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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 which dates from 1913.

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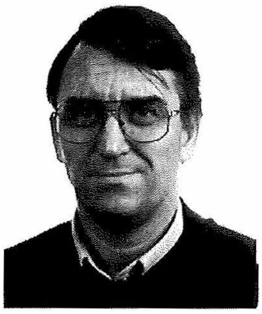
Editorial

Dear URSI Correspondent,

Welcome to the summer issue of our Bulletin that is focused to various aspects of radio communications.

In the scientific part of the issue you have in hand you will find four contributions.

Two of these are based on studies related to techniques specific to communications systems. The first one deals with problems of linearization in mobile transmitters, while the other one presents modulation aspects implemented through software radio techniques. Both papers contribute to a better and more efficiency use of the frequency spectrum which is a shared and limited resource to all of us.



The third contribution comes just before the first anniversary of the eclipse that occurred last summer and underlines some interesting radio propagation effects related to this interesting event, while the fourth one deals with particular aspects of lens antennas.

In the administrative part of our Bulletin, usual announcements about future conferences sponsored or supported by URSI are given. Please take also a moment to read through the Union accounts for 1999. This will give you an highlight of how our Union is carefully managed.

I wish you a pleasant reading.

Piotr Sobieski, Editor

Letter to the Editor

Comments on "Spectrum Congestion - a Voice in Discussion"

(refers to a *Letter to the Editor* by Prof. R. Struzak in the December 1999 issue and the comment by Prof. P. Delogne in the March 2000 issue of *the Radio Science Bulletin*)

I would like to thank Paul Delogne for corrections [1] of misprinted formulas in my letter [3] and for his kind words on my proposals concerning the approach to spectrum congestion and modifications to Shannon's formula. The misprints were probably due to translation errors from the MS Word format to the Aldus PageMaker format used by the publisher. At this occasion, I would like to note that the fifth paragraph of Paul's comments might imply that I am the author of the "very unrealistic" equation (1). Actually, it is the Shannon's formula [2] with re-arranged symbols only.

Ryszard Struzak

References

[1] Delogne P: Comments on Spectrum Congestion - a Voice in Discussion; Radio Science Bulletin No 292, p. 3-4

[2] Shannon C: Communication in the Presence of Noise; Proceedings of the IRE, January 1949, p. 16, equation No 19

[3] Struzak R: Spectrum Congestion - a Voice in Discussion; Radio Science Bulletin No 291, p. 4-5

URSI Accounts 1999

As usual in a year of a General Assembly, the accounts of URSI show a deficit. This is a normal situation in the 3 year cycle of URSI and is compensated during the intervening years. The depreciation of the Euro with respect to the dollar shows up in the accounts but does not represent a problem for URSI since the vast majority of both income and expenditure are expressed in Euro. With the contributions from member committees remaining steady, the administrative costs well under control and thanks to the prudent policies of the Board, the overall financial health of URSI remains good.

Paul Lagasse
Secretary General

Kristian Schlegel
URSI Treasurer

BALANCE SHEET : 31 DECEMBER 1999

ASSETS	US$	US$	EURO	EURO
Dollars				
Merrill Lynch WCMA	20,943.00		20,839.22	
Générale de Banque	8,930.27		8,886.02	
Smith Barney Shearson	140.45		139.75	
		30,013.72		29,864.99
Belgian francs				
Banque Degroof	4,772.17		4,748.52	
Générale de Banque	69,752.42		69,406.77	
		74,524.59		74,155.29
Investments				
Demeter Sicav shares	22,794.75		22,681.79	
Rorento Units	111,084.59		110,534.13	
Rorento Units '99	885.14		880.75	
Aqua Sicav	64,103.22		63,785.56	
Merrill-Lynch Short Term (405 units)	3,717.19		3,698.77	
Massachusetts Investor Fund	251,274.57		250,029.40	
	453,859.45		451,610.40	
342 Rorento units van der Pol Fund	12,476.17		12,414.34	
		466,335.62		464,024.74
Petty cash		911.71		907.19
Total Assets		**571,785.63**		**568,952.21**
Less creditors				
IUCAF	17,727.76		17,639.91	
ISES	5,511.30		5,483.99	
		-23,239.06		-23,123.90
Balthasar van der Pol Medal Fund (1)		-12,476.17		-12,414.34
NET TOTAL OF URSI ASSETS		**536,070.41**		**533,413.97**

The net URSI Assets are represented by :	US$	US$	EURO	EURO
Closure of Secretariat :				
Provision for Closure of Secretariat		50,000.00		49,752.23
Scientific Activities Fund :				
Scientific Activities in 2000	90,000.00		89,554.01	
Publications in 2000	60,000.00		59,702.68	
Young Scientists in 2000	50,000.00		49,752.23	
Administration Fund in 2000	80,000.00		79,603.57	
I.C.S.U. Dues in 2000	20,000.00		19,900.89	
		300,000.00		298,513.38
XXIV General Assembly 2002 Fund :				
During 2000 :		40,000.00		39,801.78
Total allocated URSI Assets		**390,000.00**		**388,067.40**
Unallocated Reserve Fund		**146,070.41**		**145,346.58**
		536,070.41		**533,413.97**

