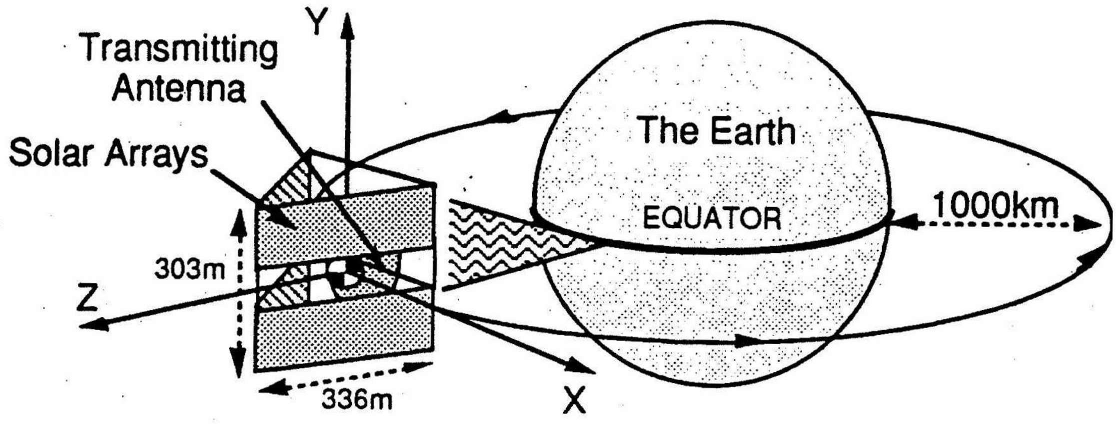



*Fig. 34 - A concept of SPS2000 which will beam down electrical energy to equatorial countries from an orbiting satellite with a shape of triangular structure.*

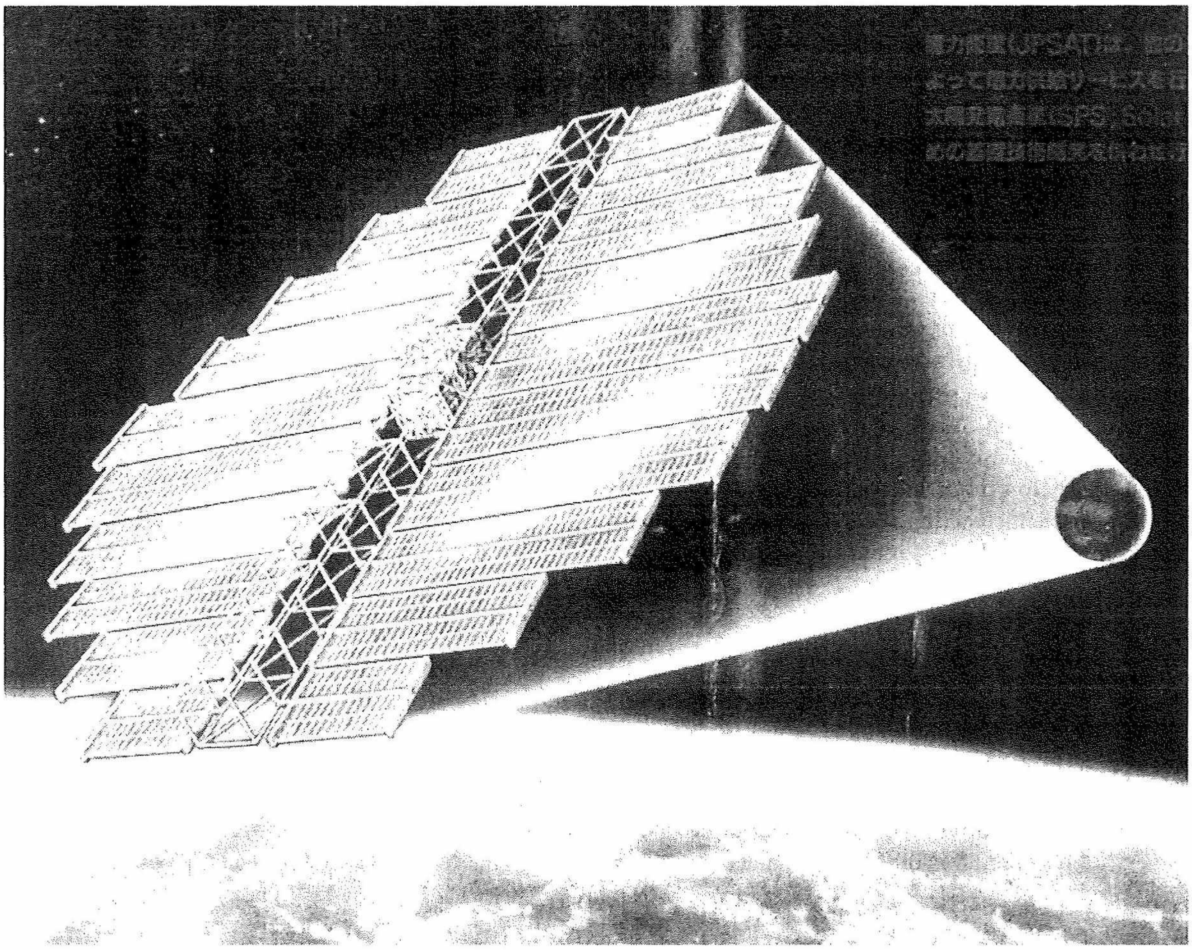


*Fig. 35 - A concept of Power Supplying Satellite. A 100 kW power will be transmitted to customer satellites.*

transmission have continued. Radio scientists have been a core of such research and development because the power transmission by radio inevitably involves problems in radio science such as those on antennas, rectennas, propagation characteristics and nonlinear interaction of microwave power beam with plasmas and neutral environments. In this paper, we have emphasized the development of such studies after 1980 as studies before that time was well documented (e.g.[1]). Since 1980, many feasibility studies have been made and a variety of new ideas of utilization of microwave power transmission have been proposed. However, as far as the present author knows, very few experiments have actually been carried out except for those discussed in the present paper except for a laboratory-based development and research of rectennas.

There are many plans and proposals for MPT applications, e.g., a French plan of a medium-scale wireless power transmission (~ 100 kW, 3 km) on Reunion island, a proposal named WISPER (Wireless Space Power Experiment) in the US which aims at ground-to-space power transmission of the order of 100 kW, and a test project called ALASKA 21 which plans to transmit electric power via microwave to scattered villages in Alaska. As well as these, private industries have their own MPT projects, while national research institutes will continue fundamental researches.

In Japan, MITI (Ministry of Trade and Industry) has re-examined the SPS feasibility based on recently developed technologies after 1980. Japanese research groups at ISAS and national universities are accordingly pursuing a conceptual study on an orbiting 10MW-scale Power satellite called SPS2000 which beams down the electricity to equatorial countries [56] (Figure 34) and on a power satellite called PSS (Power Supplying Satellite) which feeds electricity of the order of 100 kW to other orbiting customers [57] (Figure 35).

In summary, microwave power transmission has been one of the interesting topics in radio science both technologically and scientifically However, the use of radio waves as a means of transmitting electric power and energy is still in a very immature phase. More research and development will be needed before the dreams of Hertz and Tesla became reality. Radio scientists and engineers have great challenges to face in this new field.

## Acknowledgments

I would like to express my thanks to N. Kaya of Kobe University for his collaboration on this topic for many years. Without his contribution most of the experimental projects described in this paper would not have been successful. I also thank N. Shinohara, T. Miura and K. Miwa for their help in preparing this manuscript, and D. Summers for his careful reading of the manuscript.

## References

[1] W. C. Brown, The history of Power transmission by radio waves, IEEE transaction on microwave theory and techniques, MTT-32, 1230-1242, 1984.

[2] J. C. Maxwell, Treatise on Electricity and Magnetism, Dover Publications (reprinted), New York, 1954.

[3] H. Hertz, Electric Waves, MacMillan and Co., New York, 1893.

[4] G. Marconi, Nozioni Elementari de Radio Telegrafia, Ufficio Marconi, Roma, 1916.

[5] R. A. Fessenden, Wireless Telephony, 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, NJ, June, 1908.

[6] J. S. Belrose, Fesssenden and the Early History of Radio Science, The Radio Scientist and Bulletin, URSI, 5, 94-110, 1994.

[7] N. Tesla, The transmission of electric energy without wires, The thirteenth Anniversary Number of the Electrical World and Engineer, March 5, 1904.

[8] N. Tesla, Experiments with Alternate Current of High Potential and High Frequency, McGraw Pub. Co., N.Y., 1904.

[9] A. W. Hull, Effect of uniform magnetic field on the motion of electrons between co-axial cylinder, Phys. Rev., 18, 31-57, 1921.

[10]K. Okabe, Generation of Ultra short wavelength electromagnetic waves by magnetic with divided anodes, J. Institute of Electrical Engineering of Japan, 49, 284-290, 1928.

[11]H. Yagi and S. Uda, Feasibility of Electric Power Transmission by Radio Waves, Third Pan-Pacific academic conference, Tokyo, 1926.

[12]R. H. Varian and S. F. Varian, A high-frequency oscillator and amplifier, J. Appl. Phys., 10, 321, 1939.

[13]S. Nakajima and S. Yamazaki, Application of high power magnetron at Naval Research Laboratory during World War II time (in Japanese), History of Electronic Tubes, Ohm Pub. Co., Japan, 157-165, 1987.

[14]W. C. Brown, Experiments involving a microwave beam to power and position a helicopter, IEEE Trans. Aerosp. Electron. Systems, AES-5, No.5, 692-702,1969.

[15]W. C. Brown, Thermionic diode rectifier, in Microwave Power Engineering, vol. 1, E. C. Okress, Ed., N.Y. : Academic, 295-298 , 1968.

[16]W. C. Brown, The combination receiving antenna and rectifier, in Microwave Power Engineering, vol. II, E. C. Okress, Ed. N. Y.: Academic, 273-275, 1968.

[17]W. C. Brown, Progress in the design of rectennas, J. Microwave Power, vol.4, 168-175, 1969.

[18]R. M. Dickinson and W. C. Brown, Radiated microwave power transmission system efficiency measurements, Tech-Memo 33-727, Jet Propulsion Lab., Cal. Inst. Technol., March 15, 1975.

[19]Final Proc. Solar Power Satellite Program Rev. DOE/NASA Satellite Power System Concept Develop. Evaluation Program, Conf.-800491, July, 1980.

[20]P. E. Glaser, Power from the Sun, Science, 162, 857-886, 1968.

[21]F. W. Perkins and R. G. Roble, Ionospheric heating by radio waves : Predictions for Arecibo and the Satellite Power Station, J. Geophys. Res., 83, 1611-1624, 1978.

[22]L. M. Duncan and J. Zinn, Ionosphere-Microwave interactions for Solar Power Satellite, Los Alamos Scientific Lab. Report, LA-UR-78-758, March 1978.

[23]L. H. Holway and G. Meltz, Heating of the Laser ionosphere by powerful radio waves, J. Geophys. Res., 78, 8402-8408, 1978.

[24]L. M. Duncan and W. E. Gordon, Final Report, Ionosphere / Microwave beam interaction study, Rice University, Houston, TX, Final Report NAS9-15212, Sept., 1977.

[25]C. M. Rush, SPS simulated effects of ionospheric heating on the performance of telecommunication systems : a review of experimental results, Space Solar Power Review, 2, 355-366, 1980.

[26]S. Basu, S. Bau, A. L. Johnson, J. A. Klobuchar, and C. M. Rus, Preliminary results of scintillation measurements associated with ionospheric heating in overdense and underdense modes, Geophys. Res. Lett., 7, 609-612, 1980.

[27]F. W. Perkins and E. J. Valeo, Thermal self-focusing electromagnetic waves in plasmas, Phys. Review Lett., 32, 1234-1237, 1974.

[28]J. E. Drummond; Thermal stability of Earth's ionosphere under power transmitting satellites, IEEE Transactions of Plasma Science, PS-4, 228, 1976.

[29]G. D. Thome and F. W. Perkins, Production of ionospheric striations by self-focusing of intense radio waves, Phys. Rev. Lett., 32, 1238-1240, 1974.

[30]L. M. Duncan and R. A. Behnbe, Observation of self-focusing electromagnetic waves in the ionosphere, Phys. Rev. Lett., 41, 998, 1978.

[31]B. L. Cragin, J. A. Fejer and R. L. Showen, Theory of coherent parametric instabilities excited by two or more pump waves, Geophys. Res. Lett., 5, 183-186, 1978.

[32]R. L. Showen, L. M. Duncan, and B. L. Gragin, Observations of plasma instabilities in a multiple pump ionospheric heating, Geophys. Res. Lett., 5, 187-190, 1978.

[33]H. Matsumoto, Theory of nonlinear interaction of SPS microwave with the ionosphere (in Japanese), Report of Inst. Space Astro. Science, Univ. of Tokyo, 15, 407-430, 1979.

[34]H. Matsumoto, Numerical estimation of SPS microwave impact on ionospheric environment, Acta Astronautica, 9, 493-497, 1982.

[35]H. Matsumoto and T. Kimura, Nonlinear excitation of electron cyclotron waves by a monochromatic strong microwave, Space Power, 6, 187-191, 1986.

[36]M. Nagatomo, N. Kaya and H. Matsumoto, Engineering aspect of the microwave ionosphere nonlinear interaction experiment (MINIX) with a sounding rocket, Acta Astronautica, 13, 23-29, 1986.

[37]N. Kaya, H. Matsumoto, S. Miyatake, I. Kimura, M. Nagatomo and T. Obayashi, Nonlinear interaction of strong microwave beam with the ionosphere, Space Power, 6, 181-186, 1986.

[38]I. Kimura, H. Matsumoto, N. Kaya and S. Miyatake, Plasma wave excitation by intense microwave transmission from a space vehicle, Advances in Space Research, 8, 291-294, 1988.

[39]N. Kaya and H. Matsumoto, Space chamber experiments of ohmic heating by high power microwave from the Solar Power Satellite, Geophys. Res. Lett., 8, 1289-1292, 1981.

[40]H. Hirata, Nonlinear wave-wave-particle interaction induced by intense EM waves in a magnetized plasma, Master Thesis (supervised by H. Matsumoto), Kyoto Univ., 1989.

[41]H. Matsumoto, H. Hirata, Y. Hashimoto and N. Shinohara, Theoretical analysis of nonlinear interaction of intense electromagnetic wave and plasma waves in the ionosphere (in Japanese), Trans. IEICE on Communications, vol. 78-B-II, March, 1995.

[42]H. Matsumoto, Computer experiment of space plasmas, Computer Space Plasma Physics, Simulation Techniques and Software, ed. by H. Matsumoto and Y. Omura, Terra. Sci. Pub. Co., Tokyo, 3-18, 1993.

[43]H. Matsumoto and Y. Omura, Particle simulation of electromagnetic waves and its application to space plasma, Computer Simulation of Space Plasma, ed. by H. Matsumoto and T. Sato, Terra Sci. Pub. Co. Tokyo, 43-102, 1985.

[44]for example, T.Taniuchi and K.Nishihara, Non-linear Waves (in Japanese), Iwanami Pub.Co., pp.116-134, 1977.

[45]G. W. Jull, A. Lillemark and R. M. Tunner, SHARP: Telecommunications Missions and Systems, Proceedings IEEE Globecom 85, 955-959, 1985.

[46]J. J. Schlesak, A. Alden and T. Ohno, A microwave powered high altitude platfome, IEEE MTT International Microwave Symposium, N.Y. Vol.I 283-286, 1988.

[47]Report of Studies on Stratospheric Radio Relay Systems, SRRS Working Group, Ministry of Postage and Communications, March 1991.

[48]H.Matsumoto, N. Kaya, M. Fujita, T. Fujiwara and T. Sato, Microwave Lifted Airplane Experiment with active phased array antennas, to be submitted to IEEE Trans. MTT, 1995.

[49]S. Adachi and Y. Shimanuki, Theoretical and experimental study on rectenna array for microwave power transmission, Space Solar Power Review, 5, 127-129, 1985.

[50]K. Itoh, Y. Akiba and Y. Ogura, Fundamental study on SPS rectenna printed ona sheet of Copper Glad Laminate, Space Solar Power Review, 5, 149-162, 1985.

[51]K. Itoh, T. Ohgane adn Y. Ogawa, Rectenna composed of circular microstrip antenna, Space Power, 6, 193-198, 1986.

[52]Y. Fujino, M. Fujita, H. Sawada and K. Kawabata, A rectenna for MILAX, 12th Space Energy Symposium, ISAS, Tokyo, March, 1993.

[53]H. Matsumoto, N. Kaya, N. Nagatomo, T. Hashizume,and K. Nakatsuka, Feasibility Study on Retrodirective System for METS, The Sixth ISAS Space Energy Symposium, 24, March 1987.

[54]H. Matsumoto and N. Kaya, Initial results of ISY-METS rocket experiment (in Japanese), RASC report Kyoto University, May, 1993.