Statement of Income and Expenditure for the year ended 31 December 1999

I. INCOME	US$	US$	EURO	EURO
Grant from ICSU Fund and US National Academy of Sciences	5,000.00		4,975.22	
Allocation from UNESCO to ICSU Grants Programme	2,000.00		1,990.09	
UNESCO Contracts	0.00		0.00	
Contributions from National Members	222,416.76		221,314.60	
Contributions from Other Members	0.00		0.00	
Special Contributions	8,492.75		8,450.67	
Contracts	0.00		0.00	
Sales of Publications, Royalties	199.74		198.75	
Sales of scientific materials	0.00		0.00	
Bank Interest	3,330.95		3,314.45	
Gain on Exchange	0.00		0.00	
Other Income	32,360.68		32,200.32	
Total Income :		**273,800.89**		**272,444.10**

II. EXPENDITURE	US$	US$	EURO	EURO
a1) Scientific Activities		234,177.49		233,017.05
General Assembly 1999	215,375.48		214,308.21	
Scientific meetings: Symposia/Colloquia	17,075.67		16,991.05	
Working Groups/Training Courses	0.00		0.00	
Representation at scientific meetings	1,726.35		1,717.79	
Data Gather/Processing	0.00		0.00	
Research Projects	0.00		0.00	
Grants to Individuals/Organizations	0.00		0.00	
Other	0.00		0.00	
Less covered by UNESCO Contracts	0.00		0.00	
a2) Routine Meetings		8,619.41		8,576.70
Bureau/Executive committee	8,619.41		8,576.70	
Other	0.00		0.00	
a3) Publications		35,569.06		35,392.80

b) Other Activities		10,763.00		10,709.67
Contribution to ICSU	8,763.00		8,719.58	
Contribution to other ICSU bodies	2,000.00		1,990.09	
Activities covered by UNESCO Contracts	0.00		0.00	
c) Administrative Expenses		100,056.75		99,560.93
Salaries, Related Charges	50,705.08		50,453.82	
General Office Expenses	11,885.45		11,826.55	
Office Equipment	0.00		0.00	
Audit Fees	1,911.16		1,901.69	
Bank Charges	1,916.17		1,906.67	
Loss on sale of Merrill Lynch Short Term Global Income	1,352.59		1,345.89	
Loss on Exchange	32,286.30		32,126.31	
Total Expenditure :		**389,185.71**		**387,257.14**
Excess of Income over Expenditure		**-115,384.82**		**-114,813.04**
Accumulated Balance at 1 January 1999		651,455.23		558,276.23
Currency translation difference (USD-> EUR)		89,950.78		
Accumulated Balance at 31 December 1999		**536,070.41**		**533,413.97**

Rates of exchange :

1 January 1999:	$1 =	BEF 34.57	EUR 0.856968
	$1 =	CAD 1.54	
	$1 =	FRF 5.62	
31 December 1999:	$1 =	BEF 40.14	EUR 0.995045
	$1 =	CAD 1.45	
	$1 =	FRF 6.53	

	US$	EURO
Balthasar van der Pol Fund :		
The account indicated with (1) is represented by :		
342 Rorento Shares : market value on 31 December 1999 =	23,285.89	23,170.50
(Acquisition value : US$ 12,476.17)		
Market value of investments on December 31, 1999 (USD 1 = 40.14 BEF) :		
DEMETER SICAV :	43,544.12	43,328.34
RORENTO UNITS (2) :	442,568.09	440,374.99
AQUA-SICAV :	69,155.06	68,812.37
M-L SHORT TERM :	3,114.00	3,098.57
MASSACHUSETTS INVESTOR FUND :	335,903.24	334,238.71
(2) including the 342 Rorento of van der Pol Fund	**894,284.50**	**889,852.97**

APPENDIX: Detail of Income and Expenditure

	US$	US$	EURO	EURO
I. INCOME				
Other Income				
Reimbursement administrative expenses	94.17		93.70	
Reimbursement bank charges	4.56		4.54	
Interest on Massachusetts Investor Fund	24,310.45		24,189.98	
Sale of ML Short Term	7,045.50		7,010.59	
Reimbursement URSI Support to Cancelled Meetings	906.00		901.51	
		32,360.68		32,200.32
II. EXPENDITURE				
General Assembly 1999				
General Assembly - Organization	8,821.06		8,777.35	
V.d.Pol Medal	890.03		885.62	
General Assembly - Travel Expenses Officials	73,392.46		73,028.77	
General Assembly - Scientific	15,901.13		15,822.34	
General Assembly - Young Scientists	56,463.10		56,183.30	
General Assembly - MRS/RRS	59,149.17		58,856.06	
Correspondents Cards (Printing + Mailing)	758.52		754.74	
		215,375.48		214,308.21
Symposia/Colloquia/Working Groups :				
Commission A	1,514.90		1,507.39	
Commission C	1,500.00		1,492.57	
Commission E	1,884.90		1,875.56	
Commission F	1,704.98		1,696.53	
Commission G	2,149.56		2,138.91	
Commission H	2,804.33		2,790.44	
Commission J	4,400.00		4,378.20	
WG Spectral Congestion	1,116.99		1,111.46	
Other	0.00		0.00	
		17,075.67		16,991.05
Contribution to other ICSU bodies				
IUCAF (1999)	2,000.00		1,990.09	
		2,000.00		1,990.09
Publications :				
Printing "The Radio Science Bulletin (No. 287 to 290)"	14,587.89		14,515.60	
Mailing "The Radio Science Bulletin (No. 287 to 290)"	14,349.38		14,278.27	
Electronic publications - WWW-page	6,631.79		6,598.93	
		35,569.06		35,392.80

News from ITU-R

This text is being prepared just prior to a period of intense activity and of major importance for the Radiocommunication Sector (ITU-R). During the period from the beginning of May to early-June, four meetings will take place in Istanbul that will establish the "radio scene" in ITU for the next few years:

- The Radiocommunication Assembly (RA-2000) (1-5 May)
- The World Radiocommunication Conference (WRC-2000) (8 May – 2 June)
- A meeting of Study Group Chairmen and Vice-Chairmen (CVC) (6 and 9 June)
- The first meeting of the Conference Preparatory Meeting (CPM-02) (7-8 June)

Radiocommunication Assembly (RA-2000)

The Assembly has three principal themes – the working methods of the ITU-R Study Groups, the programme of work for the next study period (2-3 years) and the approval of ITU-R Recommendations.

The working practices of the Radiocommunication Sector are covered by a series of ITU-R Resolutions which will come under review at the Assembly. Essentially administrative in nature, these Resolutions are important in ensuring that the Sector functions in as an effective manner as possible. The work programme for the following study period is contained in Resolution ITU-R 5 which lists some 400 ITU-R Questions assigned to the various Study Groups according to their terms of reference. RA-2000 has to agree this programme of Questions and to ascribe appropriate priority to them. Such deliberations take account of post WRC-2000 issues, as well as studies foreseen for the following WRC which will probably be held in 2002 or 2003.

RA-2000 will also examine those Resolutions concerning the Sector's liaison with the ITU Standardization and Development Sectors, as well as with outside international organisations (of which URSI is an example).

Despite the drive in recent years towards the approval of ITU-R Recommendations by correspondence amongst the Member States, there will be nevertheless some 70 draft new or revised Recommendations presented to RA-2000 for formal approval. Notable are those dealing with IMT-2000, sharing issues involving non-geostationary satellites, high altitude platform stations and earth station coordination.

A further important duty of RA-2000 will be to elect the chairmen and vice-chairmen of the Study Groups for the next study period.

World Radiocommunication Conference (WRC-2000)

The topics to be addressed at WRC-2000 were summarized in *the Radio Science Bulletin* No. 292 with reference to the seven chapters of the Report of the previous Conference Preparatory Meeting (CPM). It is to be hoped that the numerous and complex issues will be resolved to the satisfaction of all parties and that the delegates (estimated at >2500) will not drown under the weight of the expected documentation (current estimate >30 million distributed pages).

Conference Preparatory Meeting (CPM-02) and Chairmen/ Vice-chairmen meeting (CVC)

One of the many tasks of WRC-2000 will be to prepare the agenda of the following World Radiocommunication Conference (currently designated WRC-02) and the preliminary agenda for the subsequent Conference (WRC-05/06). The Conference Preparatory Meeting (CPM) (of which this will be the first of two) will identify those topics within the agendas that call for technical studies by the ITU-R Study Groups and, in coordination with the Study Group chairmen and vice-chairmen, will determine a work programme preparatory to the next and subsequent WRC. The studies will be undertaken largely within the current Study Group structure using existing Working Parties and Task Groups as far as possible. It is likely, however, that some new groups will be established to deal with specialised topics crossing the discipline of more than one ITU-R Study Group.

And so, for ITU-R, a new cycle ends and a new one begins! Hopefully, in the next or subsequent issue of *the Radio Science Bulletin*, it will be possible to report on the results of these four events.

Kevin A. Hughes

ISES Annual Report for 1999

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

Three basic mechanisms have been selected to accomplish this program. Firstly, ISES prepares the International Geophysical Calendar each year. This calendar gives a list of "World Days" which scientists are encouraged to use for carrying out their experiments. The calendar is prepared for ISES by the World Data Center-A for Solar Terrestrial Physics in Boulder, USA. The calendar is distributed widely to the scientific community and is also published in a number of journals. *(Also available on the ISES Homepage at http://www.sec.noaa.gov/ises/calendar/calendar.html ; and there is direct link to this calendar from the URSI Homepage)*

Secondly, there is the International URSIgram Service for assisting those who need information on the state of solar activity, earth atmosphere or magnetosphere at the time of their experiment as well as alerts, warnings, and forecasts of space weather activity that may have an impact on systems susceptible to the space environment. These services are provided by ISES through Regional Warning Centers.

Both of these programs are very flexible and can be easily adjusted to fit the needs of the scientific community.