[55]R. Akiba, K. Miura, M. Hinada, H. Matsumoto and N. Kaya, ISY-METS rocket experiment, The ISAS Report No.652, 1-14, September, 1993.

[56]M. Nagatomo, 10 MW Satellite Power System: A space station mission beyond 2000, Space Power 6, 299-305, 1986.

[57]H. Matsumoto, N. Kaya, S. Kinai, T. Fujiwara and J. Kochiyama, A feasibility study of Power Supplying Satellite (PSS), Space Power, 12, 1-6, 1993.

# Wave and Turbulence Measurements with the Cluster Spacecraft

L.J.C. Woolliscroft
ET AL.

## Abstract

The ESA/NASA Cluster mission will make measurements of small and medium scale plasma processes in the Earth's magnetosphere and solar with as a part of the Solar Terrestrial Science Programme. The mission is described briefly as a background to the description of the objectives and capabilities of the Wave Experiment Consortium (WEC).

## 1. Introduction

In the late autumn of 1995 the four satellites of the ESA/NASA Cluster mission are due to be launched by the first Ariane 5 from Korou in French Guyanna. These four satellites are to carry an identical payload to study small and medium scale processes in the region of space up to about 22 Earth radii away. The teams with five of the eleven instruments on each spacecraft form the Wave Experiment Consortium (WEC) and in this paper an account of the WEC[1] is given together with some outline of the scientific capabilities and plans of the WEC instruments and team.

The orbits of the Cluster satellites are such that the interspacecraft separation will vary from a few hundred kilometres to a few thousand kilometres. Figures 1 and 2 show the near polar orbit for when the spacecraft apogee is in the solar wind (apogee at noon local time) and in the magnetotail (apogee at midnight LT) respectively. These periods are six months apart with the spacecraft exploring the dawn and dusk flanks in-between. The mission duration is planned for at least two years (depending mainly on the use of fuel and the life of the equipment). Table 1 shows the planned typical interspacecraft separations during the different mission phases (but clearly these figures apply to the main scientific target point on the particular orbit). More details of the Cluster mission and Cluster operations are given in [2, 3 and 4].

The purpose of this paper is to introduce the Cluster WEC and the scientific objectives of the WEC for making plasma wave and turbulence measurements. Section 3 outlines the technical capabilities of the WEC. Section 4 describes some of the scientific objectives and section 5 the WEC operations. The next section points out the reasons that wave measurements are important to the Cluster mission.

## 2. The role of plasma waves in the Cluster Mission

Plasma and radio waves are of specific importance to the mission objectives of Cluster, and of general importance in space plasma and solar terrestrial physics, for several reasons:

* they are either responsible for, or play a central role in, a variety of processes by which mass, momentum and energy transfer occur in collisionless plasmas. Thus they are important at numerous boundaries such as the bow shock, magnetopause and plasma sheet boundary layer and cusp. Plasma waves must provide the anomalous diffusion of magnetic field lines over these boundaries and their associated layers in which the MHD topology is not conserved. They are responsible for the thermalisation of the solar wind bulk motion in the bow shock and for many cases of particle acceleration.
* they are important indicators of *in situ* conditions, e.g. electron number density, other particle parameters such as temperature and features in the distribution functions, and fields.

| Year | Apogee in | Characteristic Separation | Comments |
|---|---|---|---|
| Year 1 | Dayside (Cusp) | 600 km (+/- 20%) | |
| | Tail | 2000 to 5000 km | |
| Year 2 | Dayside (Cusp) | 200 to 2000 km | decide after first cusp experience |
| | Tail | 1 to 3 Earth radii | decide when fuel is known |

**Table 1**: *Planned interspacecraft separation through the mission.*

Authors are : L.J.C. Woolliscroft [1], N. Cornilleau-Wehrlin [2], P.M.E. Décréau [3], D.A. Gurnett [4], and G. Gustafsson [5]

[1] Dept. of Automatic Control and Systems Engineering, The University of Sheffield, Mappin Street, Sheffield S1 3JD, United Kingdom, e-mail: l.woolliscroft@sheffield. ac.uk fax: + 44 - 114 - 2 731729

[2] CETP-USQV, 10-12 Ave de l'Europe, F-78140 Velizy, France

[3] LPCE-CNRS, 3A Ave de la Recherche Scientifique, 45071 Orleans CEDEX 2, France

[4] Dept. of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242, USA

[5] Swedish Instutute of Space Physics, Uppsala, Sweden

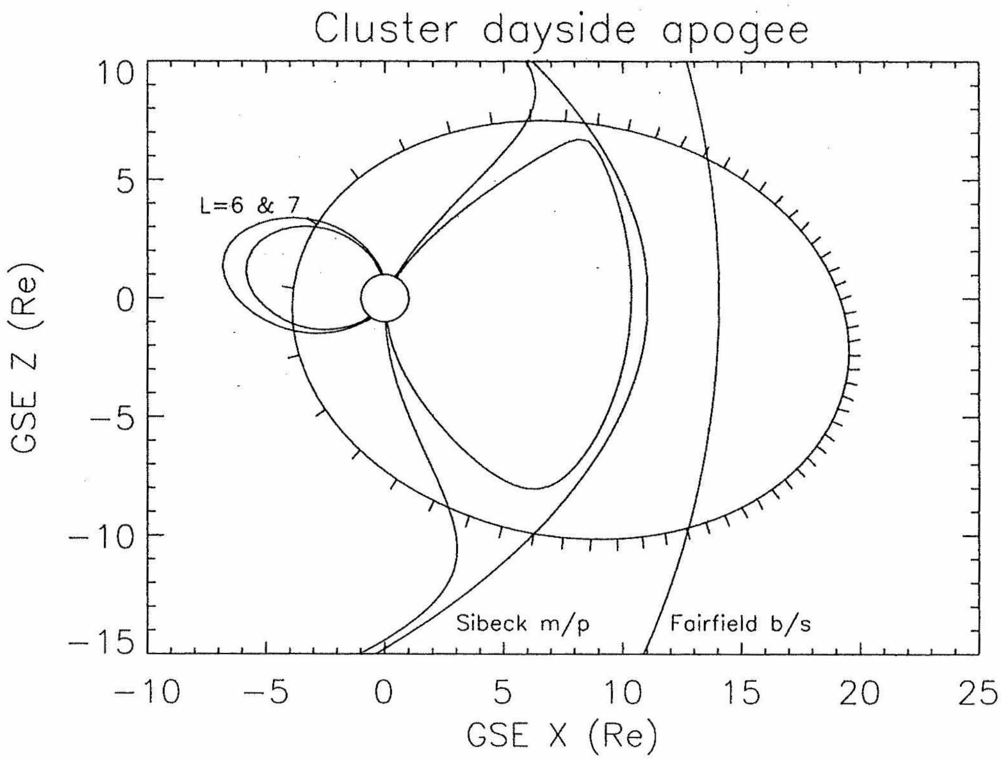



*Fig. 1 - Cluster dayside orbit (apogee noon local time) showing crossings of the cusp region. The tick marks on the orbit represent approximately the distance travelled in a two hour period. Some representative field lines (and the typical positions) of the main dayside boundaries are shown in thinner (and dashed) lines.*

* they provide remote sensing of the distant environment and physical processes which are not possible by in situ measurements; e.g. auroral kilometric radiation and type III solar radiobursts
* they are a key element in the study of transient and small scale structures where the highest possible time resolution is necessary; e.g. studies of the fine structure of boundaries or of such processes as the disruption of the current during substorm activity and reconnection events. Wave measurements can, in principle, provide a time resolution of the order of the inverse of the frequency at which the observations are being made.

Such measurements of waves and turbulence with satellites such as those of the Cluster mission are difficult for several reasons; they may develop in spatially confined regions, the corresponding structures are non-stationary in the spacecraft frame and their amplitudes are often such that a linear analysis is inappropriate.

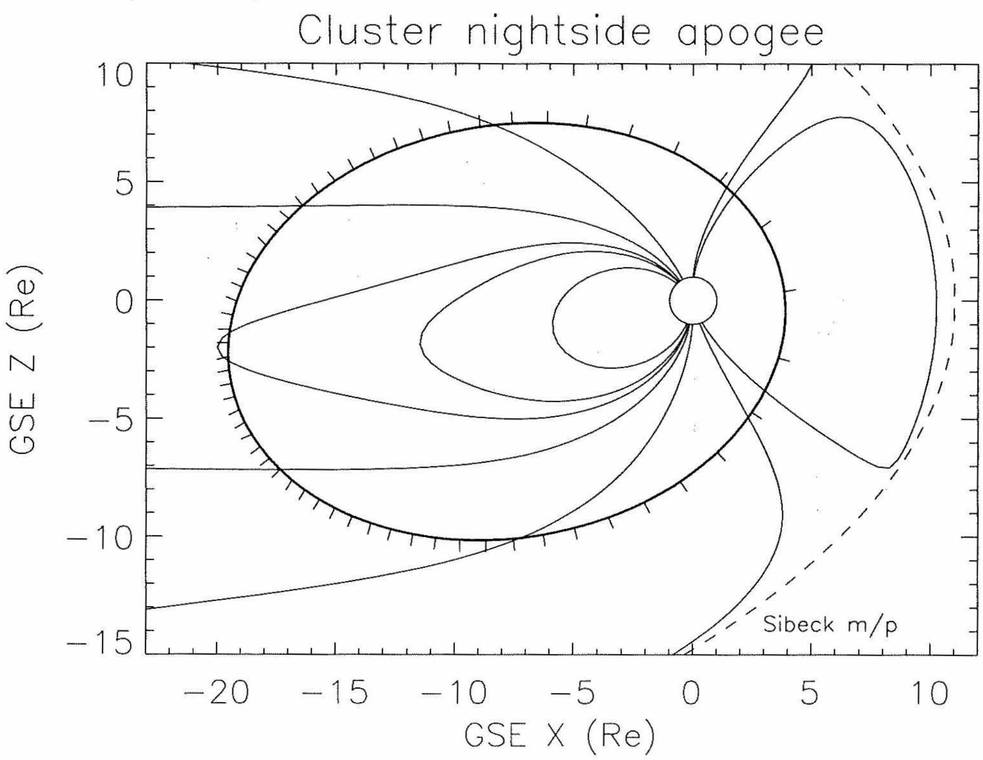



*Fig. 2 - As Figure 1 but showing the orbit when apogee is in the magnetotail (midnight local time).*

| Instrument | Principal Investigator | Key measurements |
|---|---|---|
| EFW | Gustafsson, G. | Two axis E (50 m wire booms) each sphere can work in current (Langmuir) or voltage mode, waveform up to 10 or 180 Hz (or higher with internal memory) |
| STAFF | Cornilleau-Wehrlin, N. | B tri-axial search coils, f < 4 kHz, waveform up to 10 or 180 Hz, auto- and cross- spectrum 3 B and 2 E components for f < 4 kHz |
| WHISPER | Décréau, P.M.E. | Relaxation sounder to determine ne,, total electric field power measurements in frequency 2 to 80 kHz, 300 Hz to 1 kHz resolution, *t 13 ms to 0.8 s. |
| WBD | Gurnett, D.A. | Wideband measurements, E or B, 25 Hz to 9.5 kHz, 50 Hz to 19 kHz, or 1 kHz to 77 kHz output filters after frequency conversion with 0, 125, 250 or 500 kHz |
| DWP | Woolliscroft, L.J.C. | Particle correlator and data compression |

*Table 2 - The Wave Experiment Consortium (WEC) - summary capabilities.*

## 3. The Cluster WEC Instruments

The Wave Experiment Consortium, WEC, was formed to optimise the use of the limited spacecraft resources of mass, power, data and booms [1,10]. The WEC includes five experiments [5, 6, 7, 8 and 9] each led by a Principal Investigator as shown in table 2. This table also shows, in a highly abridged form, the key observational parameters of the five experiments. The Digital Wave processor, DWP[5,11], in addition to having scientific functions, is responsible for the control of the WEC and for providing the interface to the onboard data handling system for the WEC experiments (although the Wideband Plasma Wave investigation has an additional direct interface for use with the NASA DSN ground stations).

Figure 3 shows the frequency range covered by the WEC instruments. A simplified block diagram of the WEC is given in figure 4.

The detailed choice of mode for each of the WEC instruments is quite complicated and will depend on, for example, the availability of DSN and whether the spacecraft data handling system is being operated in a high data rate (often called HBR or BM1). The choice of data rate is selected (within many constraints) by the Science Working Team so as to make the most effective use of the on-board data recorders. The data system has the capacity to handle only about half of the data per orbit which could be collected at normal data rate or one twelfth of the data if the high data rate were used throughout.

DWP provides the control, some data processing and data handling for the WEC as well as having a particle correlator which takes data from the PEACE electron instrument [12]. The normal way in which the WEC will operate is through macro commands which are issued by DWP to the other WEC instruments. These macro commands generally have a cycle associated with them. The macro command

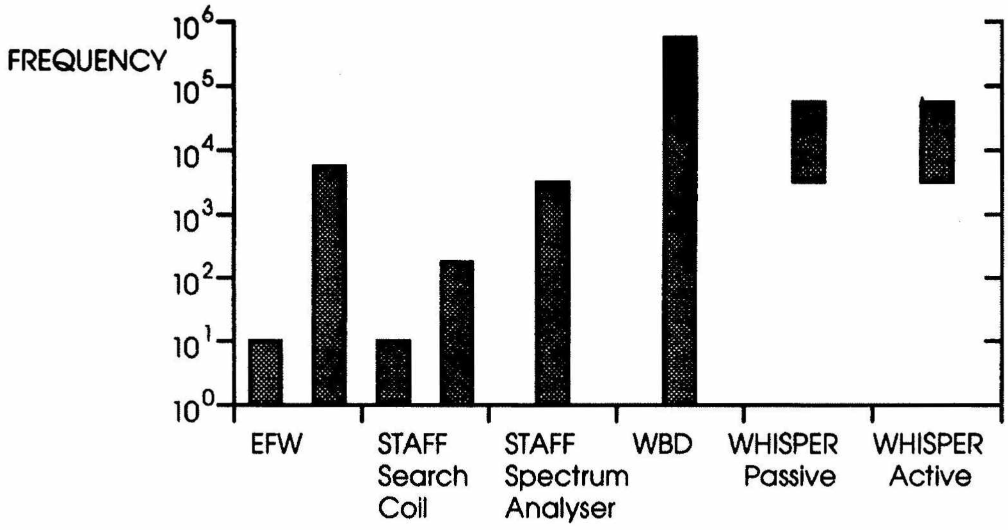



*Fig. 3 - The frequencies which are measured by the WEC instruments (note that not all of these are simultaneously possible and that this diagram is somewhat simplified).*

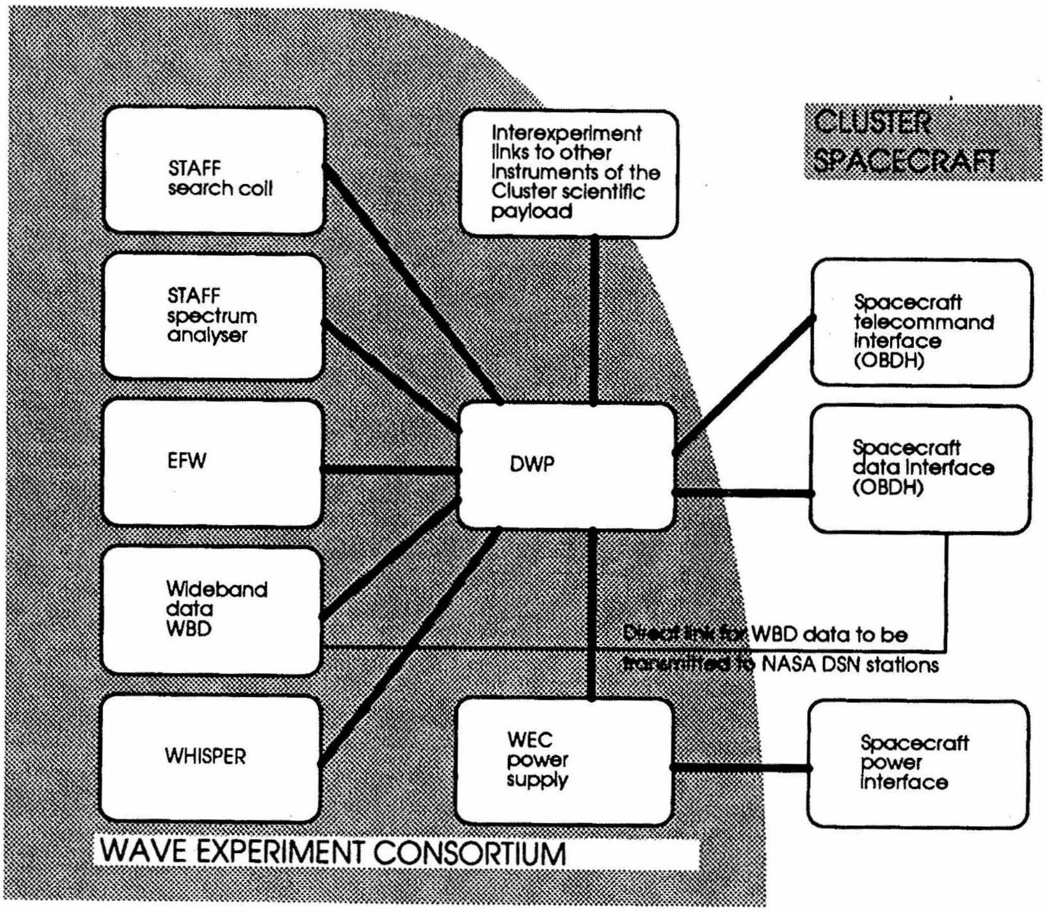



*Fig. 4 - A simplified block diagram of Cluster WEC showing only the main links between units with DWP [5] at the centre. OBDH interfaces (on-board data handling) are replicated for redundancy. STAFF [6], EFW [7], WBD [8] and WHISPER [9] are the other instruments in the WEC. This diagram does not show the magnetic antennas of STAFF which are connected to the signal processing of EFW and WBD as well as STAFF, or the EFW antennas which are connected to STAFF and WBD as well as being used for resonance sounding by WHISPER.*

sequences will normally correspond to the WEC modes and are described more fully in [13]. In order to have a reasonably consistent set of data throughout the mission the number of WEC modes has been restricted. Table 3 gives a summary of WEC modes. Other macros can be created and uplinked to the spacecraft. Most of the macros defined for the implementation of WEC modes willl loop indefinitely or until a stop command is received.