Thirdly, ISES arranges Solar Terrestrial Prediction Workshops bringing together scientists, solar terrestrial forecasters, and users of forecasts to advance the science of forecasting. Such workshops were held in Boulder (1979), Meudon near Paris (1984), Leura near Sydney (1989), Ottawa (1992), and Hitachi near Tokyo (1996). Each workshop resulted in a collection of papers - the Workshop Proceedings - being published and becoming important reference material for the field.

In addition, on behalf of COSPAR, each month ISES summarizes the status of satellite orbits around the earth and of space probes in the interplanetary medium in the Spacewarn Bulletin.

Future launches are announced, actual launches are reported, new satellites receive an international designation, decays in the earth atmosphere are predicted and announced, and finally series of satellites useful for international participation are listed. This bulletin is produced by the World Data Center-A for Satellites at the Goddard Space Flight Center in Greenbelt, USA.

Indications are that the new solar cycle - Cycle Number 23 - will be of large amplitude, comparable to recent near record cycles. This level of activity, combined with the increasing sensitivity of modern technology, emphasizes the relevance and importance of the services coordinated by ISES.

The International Ursigram Service

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

At the end of 1999, RWC Paris decided to stop the activity of the Center, and the Royal Observatory of Belgium in Brussels accepted to continue the work of RWC. It is expected that RWC Brussels will formally replace the work of RWC Paris after the next ISES Steering Committee meeting in April, 2000.

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

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

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

Publications

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

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

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

The daily Geoalerts and Ursigram messages are "real-time" information and only a summary is printed as the

"ISES Alert Periods" in the *Solar-Geophysical Data Books* published by World Data Center-A. However, the production and distribution of Ursigrams is a very important part of the current expenses of the RWCs. This expense is borne by the host institutions.

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

Recent ISES Activities

1. ISES Steering Committee Meeting

A meeting of the ISES Steering Committee was held in conjunction with General Assembly of IUGG held in Birmingham during July 1999. A major topic discussed was the future direction that ISES should take, with concentration paid to recent changes in data availability through Internet and World Wide Web, and also in the increasing interest of the scientific community in space weather.

ISES still sees an important role for itself. Being the only organization linking agencies which are directly involved in space weather forecasting, ISES has a unique and important perspective. Experience has shown that scientific understanding does not necessarily bring with it the ability to forecast. ISES can provide advice and feedback on this final and very difficult stage of turning scientific research into support for operational forecasting.

One important conclusion of the meeting is that ISES should develop a new ISES constitution defining clearly its organization and roles, and declare its mission. The draft has been prepared by the ISES Secretary, and will be discussed at the next ISES Steering Committee meeting in April, 2000.

Another important conclusion of the meeting was that the ISES would participate in the Space Weather Month campaign which had been organized as one of the programs of SCOSTEP/S-RAMP (STEP Results Applications and Modeling Program).

2. Participation in the Space Weather Month Campaign

As agreed at discussions at the ISES meeting and the S-RAMP Steering Committee meetings, the ISES participated in the Space Weather Month campaign, through September, 1999. Our purpose was to provide the ISES forecasts to scientific community, to show how the ISES makes the forecasts, to identify problems in making predictions, and thus to communicate with scientific community.

RWC Sydney (Australia) prepared the S-RAMP Web site where each RWC can input its own summaries of current conditions and forecasts on the solar, interplanetary, geomagnetic, and ionospheric conditions. Warning Centers, Boulder (USA), Ottawa (Canada), Paris (France), Sydney (Australia), Tokyo (Japan), and Beijing (China) participated in this campaign. RWC Sydney archived the inputs for future analysis.

3. Workshop on Space Weather, November 1999

An International Workshop on Space Weather Research and Operation was held in Oarai, Japan, in November 1999 under the sponsorship of CRL (Communications Research Laboratory), STEL (Solar-Terrestrial Environment Laboratory) Nagoya University, STA (Science and Technology Agency), ISES, and a Space Weather Group of SGEPSS (Society of Geomagnetism, Earth, Planetary and Space Sciences). Participants include delegates from Boulder (USA), Sydney (Australia), and Tokyo (Japan).

Main topics were: models and forecasting algorithms, review of ISES S-RAMP campaign, exchange of data and products, and future observation plans. Three Working Groups were organized to continue collaborative works, to develop virtual collaboration system, to revise ISES codes, and to develop models and forecasting algorithms.

4. The Next ISES Predictions Meeting

Because of the number of scientific meetings on space weather, ISES will hold a more restricted predictions meetings in 2000. This will be held in Boulder in conjunction with the Space Environment Center space weather week, from April 30 to May 6. Attendance will be mostly limited to those directly involved in space weather forecasting and the meeting will attempt to provide a guide to the scientific community about the needs of forecasters for data and analytical tools.