The Wideband instrument is exceptional in that the normal data path is direct to the spacecraft on-board data handling system and thence to a NASA DSN ground station. For this reason it is shown in table 3 as rather flexible as it is not involved in the normal data allocation. Thus, if real-time data into the DSN stations is possible and the Cluster spacecraft have sufficient electrical power, the use of the WBD instrument will give additional data.

There is more required to optimise the use of the WEC instruments. For example the EFW spherical probes have a bias current applied. This will be set up on a regular basis and it is not a parameter which needs to be adjusted for normal studies.

A further requirement for a high time resolution study of waves concerns the timing of the data. The acquisition of Cluster data by the onboard data handling system are normally timed with an accuracy of 2 ms. with respect to UTC for each spacecraft. To compare data from two spacecraft there is, then, an accuracy of 4 ms. Within DWP the timing is done more accurately and time differences may be measured to a few tens of microseconds [13].

## 4. Scientific Objectives

In general our understanding of processes in space plasmas is closely linked to the development of appropriate data analysis tools. This is particularly true for turbulence studies where most of the basic concepts come from spectral and correlation techniques which provide comparisons between two or more sets of measurements.

One of the most widely used techniques in turbulence analysis is the cross-spectrum, which measures the amount of similarity between two sets of measurements. It can be used to determine the delay between wavefields as measured by two satellites [14] and allows one, in principle, to derive the plasma rest frame velocity [15]. Another application is the determination of the joint frequency-wavenumber spectrum, which is needed for the identification of dispersion relations. This spectrum can be determined directly if the turbulence consists of a few distinct modes [16]: in the case of broadband turbulence, the determination is still feasible, but in a statistical sense. All of these techniques can readily be generalised to the four-point measurements of Cluster, thereby enabling the wavefield energy distribution with

| Name | WHISPER | STAFF search coil | STAFF spectrum analyser | EFW | WBD | Correlator |
|---|---|---|---|---|---|---|
| NBR-basic | 3s active, 25s passive | Normal | Normal | Normal | Normal | On |
| NBR-low recurrence | 4s active, 100s passive | Normal | Normal | Normal | Normal | On |
| NBR-Langmuir | 4s active, 100s passive | Normal | Normal | Normal (Langmuir) | Normal | On |
| NBR-spin synchronized | 129 spins (516s) active | Normal | Normal | Normal | Normal | Off (on) |
| NBR-active continuous | 104s active | Normal | Normal | Normal | Normal | On |
| NBR-WBD | 4s active, 4x25s passive | Normal | Normal | Normal | Many modes | On |
| HBR-basic | 3s active, 25s passive | High | Fast | High | Normal | Off |
| HBR-low occurence | 4s active, 4x25s passive | High | Fast | High | Normal | Off |
| HBR-Langmuir | 4s active, 4x25s passive | High | Fast | High (Langmuir) | Normal | Off |
| HBR-spin sync., gliding | 580s active | High | Fast | High | Normal | Off |
| HBR-active continuous | 185s active, 13s passive, 2s off | High | Fast | High | Normal | Off |
| HBR-EFW | passive (off) | High (off) | Off | High (many modes) | Normal | Off (on) |

*Table 3 - Some of the Main WEC Operation Modes (simplified). Terms such as "normal" or "fast" cover several possibilities and do not have the same meaning in each instance of their use. The WBD instrument is capable of many modes but is expected to be operated in normal mode much of the time that it is operational. Table 4 shows the cycle of measurements for some of these WEC modes.*

respect to the frequency and wavenumber to be determined. Non-linear coupling processes are important in space plasmas. They can be characterised by different means. The bi- and tricoherence functions [17] provide a measure of the degree of quadratic and cubic (respectively) interactions between the waves. Third and higher order moments of the wavefield probability distribution function the characterisation of intermittent behaviour. Furthermore, the representation of such moments versus the fluctuation scales gives the structure function and hence insight into the possible multifractal nature of turbulence [18].

Finally the spatially resolved measurements provided by Cluster may make it possible to study coherent structures and self-organisation in turbulence. For that purpose visualisation techniques that are already in use in fluid mechanics are applicable. The conditional averaging [19], for example, allows the determination of the characteristic shape of coherent structures.

Most of the analysis techniques are traditionally applied to stationary signals for which the Fourier transforms are well applicable. The extension to transient and non-stationary phenomena is often possible and the use of wavelet transforms is a promising alternative [20].

We present here an initial plan for some specific studies, others are likely to be added when we have experience with the data. Although Cluster is a detailed investigation and not an exploratory class of mission, we expect many exciting and novel results. The choice of these studies is subjective and does not reflect the total of the plans of the WEC. It is organised according to region and physical process but many of the radioscience techniques will be applied to several regions.

4.1 *Quasi-perpendicular bow shock - low frequency waves.* The study of wave activity in the vicinity of quasi-perpendicular shocks is important to the understanding of electron heating, the energy redistribution between electrons and ions and for the creation of the electron beams upstream of the shock. The Cluster satellites allow us to use different techniques to obtain information about wave activity which were never previously possible. The experimental study requires the routine determination of wave characteristics such as polarisation properties, group and phase velocities. This will allow us to establish the energy source for the wave activity and identify the groups of particles interacting with the waves.

4.2 *The Thickness of the Quasi-perpendicular Shock.* All subcritical shocks can be subdivided into two main groups: dissipative (when the dissipation is strong enough to stop steepening of the shock front, the scale for the shock front in this case is determined by the scale of the dissipation process) and dispersive (when dispersion is strong then the scale of the shock is determined by the dispersion lengths of the wavetrain). The dispersive shocks have been studied using ISEE data. It was shown that the order of magnitude of their scale is determined by the precursor whistler waves [21, 22]. But a precise comparison performed in [23] for low $\beta$ shocks has found substantial deviations from this scale length. The situation is even less clear for dissipative shocks, which have not been studied using ISEE data, but were observed in previous single satellite experiments where the scale could not be determined. There are several models for the plasma turbulence predicting different scales for the thickness of these shocks. These are the ion-sound turbulence theory [23], marginal stability [24], and drift wave turbulence [25], which all have different dependencies on the plasma parameters.

The experimental study using Cluster data is based on the direct comparison of the shock front thickness with measurements of the wave activity in the ion-sound and lower hybrid frequency ranges in order to determine experimentally the relationship of the shock thickness on the plasma parameters. Cluster will provide new high resolution, three dimensional data on the Earth's bow shock. This will allow the investigation of both dispersive and dissipative subcritical shocks and will thus either confirm existing theories or lead to a new theoretical analysis. This study will also be performed at supercritical shocks.

4.3 *Quasi-parallel shocks.* The quasi-parallel shock is an notable example of wave activity together with various non-linear process and strong wave-particle interactions. This study is important not only for magnetospheric physics but also for the general physical problem of cosmic ray acceleration: it is the only likely in situ measurement of this sort. Most of the characteristics of plasma turbulence may be measured by Cluster and the waveform data are especially suitable for comparison with the particle distribution functions. We expect to use these data for coherence length measurements and direct calculation of diffusion coefficients for the different particle populations. The 3-dimensional Cluster measurements will provide data which are not yet available in computer simulations (which will act as a spur to such modelling). One particular interest is in the components of plasma turbulence, or SLAMS [26] and their role in particle acceleration.

4.4 *High frequency wave activity in the electron foreshock region.* In the Earth's foreshock region strong electron plasma emissions are observed. These emissions are thought to be induced by beams of electrons that are reflected from the bow shock and travel back along the solar wind field lines [27]. The only direct waveform measurements of the electric field in the electron foreshock region were made at Jupiter by the Voyager spacecraft. Plasma conditions at Jupiter were such that the oscillations were at very low frequencies and measurable by the Voyager wave receiver. Cluster will be able to make these waveform measurements at the Earth for the first time. This activity is likely to be accompanied by strong non-linear effects of wave-wave interactions (this is supported by the Jupiter data of Gurnett et al [28]). Such a turbulent field provides different non-linear phenomena, particularly correlations between such parameters as density fluctuations and electric field wave intensity. These non-linear correlations will be studied using bi-coherency analysis, non-linear correlation functions combined with the application of wavelet analysis [29, 30]. The four Cluster satellites will allow us to determine the turbulence characteristics in much more detail than previously [28]. The ion foreshock exhibits wave activity at lower (below 10 kHz) frequencies which is usually considered to be Doppler-shifted ion-acoustic noise. It is not understood why there is so much structure to this noise. How is it produced? The use of the multipoint Cluster measurements will help to determine the source and processes involved in these waves.

4.5 *Magnetosheath.* A major question concerning the waves in this region is their origin. Are they caused by processes at the bow shock, magnetopause or local hotspots? Possible studies include: correlation of the multipoint measurements of nonplanar wave fronts, wave-particle interactions e.g. whistler mode and electron thermal anisotropy, turbulence and velocity shears. Anderson [31] reported the occurrence of large amplitude impulsive bursts of noise within the magnetosheath. They appeared to be correlated with other bursts around the electron cyclotron frequency. Their estimate was that these bursts lasted for less than 8 milliseconds. Thus, in order to study these short lived events, very high time resolution data is required. This resolution should be available within the WEC instruments aboard Cluster.

4.6 *Magnetopause.* The appearance of low frequency mirror and electromagnetic ion cyclotron waves in the plasma depletion layer are linked to the geometry of the shock. These waves are observed mainly when the shock is quasi-perpendicular. The waves themselves are mutually exclusive, depending upon the local plasma conditions such as the anisotropy and $\beta$ factor. Present theoretical studies link the appearance of these mirror waves to the presence of $\alpha$ particles within the plasma.

The nature of the magnetopause and the processes that occur in its vicinity are very much open to question. The shape of the magnetopause and its position are governed by conditions within the solar wind plasma. Mass and momentum from the solar wind are transmitted across the magnetopause by 3 possible mechanisms namely magnetic merging, impulsive penetration and viscous/diffusive mixing of plasma. It is likely that all three mechanisms play a part, the size of their role depending upon the local plasma conditions. The magnetopause itself is characterised by several regions of differing plasma parameters. These layers have to be accounted for in any model of the magnetopause. The concept of magnetic merging was first discussed by [32] and evidence for its existence was discovered by Russell and Elphic [33]. These flux transfer events were signatures of the reconnection process occurring at the magnetopause. More recently, [34] has interpreted these events as changes in the magnetopause due to changes observed in the solar wind. The Cluster mission will allow the observation of these events in 3 dimensions. The high resolution data should allow the characteristics of these events to be determined. Due to the nature of its orbit, Cluster will be able to observe these events at both low and high magnetic latitudes. Attempts have been made to tie these events to signatures observed by groundbased magnetometers such as substorm commencements and sudden impulsive events [35, 36].

A mechanism for the impulsive penetration of plasma into the magnetosphere was proposed by Lemaire and Roth [37] using calculations based upon MHD. However, more recent studies by Owen and Cowley [38] point out that this mechanism cannot work within ideal MHD. The third mechanism, involving the viscous/diffusive mixing of plasmas has been the subject of many simulations. It is set up by the shear flow in the plasma velocity observed across the magnetopause. The resulting Kelvin Helmholz instability sets up eddies in the plasma boundary where it is thought that wave particle interactions may occur that give rise to the diffusion of particles across the boundary. The four Cluster spacecraft will allow us to look at the 3 dimensional structure of these vortices and the high time resolution data allows the characteristics of the waves to be determined as well as plasma and field gradients that provide the free energy source.

Waves with relatively high frequencies in the vicinity of the lower-hybrid frequency have been suggested yield sufficiently high diffusion coefficients in spatially localized regions to generate the Low Latitude Boundary Layer [39,40]. The important observation is that the resistivity produced by these waves even for non-localized conditions is sufficiently high to provide the resistivity required for magnetic reconnection in the magnetopause current layer especially if there is a guide field present.

A particular Cluster objective is the understanding of processes in the Cusp. Wave activity, such as we will study with the WEC data, is likely to be critical to our understanding of this region.

4.7 *Auroral regions.* High frequency wave measurements simultaneous with the flux of magnetic field-aligned accelerated particles will be combined with ground-based measurements of auroral phenomena to study acceleration processes. Direct in situ measurements from Viking [41] have shown fine structure in the wave activity, but there are questions about the extent of this region along the field lines and the consequences it has. The 3-dimensional Cluster measurements will allow us to understand the structure of these regions. A particular technique which will be used for auroral region studies will involve the characterisation of nonlinear electrostatic structures. This will be achieved by high-resolution time-domain studies using data from the EFW instrument..

4.8 *Remote sensing.* The source locations of waves may be determined from the wave vector measured at various spacecraft positions. This technique will be used by the WEC for various types of source and in various frequency bands. At high frequencies, for example at the frequency of Auroral Kilometric Radiation, the interferometric capabilities of the Wideband instrument will be used to resolve the source regions and structures.

4.9 *Measurements of elf chorus.* Cluster is in a strong position to understand some of the remaining problems associated with Chorus and other elf whistler mode waves. Chorus is essentially a non-linear phenomenon. There have been attempts to explain the origin of the individual chorus elements, see e.g. [42] (and references therein). The region in which the interaction between electrons and the whistler mode waves takes place is uncertain. The mechanism which saturates the wave growth is unclear, some mechanisms have proposed that a propagation effect is responsible. Observations have shown that chorus often has a two frequency band structure with elements both above and below $0.5 f_{ce}$. Another observation which is not yet fully understood is concerned with the general absence of conjugacy of chorus emissions between the two hemispheres. The specific study which is proposed here as an example of studies which can be performed using the Cluster spacecraft involves the measurement of plasma particles (electrons) and elf chorus wave on the spacecraft when they are fairly near the Earth and on field lines which connect with the auroral oval on the nightside or early morning sectors, or with field lines which enter the polar regions.

## 5. WEC Modes of Operation

Tables 3 and 4 give an indication of the range of modes of operation which the WEC instruments can support. Two out of every three orbits are expected to use rather "normal" modes, but the exact choice of which these will be has yet to be made. The third orbit will often be a special orbit with particular objectives such as exploiting a particular configuration with other satellites or instumental study. For the WEC the modes need be co-ordinated because of the complicated interaction between the capabilities of the individual instruments. Those who wish to suggest measurements should normally make contact with one of the WEC Pis listed in table 2.

## 6. Conclusions

The Cluster WEC experiments will offer many opportunities for space plasma physics and the study of solar-terrestrial processes. Among the capabilities (and not explicitely discussed in detail previously here) are:-

- the determination of those parameters which characterise plasma turbulence (distribution in the k-vectors) and small-scale field-aligned current structures (geometry, current density etc.) from interspacecraft correlations of field fluctuations.
- evaluation of magnetic vorticity, charge separation etc.
- wave/particle interactions, via correlations performed on-board using particle measurements from the PEACE instrument and analysis with wave data.
- measurements of plasma density and assessment of its spatial variations.
- the evaluation of spacecraft potential both as a scientific diagnostic and an engineering parameter.