5. ISES Home Page on the Web

ISES has a home page on the Web and this contains information about ISES and its Warning Centres, copies of the ISES code book, and references to the home pages of ISES centres. The page is a good way to navigate the Web to obtain space environment services. The address for the page is: http://www.sec.noaa.gov/ises/

IUCAF Annual Report for 1999

The Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science, IUCAF, has been formed in 1960 by URSI, IAU, and COSPAR. Its brief is to study the requirements of radio frequency allocations for radio astronomy, space science, and remote sensing in order to make these requirements known to the national and international bodies that allocate frequencies. IUCAF operates as a standing committee under the auspices of ICSU, the International Council for Science and is strongly supported by URSI, IAU, and COSPAR. ICSU works under the umbrella of the United Nations organization UNESCO.

Membership

At the end of 1999 the composition of membership for IUCAF was:

URSI	W.A. Baan	The Netherlands
	M. Davis	USA
	W. van Driel	France
	A. van Eyken	Norway
	P. Poiares Baptista	The Netherlands
	K. Ruf	Germany
	A. Tzioumis	Australia
IAU	S. Ananthkrishnan	India
	A.R. Thompson	USA
	M. Ohishi	Japan
	B.A. Doubinsky	Russia
COSPAR	D. Breton	France
	A. Gasiewski	USA

Ex Officio Advisers:

Director ITU Radio Bureau: Robert Jones, Canada

Chairman ITU Radio Board: M. Miura, Japan

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

At the end of 1998, the membership of IUCAF had decided to appoint Dr. Klaus Ruf from the Max-Planck- Institut für Radioastronomie in Bonn, Germany, as chairman after Dr. Willem Baan had expressed the desire to step down. The transition of Chairmanship took place in the meeting of IUCAF in Grenoble in January 1999.

International Meetings

During the period of January to December 1999, IUCAF Members and Correspondents took part in the following meetings:

January:	Commsphere in Toulouse, France
January:	ITU-R Task Group 1-5 on Unwanted Emissions in Phoenix, AZ, USA
March:	IUCAF Pre-Meeting at IRAM in Grenoble, France
March:	ITU-R Working Party 7D in Geneva, Switzerland
April:	Meeting of CRAF, the Committee on Radio Astronomy Frequencies of the ESF in Torún, Poland
July:	IAU Symposium 196 in Vienna, Austria
August:	URSI General Assembly in Toronto, Canada
August:	ITU-R Task Group 1-5 on Unwanted Emissions in Assen, The Netherlands
September:	Meeting of CRAF, the Committee on Radio Astronomy Frequencies of the ESF in Cambridge, UK
September:	CEPT/EU Workshop on European Preparations for WRC2000 in Brussels, Belgium
November:	Conference Preparatory Meeting in Geneva, Switzerland

IUCAF Meeting

During the year 1999, in March, IUCAF has met as a committee with invited guests at Institute Radio Astronomie Millimetric (IRAM) in Grenoble, France. This pre-WP7D meeting was held with the purpose of discussing and focussing on important issues without the interference of other (non-science) interest groups. At the end of this meeting, the membership of IUCAF confirmed the transition in chairmanship to Dr. Klaus Ruf, who has been acting since. IUCAF is thankful for the hospitality given by IRAM and its Director, Dr. Michael Grewing.

Contact with the Unions

IUCAF keeps regular contact with the secretariats of the supporting unions and with the ICSU secretariat. The Unions plays a strong supporting role for IUCAF and the membership is greatly encouraged by their support.

1. Relations with IAU

IUCAF members and correspondents assisted in the preparations of and actively participated in IAU Symposium 196 in Vienna, Austria in July 1999. This conference on "Preserving the Astronomical Skies" addressed all issues of pollution related to astronomy including light pollution, radio interference, and the issue of space debris. The topical meeting was held the week preceding the UNISPACE III conference organized by UNESCO on the "Peaceful Use of Space", for which the IAU Symposium worked out resolutions. At the Vienna meeting, the relation of IUCAF with the IAU and its president, Johannes Andersen, was strengthened considerably. The papers presented at Vienna will be printed as a book and appear in time for the IAU General Assembly in August 2000.

2. Relations with URSI

2.1 Commsphere

IUCAF members actively participated in the organization and the meeting of Commsphere held from 25 to 28 January, 1999, in Toulouse, France. This URSI meeting was co-sponsored by ITU and provided a discussion forum between passive (scientific) spectrum users, government regulators, telecom operators, and manufacturers. The need for protection of the science bands was clearly relayed. In addition, the talks by Joe Shapira (URSI VP, Israel) and Riszard Struzak (ITU, Geneva) also reemphasized the needs for the scientific services.

2.2 The URSI General Assembly

In August 1999 URSI held it's General Assembly in Ottawa, Canada. IUCAF members are appointed by the scientific unions, and URSI holds the largest share. Hence, a large fraction of the IUCAF membership was under review. The Chairman of IUCAF had asked to leave the membership unchanged, exceptionally, because IUCAF is in the middle of WRC-2000 preparations, and all IUCAF members are involved in this difficult process. URSI, however enforced the rule, from the statutes of ICSU, that members should not serve longer than 2 terms of three years each on the committee. Victims of this rule became Drs. R.J. Cohen from the UK and J. Whiteoak from Australia. Both Dr. Cohen and Dr. Whiteoak are radio astronomers and both are very experienced in frequency protection. Jim Cohen is chairman of CRAF and co-organizer of the IAU Symposium 196 in Vienna, John Whiteoak is chairman of ITU-R Working Party 7D (Radioastronomy) and had been tasked to chair the co-ordination of WRC-2000 preparations for the whole of ITU-R Study Group 7 (Science Services). IUCAF owes a lot to Jim Cohen and John Whiteoak, and the chairman would like to take the opportunity to express his sincerest thanks to the two colleagues. I am particularly grateful for their continued valuable work for IUCAF, which they now continue as IUCAF correspondents.