The WEC has a policy of encouraging collaboration with theoreticians and experimentalists involved in other space and ground missions so as to ensure a full use of the dataset which will be collected during the mission.

| | | | |
|---|---|---|---|
| **Normal Bit Rate Basic Mode** (cycle time 28 seconds) | | | |
| | First 3 seconds of cycle | or first 4 seconds of cycle | rest of cycle |
| WHISPER | 4 - 80 kHz, 1.5 s resolution, active | 4 - 80 kHz, 2.15 s resolution, passive (natural) | |
| STAFF spectrum analyser | 3 B axes, autospectrum (1 s), cross spectra (4 s) resolution, in bands 8 - 64, 64 - 512 and 512 - 4096 Hz | | 3 B + 2 E axes, autospectrum (1 s), cross spectra (4 s) resolution, in bands 8 - 64, 64 - 512 and 512 - 4096 Hz |
| STAFF search coil | 0.1 - 10 Hz, 3 B axes | | |
| EFW | 0 - 10 Hz, 2 E axes, with antennas in voltage mode | | |
| Wideband | If on (depending on DSN coverage) probable mode covers 25 Hz - 9.5 kHz but others are possible | | |
| DWP Correlator | On, details of operation depend on mode of operation of PEACE | | |
| **High Bit Rate Basic Mode** (cycle time 28 seconds) | | | |
| | First 3 seconds of cycle | or first 4 seconds of cycle | rest of cycle |
| WHISPER | 4 - 80 kHz, 1.5 s resolution, active | 4 - 80 kHz, 0.32 s resolution, passive (natural) | |
| STAFF spectrum analyser | 3 B axes, autospectrum (0.125 s), cross spectra (1 s resolution), in bands 64 - 512 and 512 - 4096 Hz | | 3 B + 2 E axes, autospectrum (0.25 s), cross spectra (1 s resolution), in bands 64 - 512 and 512 - 4096 Hz |
| STAFF search coil | 0.1 - 180 Hz, 3 B axes | | |
| EFW | 0 - 180 Hz, 2 E axes, with antennas in voltage mode | | |
| Wideband | If on (depending on DSN coverage) probable mode covers 25 Hz - 9.5 kHz but others are possible | | |
| DWP Correlator | Off | | |
| **Normal Bit Rate Langmuir Mode** (cycle time 104 seconds) | | | |
| | First 4 seconds of cycle | rest of cycle | |
| WHISPER | 4 - 70 kHz, 2 s resolution, active | 4 - 80 kHz, 2.6 s resolution, passive (natural) | |
| STAFF spectrum analyser | 3 B axes, autospectrum (1 s), cross spectra (4 s resolution), in bands 8 - 64, 64 - 512 and 512 - 4096 Hz, or autospectrum (1, 0.5, 0.5 s) cross spectra (1 s resolution), in same frequency bands | | |
| STAFF search coil | 0.1 - 10 Hz, 3 B axes | | |
| EFW | 0 - 10 Hz, 1 E axis, plus 2 probes in current mode sampled at 25 samples/s | | |
| Wideband | If on (depending on DSN coverage) probable mode covers 25 Hz - 9.5 kHz but others are possible | | |
| DWP Correlator | On, details of operation depend on mode of operation of PEACE | | |
| **Normal Bit Rate Spin Synchronized Mode** (cycle time 129 spacecraft rotations) | | | |
| | 0 - 129 spins | | |
| WHISPER | 4 - 68 kHz, active with sounder synchronized to spin over a 516 s cycle | | |
| STAFF spectrum analyser | 3 B axes, autospectrum (1 s), cross spectra (4 s resolution), in bands 8 - 64, 64 - 512 and 512 - 4096 Hz, or autospectrum (1, 0.5, 0.5 s) cross spectra (1 s resolution), in same frequency bands | | |
| STAFF search coil | 0.1 - 10 Hz, 3 B axes | | |
| EFW | 0 - 10 Hz, 2 E axes or 0 - 10 Hz, 1 axis plus 2 probes in current mode sampled at 25 samples/s | | |
| Wideband | if on (depending on DSN coverage) probably mode covers 25 Hz - 9.5 kHz but others are possible | | |
| DWP Correlator | Normally off | | |

*Table 4 - The cycle of measurements within the WEC for some of the main WEC Operational Modes as listed in Table 3. Note that the detailed measurements in each part of these cycles must be interpreted by reference to the papers for the individual WEC instruments in the ESA SP1159 references at the end of this paper.*


## Acknowledgements

Most of the work which is described in this paper has been done by other members of the WEC who should take the credit for the hard labour over several years. The present and past WEC Chairs (A. Pedersen, F. Lefeuvre and A. Roux in reverse chronology) have guided the team from the initial stages of proposal preparation through to the current activity of detailed operational planning. The WEC PIs and their teams have been responsible for their individual instruments but have always been prepared to take a wider WEC view of activities. The ESA and spacecraft teams have been both professional and helpful during the integration and testing phases. Mike Hapgood kindly provided the orbital plots in figures 1 and 2. Volodya

Krasnosel'skikh, Thierry Dudok de Wit and Ruedi Treumann made valuable comments on an early draft of this paper. The various national funding agencies have enabled the work to performed in an efficient manner. Cluster is a part of the joint ESA NASA Solar Terrestrial Science Programme.

## References

1. Lefeuvre, F., A. Roux, B. de la Porte, C. Dunford, L. J. C. Woolliscroft, P. N. H. Davies, S. J. Davis, M. P. Gough, *The Wave Experiment Consortium,* ESA SP-1159, pp. 5-15, '93
2. Schmidt R. and M.L. Goldstein, *Cluster - a fleet of four spacecraft to study plasma structures in three dimensions,* ESA SP 1103, pp. 7-13, '88.
3. Dodsworth S.J. and M. Warhout, *Cluster ground segment and mission operations,* ESA SP-1159, pp.251-258, '93.
4. Schmidt R. and L.J.C. Woolliscroft, *The Cluster Science Data System - a distributed system to serve a wide international community,* ESA SP-1159, pp. 279-290, '93.
5. Woolliscroft, L. J. C., H. St. C. Alleyne, C. M. Dunford, A. Sumner, J. A. Thompson, K. H. Yearby, S. Chapman, M. P. Gough, N. Cornilleau-Wehrlin, A. Roux, P. M. E. Decreau, V. V. Krasnosel'skikh, F. Lefeuvre, M. Parrot, A. Egeland, D. Gurnett, G. Gustafsson, G. Holmgren, C. C. Harvey, R. Horne, I. B. Iversen, W. Kofman, H. C. Koons, J. A. LaBelle, F. Mozer, A. Reznikov, *Implementation of the Digital Wave-Processing Experiment,* ESA SP-1159, pp. 81-94, '93.
6. Cornilleau-Wehrlin, N., P. Chaveau, A. Meyer, J.M. Nappa, S. Perraut, L. Rezeau, P. Robert, A. Roux, M. Belkacemi, Y. de Conchy, L. Friel, C.C. Harvey, D. Hubert, R. Manning, F. Wouters, F. Lefeuvre, M. Parrot, J.L. Pincon, B. Poirier, F. Kofman, F., M.P. Gough, L.J.C. Woolliscroft, A. Pedersen, G. Gustafsson, D.A. Gurnett, *STAFF (Spatio-Temporal Analysis of Field Fluctuations) Experiment for the Cluster Mission,* ESA SP-1159, pp. 33-48, '93
7. Gustafsson, G., R. Bostrom, B. Holback, G. Holmgren, K. Stasiewicz, T. Aggson, R. Pfaff, L.P. Block, C.-G. Falthammar, P.-A. Lindqvist, G. Marklund, C. Cattell, F. Mozer, L. Roth, M. Temerin, J. Wygant, P. Decreau, A. Egeland, J. Holtet, E. Thrane, R. Grard, J.-P. Lebreton, A. Pedersen, R. Schmidt, D. Gurnett, C. Harvey, R. Manning, P. Kellogg, P. Kintner, S. Klimov, N. Maynard, H. Singer, M. Smiddy, K. Mursula, P. Tanskanen, A. Roux, L.J.C. Woolliscroft, *The Spherical Probe Electric Field and Wave Experiment for the Cluster Mission,* ESA SP-1159, pp. 17-31, '93
8. Gurnett, D.A., R.L. Huff, D.L. Kirchner, *The Wideband Plasma Wave Investigation,* ESA SP- 1159, pp. 69-79, '93
9. Décréau, P.M.E., P. Fergeau, M. Leveque, Ph. Martin, O. Randriamboarison, F. Sene, J.G. Trotignon, P. Canu, H. De Feraudy, A. Bahnsen, M. Jespersen, P.B. Mogensen, I. Iversen, C. Dunsford, A. Sumner, L.J.C. Woolliscroft, G. Gustafsson and D.A. Gurnett, *'WHISPER' - A Sounder and High-Frequency Wave Analyser Experiment,* ESA SP-1159, pp. 49-67, '93
10. Roux, A. and B. de la Porte, *Wave Experiment Consortium,* ESA SP-1103, pp. 21-23, '88
11. Woolliscroft, L.J.C., J.A. Thompson, P.M.E. Dcrau, M. Parrot, A. Egeland, I.B. Iversen, H.C. Koons, P.J. Christiansen, M.P. Gough, G. Gustafsson, G. Holmgren, D.A. Gurnett, D. Jones, J.A. LaBelle, N. Cornilleau-Wehrlin, A. Roux, V.V. Krasnosel'skikh, A. Reznikov, A., C.C. Harvey, W. Kofman, F. Mozer, *The Digital Wave Processing Experiment,* ESA SP-1103, pp. 49-54, '88
12. Johnstone A.D., C. Alsop, P.J. Carter, A.J. Coates, A.J. Coker, R.A. Gowen, B.K. Hancock, T.E. Kennedy, P.H. Sheather, R.D. Woodliffe, S. Burge, M. Grande, D.S. Hall, D.M. Kelsh, A. Preece, D.H. Reading, B.Narheim and Y. Meyerfeld, *PEACE: a plasma electron and current experiment,* ESA SP-1159, pp. 163-184, '93.
13. Dunford, C.M., L.J.C. Woolliscroft, H.St.C. Alleyne, A. Sumner, J.A. Thompson and K.H. Yearby, *Cluster Wave Experiment Modes and Timing - How They Will be Implemented by the Digital Wave Processor,* ESA WPP-047 Proceedings of START, Aussois, France, 31 January-5 February 1993, pp. 251-254, '93
14. Hoppe M. M., C. T. Russell, *Plasma rest frames and polarizations of the low-frequency upstream waves - ISEE 1 and 2 observations,* J. Geophys. Res., 88, 2021, '83.
15. Balikhin M.A ., M. E. Gedalin, *Comparitive analysis of different methods for distinguishing of temporal and spatial variations, in Proc. of Spatial-Temporal Analysis for resolving Plasma Turbulence,* Aussois, France, 31 January- 5 February, 1993, ESA WPP-47, p.183, '93.
16. Pincon, J.L. and F. Lefeuvre, *Local characterization of homogeneous turbulence in a space plasma from simultaneous measurements of field components at several points in space,* J. Geophys. Res., 96, pp. 1789-1802, '91.
17. Randriamboarison, O., V. Kravtchenko-Berejnoi, D. Lagoutte and F. Lefeuvre, *Analysis of models of nonlinear interactions by higher order statistics, in Proc. of Spatial-Temporal Analysis for resolving Plasma Turbulence,* Aussois, France, 31 January- 5 February, 1993, ESA WPP-47, p. 285, '93.
18. Marsch, E. and S. Liu, *Structure functions and intermittency of velocity fluctuations in the inner solar wind,* Annales Geophys., 11, pp. 227-238, '93.
19. Johnson, H., H.L. Pecseli and J. Trulsen, Phys. Fluids 30, 2239, '87.
20. Lagoutte, D., J.C. Cerisier, J.L. Plagnaud, J.P. Villain and B. Forget, *High-latitude ionospheric electrostatic turbulence studied by means of the wavelet transform,* J. Atmos. Terr. Phys., 54, pp. 1283- 1293, '92.
21. Mellott M. M., and E. W. Greenstadt, *Structure of oblique subcritical shocks,* ISEE1,2 observations, J. Geophys. Res., 89, 2151 '84.
22. Farris, M.H., C.T. Russell, and M.F. Thomsen, *Magnetic structure of the low beta, quasi- perpendicular shock,* J. Geophys. Res., 98, 15,285 '93.
23. Galeev, A.A., *Collissionless shocks* in Physics of Solar Planetary Environment, edited by D.J. Williams, p. 464, AGU, Washington D.C., '76.
24. Morse, D. L. and E. W. Greenstadt, *Thickness of Magnetic Structurees Associated with the Earth's Bow Shock,* J. Geophys Res. 81, 1791, '76.
25. Krall, N. A., *Drift Waves,* in Advances in Plasma Physics, Vol 1, p. 153, edited by Simon and Thomsen, New York, '68.
26. Schwartz, Steven J., D. Burgess, W. P. Wilkinson, R.L. Kessel, M. Dunlop and H. Luhr, *Observations of Short Large-Amplitude Magnetic Structures at a Quasiparallel Shock,* J. Geophys Res. 97, 4209, '92.
27. Filbert, P. C. and P. J. Kellog, *Electrostatic noise at the plasma frequency beyond the Earth's bow shock,* J. Geophys. Res. 84, 1369, '79
28. Gurnett, D. A., J.E. Maggs, D.L. Gallagher, W.S. Kurth and F.L.Scarf, *Parametric interaction and spatial collapse of beam-driven Langmuir waves in the solar wind,* J. Geophys. Res. 86, 8833, '81
29. Lagoutte, D., F. Lefeurvre and J. Hanasz. *Application of Bicoherence Analysis in the Study of Wave Interactions in Space Plasma,* J. Geophys. Res. 94, 435, '89.
30. Lagoutte, D., J. Cousier, J. Plagaurd, J. Villain and B. Forget, *High lattitude ionospheric electrostatic turbulance studies by means of the wavelet transform,* J. Atmos. and Terr. Res. 54, 1283, '92.
31. Anderson, R. R., C. C. Harvey, M. M. Hoppe, B. T. Tsurutani, T. E. Eastman and J. Etcheto, *Plasma waves near the magnetopause,* J. Geophys. Res., 87, 2087, '82.
32. Dungey, J. W., *Interplanetary field and the auroral zones,* Phys. Rev. Lett. 6, 47, '61
33. Russell, C. T. and R. C. Elphic, *Initial ISEE magnetometer results: Magnetopause observations,* Sp. Sci Rev. 22, 681, '78.
34. Sibeck, D. G., W. Baumjohann and R. E. Lopez, *Solar wind dynamic presure variations and transient magnetospheric signatures,* Geophys. Res. Lett., 16, 13, '89.
35. Sibeck, D. G., *Transient magnetic field signatures at high latitudes,* J. Geophys. Res., 98, 243, '93.
36. Lanzerotti, L. J., A. Wolf, N. Trivedi, C. G. Maclennan and L. V. Medford, *Magnetic impulse events at high latitudes: Magnetopause and boundary layer plasma processes,* J. Geophys. Res., 95, 97, '90.
37. Lemaire, J. and M. Roth, *Penetration of solar wind plasma elements into the magnetosphere,* J. Atmos. Terr. Phys. 40, 331 '78.
38. Owen, C. J. and S. W. H. Cowley, *Heikkila's mechanism for impulsive plasma transport through the magnetopause: A reexamination.,* J. Geophys. Res., 96,5565, '91.
39. Treumann, R.A., J. LaBelle and R. Pottelette, *Plasma diffusion at the magnetopause: the case of lower hybrid drift waves,* J. Geophys Res, 96, 16009-13, '91
40. Treumann, R.A., J. LaBelle and T.M. Bauer, *Diffusion processes: an observational perspective,* in Physics of the Magnetopause, ed. M. Thomson, B. Sonnerup and P.Song, AGU Monograph in press, AGU, March '95.
41. Louarn, P., A. Roux, H. de Feraudy, D. LeQueau, M. Andre, L. Matson, *Trapped electrons as a free energy source for the auroral kilometric radiation,* J. Geophys. Res. 95, 5983, '90.
42. Sazhin, S.S. and M. Hayakawa, *Magnetospheric Chorus Emissions: a Review,* Planet. Space Sci., Vol. 40, No. 5, pp. 681-697, '92

# Recording Alouette Data at Byrd Station, Antarctica, 1965

M. Trimpi

*Foreword by Rudolf Treumann, Associate Editor*

*The following contribution arose from a correspondence between Bob Benson (Goddard Space Flight Center) and Mike Trimpi (discoverer of the well known Trimpi Effect and now at Dartmouth College). Bob Benson is trying to save the Alouette topside sounder data from being erased and forgotten like many other possibly valuable satellite data from earlier missions. Mike had been informed about Bob's efforts by Dave Rupert, a Dartmouth graduate student who is working with Bob at Goddard. He remembered that during one of his Antarctic winter-over years, he and his co-worker, using somewhat primitive equipment, successfully recorded the Alouette II signals on a scheduled basis. He wrote the accompanying story in a letter to Bob who was so excited by it that he suggested it be published in the Radio Science Bulletin. Historical remembrances like this are of widespread interest and illustrate the enthusiasm and resourcefulness of the field operators. Here it is...*

In November 1964, Bill Burtis and I arrived at Byrd Station (80{S, 120{W), as winter-over operators of the Stanford University and Pacific Naval Laboratory experiments. This was a very busy summer. In addition to all the usual summer projects, a 16 foot dish was installed to collect data from the POGO satellite which was finally launched in October 1965. Shortly before our departure from Stanford it was decided to try to record some data from the Alouette II satellite which carried VLF and topside sounder experiments. These data came down at 136 MHz so the appropriate front end for the POGO receiver was purchased. No antenna was provided so in early March we constructed a five turn helical antenna using some copper tubing which had been purchased unwittingly in New Zealand for use on station but which, of course, did not fit U.S. plumbing fittings. The boom was built-up from plywood, screws, and glue in the shape of a tapered box section. Some wire screening (no intended station use was ever determined) supported by some discarded conduit bent more or less into a circle served as a reflector. A piece of three inch pipe, set so about four feet were above the snow surface, was the support. A 144 MHz preamp, designed for ham use, had its coils squeezed a bit by Nick Dunckel, then a graduate student at Stanford, until it became a 136 MHz preamp. This was a one nuvistor amplifier which was tended to oscillate when very cold. It had to be turned on for a certain time, which depended on the temperature, before the pass for optimum results. Steering the antenna was a manual operation. The receiver AGC signal was connected to a meter on the antenna counter-weight and a pilot light, powered by the preamp filament supply, provided illumination. In the nearly uniform darkness of the Antarctic night this small light immediately caught the attention of Jim Pranke, the aurora observer, who complained noisily about data contamination until a few on-off tests proved otherwise.

*Mike Trimpi is with the*
*6127 Wilder Laboratory*
*Department of Physics and Astronomy*
*Dartmouth College*
*Hanover, New Hampshire 03755, USA*

The VLF lab at Byrd was located about one-half mile from the main station. We walked this route in all weather, often making two or three trips daily depending on work and recording schedules. The building was in a short tunnel, the floor of which, at that time, was about thirty feet below the snow surface. Access was down a vertical shaftway having a hatch at the top. The recording procedure was as follows:

The antenna was tied so it was facing north. The telemetry was turned on by the Falkland Islands station so the azimuth was always nearly the same. The preamp was turned on at the appropriate time before the pass. Since we were never sure which experiment would be turned on, two tape recorders were prepared: a 1/4 inch, 15 ips, analog for the VLF and a 1/2 inch, 60 ips, FM for the sounder. As soon as it was determined which experiment was on, the appropriate recorder was set going, and, being dressed already for the occasion, one of us charged up the ladder, untied the antenna, and, using the remote AGC meter as guide, did his best to track the satellite. Often there was deep fading, particularly during disturbed periods, so the process often depended heavily on past experience. Unfortunately, this was not a very energetic operation and on some of the colder days (I recall a somewhat windy -62 degrees Celsius) it was fortunate the telemetry stopped after about fifteen minutes. Once Bill did a pass during a very high wind. The surface was hard and well polished and just staying on one's feet while standing still required some skill without having to wrestle with the antenna which had less than optimum aerodynamic characteristics. There were some telemetry drop-outs not due to propagation effects!

The VLF data were monitored aurally and descriptions were sent to Stanford and CRC in Ottawa. We found an old ionosonde camera and mounted this on an oscilloscope which had its Z axis modified for an external input. With these we were able to generate ionograms which, of course, did not look like anything seen before - by anyone at Byrd, anyway. To describe what we saw, Bill and I devised a numerical code which was compatible with the message handling capabilities at that time and sent some data to Ottawa. They could not make sense of it. Communications were not good then; there is no telling what errors occurred between Byrd and Ottawa. After the original tapes and our ionograms found their way to Ottawa we received a letter at Stanford asking how we were able to extract the sounder sync signal to trigger the Uscope when the telemetry was poor. My recollection is that it required two transistors, three resistors, one capacitor, and a flashlight battery. We had made better ionograms with our make-shift rig than they could!

# Lille General Assembly 1996

**XXVth GENERAL ASSEMBLY OF THE INTERNATIONAL UNION OF RADIO SCIENCE**

Lille Grand Palais, Lille, France
August 28 - September 5, 1996

**Areas covered by the scientific programme:**

| | |
|---|---|
| Electromagnetic Metrology | Wave Propagation and Remote sensing |
| Fields and Waves | Ionospheric Radio and Propagation |
| Signals and Systems | Waves in Plasmas |
| Electronics and Photonics | Radio Astronomy |
| Electromagnetic Noise and Interference | Electromagnetics in Biology and Medicine |

Call for papers, guidelines for abstracts and subjects of the sessions and other information on the URSI General Assembly may be obtained from:


AG URSI
Secrétariat Pr. P. Degauque,
Université de Lille 1
F-59655 Villeneuve d'Ascq Cedex, France
Tel: (33) 20 33 72 06 Fax : (33) 20 33 72 07
email: agursi@univ-lille1.fr
server:http://www.univ-lille1.fr/ursi


**XXVème ASSEMBLEE GENERALE DE L'UNION RADIO-SCIENTIFIQUE INTERNATIONALE**

Lille Grand Palais, Lille, France
28 août - 5 septembre 1996

**Domaines couverts par le programme scientifique:**

| | |
|---|---|
| Métrologie électromagnétique | Propagation des ondes et télédétection |
| Ondes et champs | Radioélectricité ionosphérique et propagation |
| Signaux et systèmes | Ondes dans les plasmas |
| Electronique et photonique | Radioastronomie |
| Bruits et brouillages électromagnétiques | Electromagnétisme en biologie et médecine |

La première annonce, l'appel à communications et les sujets des différentes sessions peuvent être obtenus à l'adresse suivante:


AG URSI
Secrétariat Pr. P. Degauque,
Université de Lille 1
F-59655 Villeneuve d'Ascq Cedex, France
Tel: (33) 20 33 72 06 Fax : (33) 20 33 72 07
email: agursi@univ-lille1.fr
serveur:http://www.univ-lille1.fr/ursi


The Coordinating Committee of URSI (consisting of the Commission Chairs, the Chair of the Scientific Committee and the Officers of the Board) met in Brussels on 24-25 April, 1995, and discussed the main features of the scientific programme with Professor H. Matsumoto, Coordinator, and Dr. J. Hamelin, Assistant Coordinator.

More details about the scientific programme will follow in future issues of the Radio Science Bulletin.

Dr. J. Hamelin gave us the following titles for the General Lectures and Tutorials (together with potential lecturers) :

### General Lectures

- *Lightwave Communications*, M. Joindot, France
- *From Coherence to Confusion : a conservative SAR view*, R.K. Raney, USA
- *Nonlinear Physics and Chaos*, W. Lauterborn, Germany

### Guest Lecture

- *Radio Science, Pulsar and General Relativity* (J.H. Taylor, Nobel Prize, USA)

### Tutorials

Com. A *Counting of single flux and single charge quanta for metrology*, J. Niemeyer, Germany

Com. B *High frequency methods in electromagnetics*, R. Tiberio, Italy

Com. C *Communications by means of low earth orbiting satellites*, R.L. Pickholtz, USA

Com. D *Optoelectronics integration*, H. Burkhard, Germany

Com. E *Topology-based modelling of very large EM systems*, P. Degauque J.P. Parmentier, France

Com. F *Impact of numerical methods on propagation modeling*, K.H. Craig, U.K.

Com. G *The Equatorial Ionosphere*, B.M. Reddy, India

Com. H *Radio emission from instabilities in space plasmas: marginal stability, stochastic growth and fine structures*, D.B. Melrose, Australia

Com. J *Cosmic MASERS - a useful tool in Radio Astronomy*, J.M. Moran, USA

Com. K *Personal communication services - Technology and Health Concerns - Is there a common solution?*, M.A. Stuchly, Canada

## CONFERENCE REPORTS

# LES 8ÈMES JOURNÉES INTERNATIONALES DE NICE SUR LES ANTENNES (JINA 94)

Nice, France, 8 - 10 November 1994

*The eight edition of the JINA International Symposium on Antennas was held November 8-10, 1994 at the Acropolis Conference Center in Nice, France. The torrential rainfall and subsequent flooding which closed down the Nice-Côte d'Azur International Airport did not discourage almost 320 participant representing 30 countries from attending this bi-annual event..*
*The three-day technical program included four sessions of invited papers and posters, one session of invited papers and short talks, and a special session of invited contributions on recent developments in communication satellite antennas. Two keynote address were give by Prof. Bolomey of the Ecole Supérieure d'Electricité, on the occasion of this institution's centennial and 100 years of radio, and by Prof. Wen-Xun Zhang, from Southeast University on antenna theory and applications in China*
*This year, the JINA Award recipient was Dr Alan J. Fenn of MIT Lincoln Laboratory, for his poster entitled "Minimally Invasive Monopole Phase Arrays for Hyperthermia Treatment of Breast Cancer".*

Les 8èmes Journées Internationales de Nice sur les Antennes (JINA 94) se sont déroulées au centre de congrès Acropolis, à Nice (France), du 8 au 10 novembre 1994. Le Comité Scientifique a réparti en cinq sessions les 160 communications, sélectionnées parmi les 260 propositions reçues. Les sessions techniques étaient les suivantes : théorie et modélisation des antennes, surface équivalente radar (SER), mesures, applications industrielles et médicales, antennes à réflecteurs et antennes réseaux.
Les pluies torrentielles et les inondations qui ont provoqué notamment la fermeture de l'aéroport Nice Côte d'Azur deux jours avant le début du colloque, n'ont pas découragé les participants, venus aussi nombreux que les années précédentes. L'assistance, qui totalisait 312 personnes, comptait environ 40% d'étrangers, dont la participation est en légère hausse par rapport à 1992. Les délégués russes et ukrainiens, bénéficiant d'une aide des organisateurs et d'organismes externes, ont été particulièrement nombreux cette année (16 personnes).
Parmi les faits marquants de ces Journées : un exposé par le Professeur Zhang Wen-Xun (Southeast University, Nanjing, R.P. Chine) sur les études et réalisations d'antennes en Chine, et un survol, par le Pr. Bolomey de l'Ecole Supérieure d'Electricité, de 100 ans d'évolution des antennes et son impact sur leur enseignement, à l'occasion d'un double centenaire, celui de la radio et celui de l'Ecole Supérieure d'Electricité.
Les tendances majeures qui ressortent des communications présentées lors de ces journées sont résumées ci-dessous, par session.

**Session 1 - Théorie et modélisation des antennes**
Les méthodes hybrides, réunissant deux ou plusieurs approches théoriques ou numériques ont atteint un stade de maturité tel qu'elles permettent de traiter des problèmes autrefois rédhibitoires (analyse fine du comportement des antennes dans un environnement complexe, par exemple) ou d'obtenir des résultats plus précis pour des problèmes connus. L'utilisation de processeurs parallèles ou vectoriels, le développement d'algorithmes de plus en plus performants, ont également contribué à la compréhension détaillée des phénomènes physiques intervenant dans les structures rayonnantes, tout en maintenant un temps de calcul raisonnable.
La méthode "FDTD" (différences finies dans le domaine temporel) est couramment appliquée pour l'analyse d'antennes, en particulier pour les postes de radiotéléphonie mobile, lorsque le problème comprend un milieu inhomogène (la tête de l'interlocuteur, par exemple). Ces deux thèmes ont fait l'objet des conférences invitées de MM. L.N. Medgyesi-Mitschang (MacDonnell Douglas Aerospace) et L. Wolff (Duisburg University), respectivement.
On constate également, par le nombre de papiers présentés, un intérêt croissant pour de nouveaux matériaux, de type chiral ou bi-anisotrope, et pour de nouveaux types de surfaces "dures et molles", dont la caractéristique principale est d'être conducteur électrique parfait pour une polarisation linéaire et conducteur magnétique parfait pour la polarisation orthogonale.

**Session 2 - Surface équivalente radar**
Les présentations de cette session, particulièrement dense avec 25 présentations orales, ont confirmé l'importance des méthodes hybrides, évoquées plus haut. Les auteurs

invités, MM. J.M. Rius (Université de Catalunya) et R.D. Graglia (Politecnico di Torino) ont exposé respectivement une approche graphique (GRECO) au calcul de l'aire équivalente d'objets complexes, et un ensemble de techniques récentes pour traiter ce type de problème. L'accent a été mis sur les derniers développements dans les méthodes de type "équations intégrales" : approches itératives pour la solution de grands systèmes linéaires, méthodes pour obtenir des matrices peu denses et l'introduction de nouvelles fonctions de développements en série (d'ordre supérieur) permettant de réduire le nombre d'inconnues et/ou d'améliorer la précision des résultats.

**Session 3 - Mesures, applications industrielles et médicales**

Les conférences invitées, présentées par MM. Lefeuvre (ENSEEIHT) et Kagoshima (NTT), ont été consacrées respectivement aux antennes utilisées dans les fours à micro-ondes, et aux antennes pour communications avec les mobiles.

Parmi les affiches traitant des mesures d'antennes (près de la moitié des présentations de cette session), les bases compactes et les techniques holographiques pour la correction d'erreurs sur les grands réflecteurs ont représenté des thèmes majeurs.

L'hyperthermie dans le traitement médical a fait l'objet de quatre communications, et la transmission d'énergie de deux communications.

**Session 4 - Antennes à réflecteurs**

Le premier conférencier invité, T. Bird (CSIRO) a proposé un survol des activités en Australie concernant les antennes à réflecteurs. Ensuite, P. Kildal (Chalmers University of Technology) a fourni une description détaillée du développement d'une nouvelle source primaire à deux réflecteurs pour l'antenne de radioastronomie (305 m de diamètre) d'Arecibo.

Les présentations affichées ont confirmé la maturité des techniques de synthèse de réflecteurs conformés, et l'intérêt de telles structures, associées avec des réseaux comme source primaire, pour obtenir des faisceaux conformés et reconfigurables.

Enfin, en vue de nouvelles applications telles que les liaisons inter-orbitales, des solutions comprenant des réflecteurs avec balayage mécanique et électronique, ou un système de six réflecteurs (antenne Cassegrain alimentée par un "beam waveguide" à quatre réflecteurs) ont été élaborées.

**Session 5 - Antennes réseaux**

La conférence invitée présentée par G. Caille (Alcatel Espace), a été consacrée aux antennes pour l'observation de la terre, et en particulier, les applications qui font ou feront appel à l'utilisation d'antennes réseaux, telles que la transmission de données d'acquisition ou les radars imageurs à synthèse d'ouverture.

Les présentations affichées ont traité aussi bien de réalisations de réseaux que d'éléments rayonnants isolés, la présence de ces derniers étant justifiée par le fait que leur étude s'inscrit dans une optique d'intégration ultérieure dans un réseau. Les techniques de balayage et de traitement du signal ont également été abordées lors de cette session. Enfin, le nombre important de papiers sur les antennes microrubans fonctionnant en polarisation circulaire témoigne de la vitalité des recherches dans le domaine des antennes pour mobiles.

Réalisatons récentes dans le domaine des antennes pour satellites de télécommunications

Cette session spéciale, organisée pour la première fois par A. Roederer (ESA/ESTEC) et B. Mathieu (DGA), a réuni huit constructeurs et organismes parmi les plus importants du monde, dans le domaine des antennes embarquées.

Les réflecteurs conformés on, été traités par C. Prud'hon, de l'Aérospatiale, qui a décrit les grandes antennes déployables développées par le système N-STAR, et par T. Chwalek, Hughes Space and Communications Company, qui a présenté les antennes DIRECTV et Panamsat.

Les programmes internationaux INTELSAT et INMARSAT ont fait l'objet de deux exposés. B. Le Stradic, Matra Marconi Space, a mis l'accent sur le projet INMARSAT 3, et l'utilisation de la première antenne spatiale de type semi-active avec matrices d'amplificateurs. W. Bornemann, Deutsche Aerospace, a présenté les deux antennes bande C d'INTELSAT VIII pour la couverture semi globale et régionale ; ces dernières, particulièrement complexes, comprennent un réflecteur illuminé par un réseau décalé optimisé de 96 éléments, pour la génération de neuf faisceaux conformes.

Pour les communications avec les mobiles, les antennes embarquées doivent rayonner des puissances élevées afin de compenser les faibles niveaux de petits terminaux terrestres. L'élimination des interférences, dues au produit d'intermodulation, constitue un des défis majeurs aujourd'hui, puisqu'une isolation d'au moins 70 dB est exigée entre les voies réception et émission. Ce problème a été traité par S. Gupta (Spar Aerospace) lors d'une présentation des antennes fonctionnant en bande L pour le programme MSAT, et par G. Duret, qui a présenté les activités d'Alcatel Espace dans ce domaine.

Les antennes pour le satellite scientifique ARTEMIS qui regroupera trois charges utiles (transmissions de données en bande S et Ka, communications entre mobiles terrestres en bande L et une liaison optique expérimentale entre satellites) ont été présentées par G. Di Fausto (Alenia Spazio).

Enfin, A. Fenn (PIT Lincoln Laboratory) a présenté une antenne réseau adaptative, fonctionnant dans la bande 43,5-45,5 GHz (UHF), capable d'annuler des interférences provenant d'une source située à moins de 0,1° par rapport à l'utilisateur, sur une large bande de 2 GHz.

**Prix JINA**

Le Prix JINA 94 a été décerné au Dr. Alan Fenn du MIT Lincoln Laboratory, pour sa présentation d'un réseau de monopoles utilisé dans le traitement du cancer du sein.