URSI was, however, flexible enough to exempt the former IUCAF chairman, Dr. Willem Baan from the two-term rule, and leave him on the committee as ex-officio member, much to the relief of the current chairman, who still profits much from the experience of Willem Baan.

Dr. W. Keydel, Germany, from the remote sensing community, gave up his membership after one term, due to excessive workload. I would like thank Dr. Keydel for his engagement and for the time he devoted to IUCAF.

URSI newly appointed Drs. M. Davis from the Arecibo Observatory in Puerto Rico, W. van Driel from Nancay Observatory in France, and A. Tzioumis from CSIRO in Australia.

During the URSI General Assembly, an important topic in the discussions was, how to strengthen the relations between URSI and ITU. The Commsphere conferences have brought together expert from both arenas, and co-operation has been discussed there already. Now, the URSI Board set up a new scientific committee called the SCT, Scientific Committee on Telecommunications, under the auspices of Vice-President Joseph Shapira (Israel). Paul Delogne (Belgium) will chair SCT with Willem Baan (Netherlands) as one of the vice-chairs. As a start into this new activity, Prof. Delogne and Willem Baan organized a tutorial, at the URSI GA with the title: Spectrum Congestion. Spectrum Congestion will be a mayor topic at the next URSI General Assembly in Maastricht, in Summer 2002.

Affairs of the International Telecommunication Union

1. The ITU-R World Radiocommunication Conference 2000

The World Radiocommunication Conference,WRC2000, will be held in Istanbul, Turkey, during the period of 8 May – 2 June 2000. The Agenda Items that relate to Passive Scientific use of the spectrum can be found at the IUCAF Web site. The Agenda of WRC-2000 also set a large fraction of the agendas for Working Parties 7C, 7D, and Task Group 1/5 as much of the preparatory work for the Conference is done in the ITU-R Study Groups.

2. The WRC-2000 Agenda Items Related to Radio Science

(The following acronyms are used: RAS: Radio Astronomy Service; EESS: Earth Exploration Satellite Service; MSS: Mobile Satellite Service; FSS: Fixed Satellite Service; SR: Space Research)

1.2 Finalize the remaining issues on spurious emission in Appendix S3 for space services,

1.4 Consider issues relating to allocations and regulatory aspects related to RESOLUTIONS 126 (WRC-97), 128 (WRC-97), 129 (WRC-97), 133 (WRC-97), 134 (WRC-97) AND 726 (WRC-97);

1.5 Consider regulatory provisions and possible additional frequency allocations for services using High Altitude Platforms taking into account the results of RESOLUTION 122 (WRC-97);

1.6.1 Review the spectrum requirements for the operation of terrestrial IMT-2000 with the view to identify future expansion bands and adjustments to the Table of Allocations,

1.9 Take into account the results of ITU-R studies in evaluating the feasibility of an allocation in the space-to-Earth direction to the MSS in a portion of the 1559 - 1567 MHz frequency range, in response to Resolutions 213 (WRC-97) AND 220 (WRC-97);

1.10 To consider the results of ITU-R studies in accordance with Resolution 218 (WRC-97) (Use of the bands 1525 - 1559 MHz and 1626.5 - 1660.5 MHz by the MSS),

1.11 Consider constraints on existing allocations and to consider additional allocations on a worldwide basis for the non-GSO/MSS below 1 GHz, taking into account Resolutions 214 (Rev WRC-97) and 219 (WRC-97);

1.13 On the basis of the results of the studies in accordance with Resolutions 130 (WRC-97), 131 (WRC-97) and 538 (WRC-97):on the "Use of NGSO (non-geo-stationary-orbit) systems in the FSS in certain frequency bands", 1.14 Review the results of the studies on the feasibility of implementing NGSO MSS feeder links in the 15.43 - 15.63 GHz range in accordance with Resolution 123 (WRC-97);,

1.15.1 To consider new allocations to the radio-navigation-satellite service required to support developments in the range from 1 to 6 GHz,

1.16 To consider allocation of frequency bands above 71 GHz to the EES (passive) and RAS, taking into account Resolution 723 (WRC-97);

1.17 To consider possible worldwide allocations for the EES (passive) and SR (passive) services in the band 18.6 - 1.8 GHz taking into account the results of the ITU-R studies.