**Recueil des communications**

Le recueil des communications présentées lors des JINA 94 est disponible au prix de 700 FF. frais d'envoi compris, auprès du Groupe Régional Côte d'Azur de la SEE, 32 avenue Malausséna, F-06000, Nice, France.

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

24-28 April 1995, Warsaw, Poland

The Workshop was organized by the Space Research Center of the Polish Academy of Sciences. It was co-sponsored by URSI through its Commissions G and H as a part of the activity of the Joint Working Group CGH.1 Wave and Turbulence Analysis , and SCOSTEP through the Project on Global Aspects of Plasma Structures (GAPS) of the Solar-Terrestrial Energy Program (STEP). Additional support was provided by the Polish Committee on Research and the Space Research Center. We wish to thank all the sponsors for their financial help.

Originally it was planned to hold the meeting in Zakopane, Poland, but financial restrains forced the organizers to change the venue.

The Workshop was aimed at meeting specialists, theoreticians and experimenters, in the nonlinear processes such as turbulence, chaos, wave interactions in the natural and artificially modified near-Earth environment, and laboratories.

The members of the Programme Committee were Su. Basu (USA), L.M. Erukhimov (Russia), F.Lefeuvre (France), K. Schlegel (Germany), K. Stasiewicz (Sweden), A.J. Turski (Poland) and A.W. Wernik (Poland). The Organizing Committee was chaired by A.W. Wernik (Poland).

The Workshop was attended by 54 scientists from Canada, France, Germany, the Netherlands, Norway, Poland, Russia, UK, and USA presenting 45 papers. A broad scope of subjects related to the theory and observations of nonlinear processes has been presented. Papers were grouped in 7 topical sessions: (1) Application of Nonlinear Dynamics Methods to the Ionosphere-Magnetosphere System Studies, (2) Nonlinear Waves and Wave-Wave Interactions in the Ionosphere-Magnetosphere System, (3) Nonlinear Effects in Artificially Modified Plasma, (4) Nonlinearities in the Interplanetary Plasma, (5) Plasma Irregularities and Turbulence, (6) Gravity Waves and TIDs, (7) Nonlinear Processes in Plasmas: General. Contributed papers presented at each session have been preceded be one or two invited papers given by the leading scientists.
A special item on the program was a series of lectures on "Wavelets and Wavelet Packets Transform: Theory and Applications" delivered by Dr. M. Farge of Laboratoire de Me'te'orologie Dynamique du CNRS. Wavelet transform is a new tool in studying turbulence and fluid dynamics and its use in the analysis of turbulence in the ionosphere, magnetosphere and solar wind, holds a great promise. Now wonder that extremely interesting and informative lectures attracted a lot of attention of the Workshop participants.

Two general lectures have also been given: (1) "Solitons in Plasmas" by E. Infeld (Poland), and (2) "Introduction to the Analysis of Multilinear Systems From Higher Order Statistics" by F. Lefeuvre (France). The first one gave a general review of the theory and results of numerical simulations of solitons interaction, disintegration and decay. The second one introduced the audience to the basic notion and application in space experiments of the higher order statistics (multispectra, multi- coherence etc.).

During the informal, open discussion on various problems related to the study of nonlinear processes in plasmas it has been pointed out that new techniques of data analysis, such as multispectral and fractal analysis, wavelet transform etc., provide information not present in the conventional spectral analysis and should be used to solve outstanding problems of wave-wave interactions and turbulence.

Several papers presented at the Workshop will be published in a special section of the EGS journal "Nonlinear Processes in Geophysics".

Andrzej W. WERNIK

# The Low and Equatorial Latitudes in the IRI

New Delhi, India, 9 - 13 January 1995

The 1995 workshop of the International Reference Ionosphere (IRI) was held at the National Physical Laboratory in New Delhi, India from 9 to 13 of January, 1995. This was the first IRI workshop in India and quite fittingly the topic was the modelling of the low-latitude ionosphere. The IRI working group was greatly honoured by the fact that the IRI Workshop was made part of the Diamond Jubilee celebrations of the Indian National Science Academy (INSA) which took place during this same time period. The festive inauguration of the IRI workshop on Monday morning was highlighted by the inaugural address of Prof. S.K. Joshi (President of INSA). Prof. E.S.R. Gopal (Director of NPL), Dr. A.P. Mitra (Chair of LOC), Dr. D. Bilitza (IRI Chair), and Dr. D. Anderson (VIM Chair) extended their welcomes to the workshop participants and Dr. K.K. Mahajan (Local Organizer) concluded the inaugural session with his vote of thanks. Support from the local organizers was excellent during all phases of the meeting. A special vote of thanks from all participants goes to Dr. K.K. Mahajan and his team who made it all possible through their untiring efforts before, during and after the workshop. We all greatly enjoyed the warm hospitality of our Indian hosts and we will never forget our very special trip to Agra and Taj Mahal. The workshop convened under the sponsorship of COSPAR, URSI, COSTED, TWAS, ISF/Soros, IAGA, INSA and CSC, COSPAR, COSTED, URSI, TWAS, INSA and ISF provided also direct financial support for participants from developing and post-communist countries. Of the more than 60 participants about half were from India and the other half from Brazil, Czech Republic, Taiwan, China, Russia, Japan, England, Poland and USA. The host country was represented by scientists from ISRO Bangalore, PRL Ahmedabad, VSSC Trivandrum, Saurashtra U. Rajkot, Delhi U., Dibrugarh U., Andhra U. Visakhapatnam, Govt. College Bareli, Barkatullah U. Bhopal, and NPL Dew Delhi. The more than 70 papers were grouped into the following 10 sessions : Low latitude data and comparisons with IRI; Theoretical Studies; Scintillations, Spread-F and other Irregularities; Verification of Ionospheric Models; F-Region Improvements; Ion Composition; Regional Models and Mappings; TEC and Tomographic Studies; Topside and Plasmasphere; D-Region. A half-day session on Wednesday was reserved for the Validation of Ionospheric Models (VIM) effort of URSI Working Group G.4 (D. Anderson, AFPL, Chair); this activity is closely correlated with the URSI/COSPAR IRI effort. A Final Discussions and Decisions session on Friday afternoon concluded the workshop. Following the trend of recent IRI meetings, increasing weight is now being put on regional modelling/ mapping, on results from computer simulations that could benefit the IRI modelling, and on accurate representation of the total electron content (TEC), which is the ionospheric parameter most important for a wide range of applications/ forecast; this is in addition to the more traditional statistical, comparative IRI studies involving large data volume. Data sources used in comparative studies presented at this workshop included : (i) TOPEX and ACTIVE satellite data, (ii) Total Electron content (TEC) data from equatorial ground stations to the Navy Navigation Satellite System (NNSS), to FLEETSAT, and to ETS, (iii) Indian, Russian and Brazilian rocket data from equatorial rocket flights, (iv) data from low-latitude ionosondes (digisondes and earlier instruments), (v) data from incoherent scatter and HF radars at low latitudes.

## TEC STUDIES

Faraday rotation TEC measurements over New Delhi from 1977 to 1980 show reasonable agreement with IRI; IRI, however, does not reproduce the distinct postsunset maximum that is observed during winter and equinox (L. Singh, J. Gupta, T. Tyagi, NPL, India). M. Abdu (INPE, Brazil) reviewed IRI studies with data from the Brazilian longitude sector. Overall good agreement was found. However, a number of specific problems are noted that need to be addressed. In particular, it was found that at equatorial latitudes IRI overestimates TEC at low solar activity and underestimates TEC at the anomaly-crest-stations Rajkot, India (K. Iyer) and Luping, Taiwan (K. Cheng). Using the Luping TEC data K. Cheng confirmed that the equator anomaly is mainly a daytime phenomenon (sunrise to almost midnight) and that the winter crest is usually larger than the summer crest. IRI describes the diurnal occurrence pattern correct but not the winter maximum. Further studies were initiated. Using IRI with a ionospheric-effective solar index (IG, IF, T) instead of the pure solar indices (Rz, F10.7) should provide a better agreement at high solar activities. It is especially important to combine the TEC data with ionosonde data for the peak to establish the cause for the remaining discrepancy (peak or topside?). [Efforts continue : Abdu, Cheng, Iyer]. TEC values deduced from TOPEX altimeter measurements provide a global mapping of the equator anomaly region in the ocean areas with a 10-day repeat cycle. The data show considerable longitudinal and seasonal differences in the location and magnitude of the anomaly crests reflecting the influence of the neutral wind and the ExB ion drift (Bilitza, NSSSDC, USA). Interesting first results were presented from tomographic studies across the equator anomaly region at American longitudes (J. Klobuchar, D. Anderson et al., AFPL, USA) and dual frequency signals and both teams are in the process of setting up more receiving stations to improve the quality of their tomographic reconstruction. The Taiwanese team uses IRI to specify initial conditions.

## MIDDLE IONOSPHERE

Data from the incoherent scatter radar at Arecibo, Puerto Rico have contributed largely to the development and improvement of the IRI electron density model in the middle ionosphere. K. Mahajan (NPL, India) reviewed the earlier studies as well as possible future improvements. In a joint contribution with T. Gulyaeva (IZMIRAN, Russia) an improved low latitudes formula for the half-density has been proposed. This will be included in the next version of IRI (Modifications of the IRI half density option for low latitude : Gulyaeva, Mahajan and Sethi). B. Reinisch (ML, USA) used data from several digisondes operating at low latitudes to study the electron density profile between the E and F peaks. The dominant IRI parameters in this altitude range are strongly biased towards mid-latitudes because of the global unevenness of the underlying data base. Following a recommendation that was made at last year's IRI task force activity at ICTP (Trieste, Italy), his team investigated the density and gradient at a fixed height (170 km) rather than at the height of the F1 ledge, which typically varies by 10-20% from day to day. It was suggested to also study the density variation at a second fixed height in the 180-190 km range; the difference between the two points would then provide the density gradient. Inclusion of these two points in IRI should lead to a better representation of the electron density in the F1-region. The UML team also presented a better algorithm for obtaining monthly average representative profiles (MARP). [N170 and N185 : Reinisch and Digisonde community; Radicella and ICTP team]. The IRI model in the E-F region was also compared with several station-years worth of data from China (X.-Y. Huang and S.-R. Zhang, Wuhan, China), from Argentina (M. Mosert de Gonzalez, Argentina), and from Arecibo, Puerto Rico (V. Pandey and N. Sethi, NPL, India). Although overall IRI represents the most important trends, specific discrepancies were noted and need to be further investigated. N. Sethi (NPL, India) fitted a combination of 4 LAY functions to Arecibo E-F region profiles and proposed a number of improvements for the parameters used in the current implementation of the IRI LAY-option.

## THEORETICAL STUDIES

Interesting new results obtained with the Sheffield University Plasmasphere Ionosphere Model (SUPIM) were presented by G. Bailey and N. Balan (Sheffield U., U.K.). Studying the effect of the neutral winds in different longitude sectors they were able to explain the longitudinal differences in the inter-hemispheric asymmetry of the anomaly. During prenoon hours when the upward drift is large and the plasma flows towards the equator from both hemispheres they find an additional peak/layer ("G-layer") a few 100 km above the F layer. Y. Su, K. Oyama et al. (ISAS, Japan) find that SUPIM reproduces quite well the electron densities and temperatures measured by the HINOTORI satellite at 600 km altitude, if the ExB drift and the neutral winds are reasonably adjusted. A discrepancy between IRI and observations, that was often mentioned during this workshop, involves the F peak height hmF2. IRI does not reproduce the characteristic evening peak in hmF2 observed at the magnetic equator. This feature is closely related to the sharp spike in upward ion drift at that time. D. Anderson (AFPL, USA) showed how this aspect of IRI could be improved using parameters from his Parameterized Ionospheric Model (PIM). PIM is based on a theoretical model that includes as input the Jicamarca ion drifts, and thus provides a much better representation of the equatorial hmF2 in the evening. D. Anderson offered to provide analytic representations of the PIM hmF2 and F layer thickness parameters and it was decided to include these as a new PIM option in IRI. Outside the equator anomaly region good agreement is found between hmF2-IRI and observations, as was shown by V. Pandey and N. Sethi (NPL, India) for Arecibo incoherent scatter data. [PIM formulas : Anderson]. First results of their respective modeling efforts were presented by the Wuhan/ICTP modeling team (S.-R. Zhan, Wuhan, China), by K.S. Murthy (Andhra U., India) and by M. Goel (NPL, India). Modeling efforts of the ICTP/Wuhan team are focussed on the lower transition height (atomic to molecular ions). Their theoretical results favour the formula established by W. Oliver (1975). Efforts are currently underway to include the transition height as a separate parameter in IRI; the Oliver model would be an excellent candidate for this project. [Transition heights in IRI : Bilitza, Danilov, Zhang].

## ELECTRIC FIELD, ION DRIFT, AND SPREAD-F

B. Krishna Murthy (Trivandrum, India) reviewed studies of the F region electric field in the low-latitude ionosphere with particular emphasis on the work done at this equatorial station stressing the similarities and differences to results from Jicamarca. Data from an All-Indian HF Doppler radar network (dip=0-42N) were used by O. Nagpal (U. Dehli), J. Shastri (Bangalore), and C. Raghava Reddi (Trivandrum) to study the contribution of electric fields and meridional winds to the F-region plasma vertical drift. N. Balan and G. Bailey (U. Sheffield, U.K.) find that vertical drifts deduced from hmF2 measurements at Trivandrum (India) agree favourably with Jicamarca incoherent scatter measurements but differ significantly from Trivandrum HF Doppler data. [Bilitza to contact B. Fejer and his team about participation in the IRI ion drift modeling.]. Spread-F and Sporadic-E occurrence statistics for the Indian sub-continent were presented by R. Saksena (NPL, India) based on data from this longitude sector. K. Iyer et al. (Rajkot, India) compared scintillations obtained near the anomaly crests with the scintillation models of Aarons (AFPL) and Basu (AFPL) and suggested suitable modifications. Scintillation and Spread-F occurrence statistics were also reported for Waltair (P. Sriram et al., Andhra U., India) and China (X.-Y. Huang and S.-R. Zhang, Wuhan, China). A diffracting lenses simulation of scintillation patterns in the ionosphere was discussed by R. Dabas and D. Lakshmi (NPL, India). A special IRI task force was established under the leadership of M. Abdu (INPE, Brazil) to establish/recommend Spread-F/Scintillation models for inclusion in IRI. [Spread-F task force : Abdu, Basu, Saksena, Iyer, Matuura/Maruyama].

## GLOBAL AND REGIONAL MAPPING OF F-PEAK PARAMETER

S. Shastri, S. Aggerwal and N.K. Sethi (NPL, India) compared the IRI/CCIR maps for the F peak critical frequency foF2 with several years of data from three Indian stations stretching across the anomaly region (Kodaikanal, magnetic equator; Ahmedabad, anomaly crest; Delhi, outside anomaly). They find good agreement at low and medium solar activity but large discrepancies for K and A during high solar activity with IRI overestimating the measured foF2 (contrary to the trend observed in TEC!). This might be attributed to the movement of the location of the anomaly crests with solar activity (due to the increase in neutral winds) and to the insufficient representation of this effect in IRI. Jiao Peinan and Wu Jian (Xinxiang, China) described the Chinese Reference Ionosphere (CRI) and the solar activity index Ic and the Asia-Oceania Region (AOR) F-peak mapping used in CRI. A regional model for F-peak parameters over the Indian subcontinent was presented by S. Aggerwal (NPL, India). P. Bhuyan (Dibrugarh U., India) used data from four Indian stations to establish a model for the 75° E meridian. Comparisons with IRI high-light the advantages of these regional models/maps. Inclusion of some the regional maps presented during this and the previous IRI workshop are planned for a future edition of the IRI model. [Inclusion of PRIME maps : Mikhailov]. An empirical model for TEC at Luping, Taiwan was presented by St. Jain (Bareli, India). The low-latitude electron density and temperature in the height range 500 to 2500 km was modelled based on data from the ACTIVE satellite (L. Triskova, Praha, Czech Rep.).

## TOPSIDE AND PLASMAPSPHERE

V. Pandey and N. Sethi (NPL, India) find that topside data from the Arecibo incoherent scatter radar are consistently below IRI predictions. This is in contrast to the equatorial ionosphere where IRI has been shown to underestimate the topside densities measured by the radar at Jicamarca, Peru. K. Oyama et al. (ISAS, Japan) further pursued the mapping of HINOTORI electron temperature and density data at the satellite altitude of 600 km. I. AKEBONO-based model with IRI. [Continuing efforts : Kimura, Oyama, Bilitza].

**LOWER IONOSPHERE**

S. Gupta (Ahmedabad, India) gave an overview of Indian rocket measurements and comparisons with IRI. Electron density profiles obtained from rockets launched from Thumba and SHAR in India were discussed and interpreted by S. Prakash (Ahmedabad, India). A.P. Mitra (CSIR, India) reviewed Indian measurements and modeling activities in the region below 100 km down to stratospheric and Tropospheric altitudes. Rocket data are particularly important for the improvement of IRI in the E- and D-regions. Unfortunately only a rather limited set of measurements exists for low latitudes. A. Danilov (IAG, Russia) compared the IRI ion composition with measurements from rockets launched from Thumba, India and from Russian research vessels and suggested appropriate low-latitude modifications of the IRI model. At last year¿ ¿s IRI meeting it was decided to include in IRI the D-region models of Friedrich (Graz, Austria) and A. Danilov (IAG, Russia); incorporation of these two new options is currently underway. [D-region team : Friedrich, Danilov, Kopp, Singer].

**MISCELLANEOUS**

It was suggested (and accepted) to allow input of measured M(3000)F2 values if available for computation of the F2 peak height hmF2.

P. Pasricha, S. Aggerwal and S. Shastri (NPL, India) pointed out that traditional RMS-type descriptions of ionospheric variability underestimate the actual hour-to-hour, day-to-day, or month-to-month variability due the non-random nature of foF2 variations.

A. Mikhailov (IAG, Russia) discussed equatorial F-region storm effects and their dependence on changes in the neutral gas composition and the ExB vertical ion drift. T. Gulyaeva (IZMIRAN, Russia) further explained the ionospheric disturbance index developed for the European PRIME project and compared indices obtained from high and mid-latitude stations with those from low-latitude stations. I. Stanislawska (SRC, Warsaw, Poland) described a Kriging method that can be used for the regional mapping of ionospheric parameters.

*WORKSHOP PROCEEDINGS*

The papers presented at the workshop will be published in the scientific journal Advances in Space Research (ASR) similar to the proceedings from earlier IRI Workshops. The papers from the 1993 IRI Workshop on Off-Median Phenomena and IRI" were just published in Advances in Space Research, Volume 15, Number 2, February 1995. (This section was reported by D. Bilitza).

A.P. Mitra
URSI-Representative

## CONFERENCE ANNOUNCEMENTS

# INTERNATIONAL WORKSHOP ON DIRECT AND INVERSE ELECTROMAGNETIC SCATTERING

24-30 September 1995, Marmara Reseach Center, Gebze, TURKEY

**Organized by**

Marmara Research Center of the Scientific and Technical Research Council of Turkey.

**Scope**

The need for practical solutions to scattering problems and the difficulties of the rigorous solution techniques have led to the development of a number of approximate methods. The main aim of all these techniques consists of determining the geometrical and physical properties of remote or inaccessible bodies by considering their effect on the propagation and scattering of acoustic or electromagnetic waves, which requires the knowledge of the interaction of waves with complex structures. This workshop will gather the leading active researchers of the field from all over the world and the actual situation of the topic as well as the new directions of future research will be discussed.

The scientific program of the Workshop will include presentations mainly in the following topics :

- *Electromagnetic Modeling and Canonical Solutions*
  Derivation of approximate boundary conditions simulating materials and their applications.
- *Analytical Methods for Electromagnetic Diffraction*
  Recent developments in Wiener-Hopf method and other analytical techniques.
- *Computational Techniques for Scattering Problems*
  Recent developments in method of moments, variational methods, finite element methods and other computational techniques.
- *Inverse Scattering and Polarimetric Remote Sensing*
  Exact and approximate analytical techniques, numerical and hybrid methods, buried object identification, one-dimensional profile inversion and mathematical fundamentals of polarimetry.
- *Special Topics in Wave-Material Interaction*
  Time-domain electromagnetics, theoretical and numerical modeling techniques for predicting the interaction of antennas with their environment, application of GTD. PTD and hybrid techniques for calculation of RCS of complex structures.

The programme will mainly include invited lectures related with the abovementioned paper categories. Besides invited lectures, a small number of contributions will also take place in the technical program. The prospective authors are invited to submit summaries in any of these or related areas according to the below instructions.

**For further information, please contact**

Prof. Dr. A. Hamit Serbest
Chairman of the Organizing Committee
International Workshop on Direct and Inverse EM Scattering
Department of Electrical and Electronical Engineering
Cukurova University, Adana 01330, TURKEY
Phone : +90-322-338 68 68, Fax : +90-322-338 63 26

# Conference on Precision Electromagnetic Measurements

Braunschweig, Germany, 17 - 20 June , 1996

The Conference on Precision Electromagnetic Measurements (CPEM) is the international forum for scientists working in the field of electromagnetic precision measurement techniques.

The forthcoming 20th conference is held in Braunschweig, Germany, from 17. to 20. June, 1996, and is organized by the Physikalisch-Technische Bundesanstalt (PTB). Preceeding conferences had been in Boulder, USA (1994), Paris (1992), Ottawa (1990) and Tsukuba, Japan (1988) and each had been attended by about 400 people.

The following topics have been selected for CPEM 96:

- Units and fundamental constants
- Quantum metrology
- Cryoelectronics
- Direct current and low frequency
- New sensors
- Automated systems, software algorithms and validation
- RF, microwave, and millimeter waves
- Antennas, fields, and EMC
- Time scales and frequency standards
- Lasers and optoelectronics

CPEM has proved its outstanding reputation over more than three decades as an international forum for precision electromagnetic measurements and was always open to new objectives and developments.

Plenary speakers of CPEM 96 will be:

- Klaus von Klitzing, Max-Planck-Institut für Festkörperforschung, Stuttgart
- Konstantin K. Likharev, State University of New York
- Herbert Walther, Max-Planck-Institut für Quantenoptik, Munich

The meeting is co-sponsored by URSI through its Commission A.

For further information please contact the conference secretary of CPEM 96:
Mrs. Sabine Rost,
Physikalisch Technische Bundesanstalt,
Bundesallee 100
D-38116 Braunschweig, Germany,
Tel (0531) 592 2129, Fax (0531) 592 2105
e-mail: erich.braun@ptb.de

## OTHER MEETINGS BROUGHT TO OUR ATTENTION

# ICSU Forum on Earth System Research & Fourth Scientific Advisory Council for the IGBP

Beijing, China, 22 - 27 October 1995

**Sunday 22 October**
Registration : ICSU Forum
Earth System Research : Presentations
Panel Discussion on Science and Decision Making

**Monday 23 October**
Opening of SAC IV Scientific Symposium
Natural and Anthropogenic Changes : Impacts on Global Biogeochemical Cycles
Session 1 : Change : The Historical Perspective
Session 2 : Changes in Land Use and Mobilisation Rates of Carbon, Oxygen, Nitrogen, Phosphorus, and Sulphur
Poster Session

**Tuesday 24 October**
Session 3 : Effects of Changes for Biochemical Cycles
Poster Session

**Wednesday 25 October**
Session 4 : Overview
Excursion arranged by the Chinese IGBP Committee

**Thursday 26 October**
IGBP Developments :
ICSU/International Group of Funding Agencies Evaluation
New Core Projects and Plans
Regional Research Networks

**Friday 27 October**
National Committees
Role of the National Committees in the IGBP Implementation Phase
the IGFA Resource Assessment Procedure
Future Directions
Discussions in research, data and communications
Closing session

For further information, please contact :
IGBP Secretariat, The Royal Swedish Academy of Sciences
Box 50005, S-104 05 Stockholm, Sweden
Tel. +46-8 16 64 48, Fax +46-8 16 64 05
E-mail sec@igbp.kva.se
or
Chen Panqin,
Secretary General, Chinese Committee for the IGBP,
Bureau of Coordinative Development
Chinese Academy of Sciences
52 Sanlihe Road, Beijing 100864, China
Tel. +86-10 859 7531, Fax +86-10 851 1095
e-mail : chenpq@sun.ihep.ac.cn

**July 1995**

**Radio Emission from the Stars and the Sun**

*Barcelona, Spain, 3-7 July 1995*

Contact : Dr. J.M. Paredes, Dept. d'Astronomia i Meteorologia, Universitat de Barcelona, Av. Diagonal 647, E-08028 Barcelona, Spain, Fax +34-3-4021133, e-mail: josepmp@mizar.am.ub.es

**IGARSS'95**

*Florence, Italy, 10-14 July1995*

Contact : Dr. Paolo Pampaloni, Istitutio di Recerca sulle Onde Elettromagne-tiche del Consiglio Nazionale delle Ricerche, Via Panciatichi 64, I-50127 Firenze, Italy, Fax +39- 55-41 08 93

**August 1995**

**1995 Int. Conf. on Radio Science (ICRS'95)**

*Beijing, China, 10-12 August 1995*

Contact : Prof. Zong Sha, P.O. Box 165, Beijing 100036, China, Tel. +861-828-3463, Fax +861-828-3463, e-mail shaz@bepc2.ihep.ac.cn

**22nd Int. Symp. on Compound Semiconductors**

*Cheju Island, Korea, 28 Aug.-1 September 1995*

Contact : Dr. M. Shur, Dept. of Electrical Eng., Univ. of Virginia, Charlottesville, VA 22903-2442, USA, Tel. : +1-804-924-6109, Fax : +1-804-924-8818, e-mail : ms8n@virginia.edu

**September 1995**

**Biophysical Aspects of Coherence**

*Prague, Czech Republic, 11-15 September 1995*

Contact : Faculty of Mathematics and Physics, Charles University Ke Karlovu 3, 12116 Prague 2, Czech Republic, Tel : +42-2-24915014, Fax: +42-2-299272, E-mail : pokorny@quantum.karlov.mff.cuni.cz

**ISRAMT'95**

*Kiev, Ukraine, 11-16 September 1995*

Contacts : Dr. B. Rawat, Dept. of Electrical Eng., Univ. of Nevada, Reno, NV 89557-0153, USA, Tel. +1702-784-1457, Fax +1702-784-6627

and : Dr. K.S. Sunduchkov, SRI "Saturn", Pr. 50, Let Oktyabrya 2B, 252148 Kiev, Ukraine, Tel. +044-477-6739, Fax +044-477-6208

**ECOC'95**

*Brussels, Belgium, 17-21 September 1995*

Contact : ECOC'95, INTEC Dept., Univ. of Gent - IMEC, St-Pietersnieuwstraat 41, B-9000 Gent, Belgium, Tel. +32-9-2643316,Fax +32-9-2644288,e-mail: ecoc95@intec.rug.ac.be

**Int. Workshop on Direct & Inverse Electromagnetic Scattering**

*Gebze, Turkey, 24-30 September 1995*

Contact : Prof. Dr. A. Hamit Serbest, Int. Workshop on Direct & Inverse Electromagnetic Scattering, Cukurova University, Faculty of Eng. & Architecture, Dept of Electrical & Electronic Eng., Tel. +90-322-338-6868, Fax +90-322-338-6326

**October 1995**

**Asia Pacific Microwave Conference**

*Taejon, Korea, 10-13 October 1995*

Contact : Prof. Dong-Chul Park, Programme Committee, APMC'95, Dept. of Radio Sciences & Engineering, Chungnam National University, 220 Kung-dong, Yusong-gu, Taejon 305-764, Korea, Tel. +82-42-821-5665, Fax +82-42-823-5436,2931, e-mail : dcpark@micro.chungnam.ac.kr

**Extra Galactic Radio Sources - IAU Colloquium 175**

*Bologna, Italy, 10-14 October 1995*

Contact : Dr. L. Padrielli, Istituto di Radioastronomia, Via P. Gobeti 101, 40129 Bologna, Italy, +39-51-6399431, E-mail padrielli@astbo1.bo.cnr.it

**Retrieval of Geo-and Bio-Physical Parameters from SAR data for Land Applications**

*Toulouse, France, 17-20 October 1995*

Contact : Mr. Michel Rouzé, Centre Spatial de Toulouse, 18, Avenue E. Belin, F-31055 Toulouse Cedex, France, Fax +33-6127-4013

**ISSSE'95**

*San Francisco, USA, 25-29 October 1995*

Contact : Prof. Ming C. Wu, UCLA, Electrical Eng. Dept., 405 Hilgard Ave, Los Angeles, CA 90024-1594, USA, Tel. +1-310-825-6859, Fax +1-310-825-6954, e-mail : wu@ee.ucla.edu

**November 1995**

**Commission F Open Symposium**

*Ahmedabad, India, 20-24 November 1995*

Contact : Prof. O.P.N. Calla, SATCOM Area Space Applications Centre, Ahmedabad, India, Tel. +91-79-429-180, Fax +91-79-404-563, e-mail: calla@sac.ernet.in

**January 1996**

**Pulsars**

*Sydney, Australia, 8-12 January 1996*

Contact : Dr. Dick Manchester, Radiophysics, CSIRO, P.O. Box 76, Epping, NSW 2121, Australia, Fax +612-372 4400, e-mail : rmanches@atnf.csiro.au

**March 1996**

**EUSAR'96**

*Konigswinter, Germany, 26-28 March 1996*

Contact : Dr. R. Klemm, FGAN-FFM, Neuenahrer Str. 20, D-53343 Wachtberg, Germany, Tel. +49-228-852-377, Fax +49-228-348-953, e-mail: r.klemm@elserv.ffm.fgan.de

**May 1996**

**IGARSS'96**

*Burnham Yates Conference Center, Cornhusker Hotel, Lincoln, Nebraska, USA, 27-31 May 1996*

Abstract deadline : 1 December 1995

Contact: Ms. Tammy Stein, IEEE Geoscience and Remote Sensing Society, 2610 Lakeway Drive, Seabrook, Texas 77586-1587, USA, Tel. +1-713 291 9222, Fax +1-713 291 9224, e-mail : stein@harc.edu

## June 1996

**10th Int. Conf. on Atmospheric Electricity**
*Osaka, Japan, 10-14 June 1996*
Contact : Prof. M. Hayakawa, The Univ. of Electro-Communications, 1-5-1 Chofugaoka, Chofu Tokyo 182, Japan, Fax +81-424-80-3801, e-mail: hayakawa@aurora.ee.uec.ac.jp

**Conference Precision Electromagnetic Measurements (CPEM'96)**
*Braunschweig, Germany, 17-20 June 1996*
Contact: Mrs. Sabine Rost, Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany, Tel. +49-531-592-2129, Fax +49-531-592-2105, e-mail: erich.brau@ptb.de
Please note that Dr. U. Stumper is not the contactperson for this conference, as was mentioned in the previous issue of the Radio Science Bulletin.

## 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

## 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 20-337134, Fax: +33 20-436523, e-mail : martine.lienard@univ-lille1.fr

## 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 20-436523

**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

**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

**Int. Symp. on Antennas and Propagation**
*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

# Book Reviews

## Dielectrics and Waves

by A. R. von Hippel, Artech House, 1995, 284 pages, ISBN 0-89006-803-8
Hardcover, $55.00
and

## Dielectric Materials and Their Applications

by A. R. von Hippel, Editor, Artech House, 1995, 433 pages, ISBN 0-89006-805-4
Hardcover, $55.00

These two hardback books are reprints of material published in 1954. They have been out-of-print for sometime and current availability is to be welcomed. So often such classics are forgotten when today's commercial publishers favor the printing of undergraduate lecture notes, in glossy cardboard covers, which are usually described as fresh and up-to-date. Yet the core material is to be found in undiluted form, in such volumes as being reviewed here.

The first volume is intended for physicists, chemists, and electrical engineers. The subject matter of dielectrics deals not with just a narrow class of "insulators" but rather von Hippel is dealing broadly with all non-metals and also most metals if electromagnetic interactions are considered. The relevant phenomena are 'polarization', 'magnetization' and 'conduction'. The author's initial approach is macroscopic and he makes much use of equivalent electrical circuits without short changing the basic physics. He then surveys the molecular approach touching on such subjects as: anomalous dispersion, quantum mechanical resonance, microwave spectroscopy, piezoelectricity and ferromagnetism. A useful appendix parallels the two sections of the main text with the objective of amplifying important concepts and treating the more difficult mathematics which is still at the senior or first year graduate level in engineering science.[1]

In the second (companion) volume, von Hippel's stated objective is to establish alliances between the research worker, development engineers, manufacturers, and the actual users of "non-metals." The first chapter (45 pages) summarizes the essential material from the first volume.

The following three chapters are written by various authors selected by von Hippel and cover: dielectric measuring techniques, dielectric (and magnetic) materials, dielectric devices such as piezoelectric transducers, and dielectric (and magnetic) amplifiers. The lengthy appendix (150 pages) lists properties of dielectric (and magnetic) materials in a very comprehensive fashion.

The quality of the reproduction of these two volumes is very high. Also the numerous illustrations (uncluttered) are excellent and the captions are meaningful. The references cited in the text and those, collected together at the end of each volume, are exhaustive but, of course, nothing later than 1954. However, one surprising omission is S.A. Schelkunoff's *Electromagnetic Waves* (1943); von Hippel employs the same conventions, units, impedance parameters and notations.

Engineering science libraries should acquire these two volumes quickly before they go out of print again. Individual researchers in electromagnetics would also benefit by having these two attractive companion books at arms' length.