3. IUCAF Activities Related to the Agenda Item 1.16 of WRC-2000

WRC-2000 will provide the last opportunity for the radio science community to make significant changes in the frequency allocation table above 71 GHz. Such changes are needed in order to reflect the changes in scientific insights that were gained since the current table was adopted at WARC-79. Proposals have been prepared for this agenda item and submitted to the ITU by a number of countries from all three ITU Regions, which were mostly based on the results of the IUCAF mm Wave Working Group The guiding principles for re-allocation of the RAS bands have been the following: 1) the RAS can share some spectrum with terrestrial services by means of protection zones around the few mm wave observatories, 2) satellite down-links and aeronautical operations need to be located adjacent to each other at the edges of atmospheric spectral windows, 3) any potentially damaging active operations need to be located in places where they do least damage to passive spectrum use, and 4) all services need to have continued access to the spectrum.

This issue was finally addressed and brought in line with the requirements of the remote sensing community during the Conference Preparatory Meeting in the Fall of 1999. The current proposals would give the remote sensing community access to bands that are of crucial importance for the studies of the Earth atmosphere and the surface. Similar the RAS will obtain dramatically increases in spectrum shared with terrestrial telecommunication services.

4. CPM-2, Preparation for WRC2000

The second Conference Preparatory Meeting, CPM-2, concluded about the studies performed in ITU-R in preparation of WRC-2000. CPM also writes the CPM-Report, a 500+ pages document, which is normally accepted by the conference as the guideline in all technical questions. This meeting is therefore often considered to be of comparable importance as the conference itself.

Seven radio astronomers from different countries of the world participated in CPM, three of them are IUCAF members, but more than 1000 delegates of administrations, sector members (operators and manufacturers), and regional/ scientific organizations participated in the meeting. The meeting organization was divided into 7 Working Groups: one for each CPM chapter. Each of the Working Groups was divided into a number of sub-working groups and even sub-sub-working groups. Proposals were submitted to the CPM-2 and were discussed in the various Working Groups, which in turn produced modified text for the final CPM Report. The "Input CPM Report" was produced by the ITU-R Study Groups. Working hours continued into late evening hours and on Saturday and Sunday.

The end result of the exhausting experience, the CPM Report, is generally in agreement with the protection requirements for radio astronomy in most cases, where allocations to radio astronomy are part of an agenda item of WRC-2000, explicitly or by consequence. IUCAF is moderately optimistic about the outcome of WRC-2000.

5. ITU-R Task Group 1-5 on Unwanted Emissions

IUCAF members have been playing a leading role in the ongoing work of Task Group 1-5, providing many input papers and the chairmen of large and critical drafting groups. IUCAF has considered TG 1-5 and its work very important for radio science and both TG 1-5 meetings in 1999 had some six radio astronomy participants from various countries. Nevertheless, protection of passive services from unwanted emissions remains one of the tasks on which TG1-5 could not yet conclude. Many action items on TG1-5's agenda could be closed, like the preparation of text for the CPM of WRC-2000, where inclusion of spurious emission limits to space services into the Radio Regulations is now proposed, which until now are qualified as design objectives only. Out-of-Band emission limits will not make into the Radio Regulations. This concession had to be made in order to achieve progress on ITU-R Recommendation SM.329 on Out-of-Band emissions, which has now been finalized in TG1-5. Protection procedures for the safety and passive services, however, are among the few remaining issues to be solved.

Although Recommendation 66 was initially meant to promote the study of new standards for unwanted emissions in order to protect the passive services, this part of the objective has been pushed back further and further. As a result of an Space Services effort the protection of the passive services and of the safety services have been relegated to a consideration on a "band-by-band" basis. Rather than having general limits that would benefit all spectrum users by reducing unwanted emissions as intended by Rec. 66, this proposal will only protect the radio science bands to a level that is practical for the interfering service. Last years work in TG1-5 has shown, based on a good will action of Eutelsat, first evidence that at least some satellites in the geostationary orbit could meet the protection requirements of radio astronomy.

Despite the goodwill and the hard work of the IUCAF and RAS participants, the protection of the radio science bands will remain in jeopardy. The Draft New Resolution on the Protection of Passive Services is very week, apart from being still in a preliminary form, and it is still lacking input from the satellite operators or their ITU-R Working Groups.

6. ITU-R Working Parties 7D and 7C

Working Party 7D (Radio Astronomy) met only once last year. The autumn meeting did not take place because of the meeting of the Conference Preparatory Meeting for WRC-2000 in November 1999. WP7C addresses the issues of the remote sensing community. WP7C met at the same time as WP7D. Some twelve to fourteen radio scientists participated in the WP7D meeting of which six were IUCAF members. A major effort for Study Group 7 has been the preparation of the guidance text on all relevant issue to be included in the Report for the Conference Preparatory Meeting for WRC-2000. CPM text has been produced on the following major issues:

a) the use by the Fixed Satellite Service of the 42.5-43.5 GHz band, which is adjacent to an important RAS band (Item 1.4 & Resolution 128),
b) the use of the 48 GHz band by High Altitude Platforms above major metropolitan areas for high density (broad band) applications (Item 1.5 & Resolution 122),
c) the use of the 1626.5-1660.5 MHz band usage by the Mobile Satellite Service (Item 1.10 & Res. 218). This concerns a revision of text and application of Recommendation ITU-R M.1316 "Principles and methodology for frequency sharing in the 1610.6-1613.8 and 1660-1660.5 MHz bands between the MSS (Earth-to-Space) and the RA service",
d) the re-allocation of bands below 1 GHz Item 1.11 (Res. 214 and 219),
e) the creation of a global allocation for the Earth Exploration Satellite Service in the 18 GHz band as contained in Item 1.17,
f) the mm wave radio spectrum for the EES and the RAS above 71 GHz (Item 1.16 & Res. 723), and
g) Item 1.2 relating to Recommendation 66 and Unwanted Emissions as part of the work of Task Group 1-5 (see section 4.5.1 above).