James R. Wait
2210 East Waverly
Tucson, Arizona 85719-3848

1. *A somewhat more advanced, yet readable, coverage is to be found in Physics of Dielectric Materials by B. Tareev, (in English) Mir Publishers, Moscow, 1975. See also Dielectric Phenomena and the Double Layer by S.S. Dukin and V.N. Shilov, Halsted press, New York, 1974. and "Complex Resistivity of the Earth" by J.R. Wait, Progress in Electromagnetic research, Vol. 1, pgs. 1-175, Elsevier, 1989.)*

# News from the URSI Community

## AWARDS PRESENTED TO URSI COLLEAGUES

### Dr. Richard K. Moore Wins 1995 Australia Prize

Since 1990, when the Australia Prize was established by the Government of the Commonwealth of Australia, world-renowned individuals have been recognized who have made outstanding specific achievements in selected areas of science and technology promoting human welfare.

The category of Remote Sensing was selected for the 1995 Australia Prize. The four laureates of the Prize were recently announced by the Minister for Industry, Science and Technology, Senator Peter Cook, and include Dr. Richard K. Moore, Black and Veatch Professor Emeritus of Electrical Engineering and former Director of the Radar Systems and Remote Sensing Laboratory of The University of Kansas. His significant contribution has been pioneering achievements in radar remote sensing of the land and oceans, from air and space platforms.

Other laureates were three Australians whose work in visible/IR remote sensing was at the Commonwealth Science and Industrial Research Organization (CSIRO). They were Dr. Ken McCracken, Dr. Andrew Green, and Dr. Jonathan Huntington.

The Presentation Ceremony took place on 10 April 1995, at Parliament House in Canberra, Australia. Dr. Moore preceded and followed this with lectures and visits to various facilities in Australia.

Dr. Moore is Chairman of URSI Commission F. He is a Life Fellow of IEEE and member of the U. S. National Academy of Engineering. The first IEEE Council of Oceanic Engineering Distinguished Achievement Award was presented to Dr. Moore in 1978 and the first IEEE GRSS Distinguished Achievement Award in 1982.

Our heartiest congratulations to Dr. Richard Moore!

# JOINT URSI COMMITTEE OF THE CZECH AND SLOVAK REPUBLIC

## BIOPHYSICAL ASPECTS OF COHERENCE

Prague, Czech Republic, September 11-15, 1995

**Organized by:**
The Faculty of Mathematics and Physics
Charles University, Prague

**Language**
The official language is English.

**General scope**
The aim of the Workshop is to provide a comprehensive presentation of the state of the art of the biological aspects of coherence, mechanisms of coherent states in biological systems and their interaction with electromagnetic fields. The Workshop will include plenary review lectures by invited speakers, symposia and poster sessions.
On the occasion of the Workshop the Froehlich memorial lecture will be delivered by Professor G. J. Hyland, followed by a concert.

**Scientific programme:**
The tentative programme for plenary lectures, symposia oral presentation, and posters includes the following topics:

- Quantum mechanical concepts of coherent states and synergetics behaviour of biological systems
- Biophysical principles of selforganization
- Dynamics of biological macromolecules
- Nonlinear vibrations, Frohlich coherent states and Froehlich rate equation
- Froehlich electromagnetic field generated in biological systems
- Measurements of the Froehlich electromagnetic field
- Interaction of biological systems with external eletromagnetic fields on cellular and subcellular levels
- Information and selforganization
- Coherence and neural network activity
- Biophysical aspects of cancer
- Mechanisms of hyperthermic effects of electromagnetic fields

**Workshop Proceedings**
Invited lectures of the Workshop will be published in a special issue of the journal "Neural Network World". The special issue will be ready just before the beginning of the workshop and will be given to the participants of the workshop.

**For further information, please contact :**
Biophysical Aspects of Coherence
Faculty of Mathematics and Physics, Charles University
Ke Karlovu 3, 12116 Prague 2, Czech Republic
Phone: +42-2-24915014 Fax: +42-2-299272
E-mail: pokorny@quantum.karlov.mff.cuni.cz

# IRELAND

## 8TH SYMPOSIUM ON RADIO SCIENCE

Royal Irish Academy, Thursday, 23 November 1995

Draft Programme

9.15 a.m.Opening : Professor J.O. Scanlan, President, Royal Irish Academy

9.30 a.m.Session 1 : Dr. Brian P. McArdle, Secretary, URSI Sub-Committee

(1) "RTE Satellite News Gathering", Mr. Colm Curley, Radio Telefis Eireann.

(2) "The INMARSAT B-Terminal in the 3 GHz Band for Voice and Data Communications", Mr. John Loftus, Euro Electronic Systems.

(3) "High Bit Rate Services using HDSL in the Local Loop", Mr. Sean Boland, Data Communications Technical Division, Telecom Eireann.

10.45 a.m.Coffee

11.00 a.m.Session 2 : Professor Michael C. Sexton, Chairman, URSI Sub-Committee

(4) "An Analysis of Coding Operations in the Terrestrial Flight Telephone System", Dr. Brian P. McArdle, URSI Sub-Committee

(5) Keynote address : "Some Ideas from the Early Days of URSI in Modern Dress", Prof. E.D.R. Shearman

12.30 p.m.Lunch Break

2.00 p.m.Session 3 : Professor J.R. Carson Stewart

(6) "Transient Analysis of Electromagnetically Coupled Lossy Transmission Lines", Mr. Mustafa Abu Shaban, Professor T. Brazil & Professor J.O. Scanlan, University College Dublin

(7) "A Mathematical Framework for Signal Identification", Dr. Anthony Quinn, Trinity College Dublin

(8) "An Integrated 27 GHz Receiver for Cellularvision TV Distribution", Dr. Patrick Murphy, University College Cork

3.30 p.m.Coffee

3.45 p.m.Session 4 : Dr. Conor Downing

(9) "GSM and IS-54 Digital Mobile Radio Test Techniques", Dr. Martin O'Droma, University of Limerick & Mr. Michael Keaveney, Analog Devices B.V.

(10) "Microstrip Antennas for In-Door Wireless Channels", Mr. Max Ammann, DIT (Kevin Street)

(11) "Active Antennas for Wireless Lans", Dr. Vincent Fusco, The Queen's University of Belfast

5.00 p.m.Close : Dr. Brendan K.P. Scaife

Brian P. McArdle

# UKRAINE

## THE BEGINNING OF ACTIVITY OF UKRAINIAN COMMISSION D

The Ukrainian branch of commission D was created in 1993, in the frame of the Ukrainian Member Committee (President : Professor Nakhodkin) at the same time with the establishment of the Ukrainian Committee of URSI as an official URSI member committee. This commission unites scientific, educational and industrial institutions, that are actively working in the fields of electronics and photonics for the radio and telecommunications.
In the field of materials science and technology the main direction is the utilization of semiconductor materials and microelectronics technologies. Correspondingly the applied part is based on the solid state electronic devices, including the radio HFW and optical regions of EM waves spectra. The themes of applied character include generation systems, propagation, detection and processing of information. In the institutions, organizations that are united in the D commission the wide range of fundamental and applied investigations are carried out. In particular, Radiophysical faculty of Kiev University (Head Professor Melkov G.A., Professor N. Nakhodin, Professor Strikha) is active in the field of HF technics, solid state microwave materials etc.
In Kharkov we have specialized Radioelectronics Institute, engaged in the development of new types of solid state microwave generators, space communication, including sub-micron range (director- Professor V.M. Yakovenko, Professor Ya. M. Usikov, Professor V.P. Shestopalov). In the Institutes of General Physics and Physics of Semiconductors a group of departments lead the works on the nano-electronic input- output elements (gratings, holographic optical elements) development of high-efficient LC displays and optoelectronic devices (Professor M. Brodin, Professor S. Svechnikov, Professor V. Litovtchenko, Professor Korbutyak, Professor P. Oleksenko, Professor I.Z. Indutnyi, Dr. A.V. Stronski). There are others industrial and educational institutions involved in our activities : Kiev Polytechnical University (Professor S.V. Denbnovetski), Vinnitssa Polytechnical University (Professor N.A. Felenjuk), Lviv University (Professor M.S. Savitskii), Industrial Institute "Orion", Kiev (Dr. Yu.A. Tsvirko), "Khartron ("Kharkiv, Professor Aisenberg), Koroliov Electronic Association (Dr. Yu.P. Medvedev), etc.
We created an executive body of our commission, which meets twice a year. Our main objective now is to organise in the Ukraine a periodical international conference under the title 'Modern base of micro (nano) electronics and photonics' and to include it into the calendar of URSI events, EEC programme on nanoelectronics and mesascopic 'Fantom".
We intend to provide the active participation in URSI events, as soon as possible and as a novice we need support of other national commissions.

V.G. Litovtchenko
P.F. Oleksenko
A.V. Stronski

# UNITED STATES OF AMERICA

## 1995 INTERNATIONAL SEMICONDUCTOR DEVICE RESEARCH SYMPOSIUM (ISDRS'95)

Charlottesville, VA 22901, USA, December 6,7,8 1995

The Symposium will emphasize fundamental concepts in novel devices and advanced processing technologies. The extended abstracts will be afforded a quick review and publication. Participation of students, university faculty, and foreign researchers is strongly encouraged.

TOPIC AREAS INCLUDE:
Amorphous and Polysilicon Thin Film Transistors/ Carrier Transport/ Cryogenic Electronics/ Materials and Device Characterization/ Microelectromechanical Devices/ Microwave and Millimeterwave Devices/ New Device Fabrication Technology/ Novel Semiconductor Device Ideas and Concepts/ Photonics and Optoelectronics/ Simulation and Modeling/ Ultra Small Devices/ Wide Band Gap Materials and Devices

THE VAN DER ZIEL AWARD: Nominations are now being taken for the van der Ziel Award for 1995. The 1993 winner of the Award was Professor A. Milnes from Carnegie Mellon University. Please send nominations to Stephen H. Jones (1995 Program Chair) by e-mail at shj2n@virginia.edu

ABSTRACT DEADLINE: August 28, 1995

For more information, please contact :
Stephen Jones (Program Chair)
Department of Electrical Engineering
Thornton Hall, University of Virginia
Charlottesville, VA 22903-2442 USA
Phone: +1-804-924-6080
Fax: +1-804-924-8818
e-mail: shj2n@virginia.edu

# RAY MITTRA TRAVEL GRANT

In honor of his many contributions to applied electromagnetics, former students and research associates of Raj Mittra have established a fund to support travel by qualified graduate students and research scientists to the annual IEEE AP-S/USNC URSI Symposium. The purpose of the Raj Mittra Travel Grant (RMTG) is to encourage participation in the annual Symposium by graduate students and researchers who could not otherwise afford the cost of travel to the meeting. Parties interested in applying for an award in 1996, when they will be initiated, are encouraged to carefully read the following information before applying to insure that they are both eligible and can comply with the application requirements and deadlines.

**Eligibility:**
Candidates need not be members of either the IEEE or URSI, but must have contributions accepted for presentation at the 1996 IEEE Antennas & Propagation and USNC/URSI Commission B International Symposium. In order to receive an award, awardees must personally present their contributions at a regular AP-S or USNC/URSI Commission B session organized at the Symposium. Since the intent of the award is to encourage participation in the annual Symposium by promising researchers who likely could not otherwise attend due to financial reasons, financial need shall also be a consideration in the selection process.

**Awards:**
Two (2) grants in the amount of $750 each are to be offered to young scientists pursuing research in areas of traditional interest to AP-S and Commission B of USNC/URSI. The third grant, for $1,000 will be awarded to a senior researcher associated with a research or educational institution and having an active research program in areas of interest to AP-S and USNC/URSI. Awards cannot be presented before the Symposium, and candidates must make their own arrangements to cover travel expenses to the meeting.

**Application & schedule:**
The schedule for evaluating candidates and notifying awardees is very short, and parallels the review process for Symposium submissions. For this reason, all applications must be submitted via e-mail to the RMTG Awards Chair at "WILTON@UH.EDU". All applications must be in English and must contain the following information; name, mailing address, e-mail address, type of grant sought (young or senior researcher), number of years since undergraduate degree or graduate degree, name of advisor or laboratory head as a reference, previous attendance at AP-S/USNC-URSI International Symposia, expected date of graduation, a list of publications, a statement of need for travel support from the candidate's institution, and a copy of the abstract (URSI) or summary (AP-S) (state which) of the paper submitted. A candidate's application must state if his/her attendance at the Symposium is contingent upon receiving a Travel Grant; if so, the candidate's paper will be automatically withdrawn from consideration by the Technical Program Committee if he/she is not selected. Finally, the e-mail application must be followed by a letter of endorsement from the candidate's home institution, e.g., from a student's thesis advisor or from a researcher's department head, clearly indicating the institution's committment to supplement the travel expenses on an as-needed basis, if the candidate is selected to receive a grant. NO APPLICATIONS WILL BE PROCESSED UNTIL THIS SIGNED LETTER AND ALL APPLICATION MATERIALS ARE RECEIVED BY;
Prof. Donald R. Wilton,
Awards Chairman (RMTG), Dept of Electrical Engineering
University of Houston, Houston, TX 77204-4793, U.S.A.
e-mail: WILTON@UH.EDU, Fax: (713)743-4442

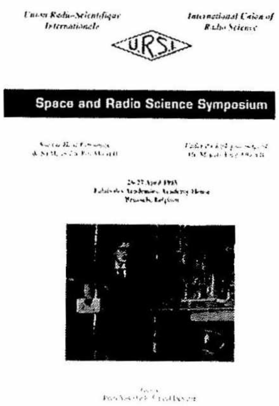
The due date for applications and letters of endorsement is the same as that for submission of abstracts and summaries to the Symposium. The selection process for awardees and alternates will be completed prior to the meeting of the Symposium Technical Program Committee (TPC).

**Selection:**
Selection of an Awardee will be based upon a candidate's need for travel support and his/her potential or demonstrated aptitude for research. Candidates and alternates must also have their abstracts or summaries accepted by the TPC. Successful candidates will be notified immediately after the TPC meeting. Upon being notified of their selection, prospective Awardees will be asked to submit the minimum applicable Symposium registration fee as a non-refundable deposit to be applied toward the registration fee. If it is determined that a prospective Awardee has not met this requirement within 60 days after award notification, the Chair of the Awards Committee may select an alternate Awardee. The awards will be presented along with a check in the appropriate amount at the Symposium. All candidates must also submit their abstracts and/or summaries to the Symposium following the usual submission guidelines.

# URSI Publications

## Proceedings of the "Space and Radio Science Symposium"

Editors: Peter Van Daele and Paul Delogne




**This "Space and Radio Science Symposium" was held on 26-27 April 1995, at the occasion of the 75th Anniversary of our Union.**

Copies of these Proceedings are available at the URSI Secretariat for 500 Belgian francs per copy (for countries outside Europe we charge an extra 140 Belgian francs per copy for mailing costs).

**Table of Contents :**

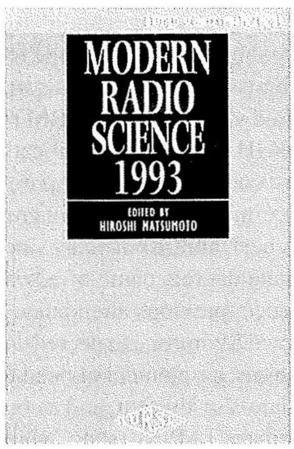


## Modern Radio Science 1993

Editor: Hiroshi Matsumoto

ISBN 0-19-856379-5

£30.00 (+10% postage and packing charges)




Orders and payments to be sent to :

CWO Department
Oxford University Press
Saxon Way West, Corby
NORTHANTS NN18 9ES
UNITED KINGDOM
fax +44 1-536-744-964
tel +44 1-536-746-337

I wish to become an URSI Correspondent for the 1994-96 triennium.
Subscription to "The Radio Science Bulletin" is included in the fee.
(please type or print in BLOCK LETTERS)

Name: Prof./Dr./Mr./Mrs./Ms. ____________________________________________

*Family Name* *First Name* *Middle Initials*

Present job title: ____________________________________________

Years of professional experience: ____________________________________________

Professional affiliation: ____________________________________________

Company name: ____________________________________________

Department: ____________________________________________

Street address: ____________________________________________

City and postal / zip code: ____________________________________________

Province / State: ____________________ Country: ____________________

This is my ☐ home ☐ business address

Phone: ____________________ ext: __________ Fax: ____________________

E-mail: ____________________________________________

**Areas of interest (please tick)**

☐ A Electromagnetic Metrology

☐ B Fields and Waves

☐ C Signals and Systems

☐ D Electronics and Photonics

☐ E Electromagnetic Noise & Interference

☐ F Wave Propagation & Remote Sensing

☐ G Ionospheric Radio and Propagation

☐ H Waves in Plasmas

☐ J Radio Astronomy

☐ K Electromagnetics in Biology & Medicine

The fee - for the rest of this triennium - is US$ 20.
(The URSI Board of Officers will consider waiving of the fee if the case is made to them in writing)

Method of payment: VISA / MASTERCARD

Credit Card No ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ Exp. date: __________

Date: ____________________ Signed ____________________________________________

Return this form to:

The URSI Secretariat
c /o University of Gent / INTEC
Sint-Pietersnieuwstraat 41
B-9000 GENT, BELGIUM
fax (32) 9-264.42.88