Other important issues within WP7D during the1999 meeting have been:

a) the "x percent issue", relating to the amount of observing time or data that can be lost to man-made interference,
b) the use of Monte Carlo methods for the determination of coordination distances between mobile spectrum users and radio astronomy observatories, and
c) the use of the bands 1390-1400 MHz and 1427-1432 MHz by the Mobile Satellite Service and the interference to the RAS in the 1400-1427 MHz band, which may become a WRC item in the future.

Specific Spectrum Issues

IRIDIUM has kept radio astronomy frequency protectors busy since 1992. IRIDIUM offered to provide world-wide telephone (and fax and data transmission) service via a fleet of 66 low-Earth-orbit satellites. Unfortunately, these satellites use frequencies in the band 1621.35 - 1626.5 MHz to connect to the mobile Earth stations with both up-links and down-links. However, satellites had been designed such that unwanted emissions would spill over into the nearby Hydroxyl OH frequency band 1610.6 - 1613.8 MHz, at an unacceptable level at already moderate traffic loads on the system. Even though licensing conditions had been developed in many countries, pointing at the necessity to protect radio astronomy, before the system went into operation in November 1998, much negotiation work remained to be performed in the year 1999. The regulation found in Europe had asked for finding further agreement, between Iridium and CRAF, the ESF supported Committee for Radio Astronomy Frequencies, about the "time sharing" until the year 2005, and about mitigation factors. Time sharing in this context means sharing between a service with a primary allocation and the unnecessary, unwanted emissions of a service with a secondary allocation in a nearby frequency band. Given that a special footnote in the Radio Regulations explicitly says that harmful interference to radio astronomy in the band 1610.6 – 1613.8 MHz shall not be caused by the Mobile satellite Service in the band 1610 – 1626.5 MHz, it is still difficult to understand, why we had to negotiate so much. The Iridium system never achieved traffic density levels high enough to produce the really bad level of unwanted emissions, and the forecasts are, that it never will in future. We had to learn the lesson, however, that even the best rules do not protect us, if they are not enforced, and they will not be enforced, if we do not fight for it.

Publications and reports

IUCAF has contributed a number of documents to the proceedings of Task Group 1-5 and Study Group 7. These documents have all appeared on the ITU-R Home Page and have not all been distributed by email. As a result there was less need to post these documents on the IUCAF Home Page. Information about IUCAF documents and meeting reports is generally available on the IUCAF Home Page and has been distributed by email to the general IUCAF electronic mailing list.

Conclusion

The pressure for commercial spectrum applications has remained steady and intense during recent years. In order to obtain access to large bandwidths the commercial applications are now calling for spectrum up to the edge of the atmospheric window at 60 GHz. These applications mostly relate to high density (and wide band) applications such as Internet from the sky or from stratospheric (aerostat) platforms located above major cities, and as terrestrial wide-area distribution systems. This drive for spectrum results in part from the desire to be first in the targeted market. In addition, the technology for operating at these high frequencies is now becoming commercially available, in part as a result of the pioneering work of the radio astronomers and Earth exploration scientists. In this regard it is of extreme importance that the band allocations above 71 GHz are being considered at WRC-2000. This will indeed be the last chance for the radio science community to change things in that part of the spectrum. It is good to see that IUCAF has been able to take up a central role in the preparations for this Agenda Item at WRC-2000.

IUCAF members and correspondents clearly have their plate full of spectrum issues relevant to radio science.

Many existing spectrum issues have remained and the interference problems continue to expand to higher frequencies. IUCAF will continue to emphasize the message of protecting the radio science for future generations. In particular, the need for expounding on the relevance of such efforts in developing countries and for expanding personal contacts there remain urgent for the coming years. Also the satellite down-link issues will continue to draw attention.

IUCAF is thankful for the moral and financial support that has been given for these continuing efforts by ICSU, URSI, IAU, and COSPAR during the recent years. IUCAF also recognizes the clear support that has been given by radio astronomy observatories and universities to individual members in order to participate in the work of IUCAF.

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Mobile Transmitter Linearization for Spectrum-efficient Modulation Formats

Peter Kenington

ABSTRACT - Many current and proposed modulation formats and air interface designs are based on the assumption that high-linearity transmitters are either not commercially viable or inefficient or both. Modulation formats are therefore chosen primarily for their constant envelope or modest linearity characteristics and not primarily out of regard for spectral efficiency. Whilst these assumptions on transmitter linearity may have been true some years ago, they are clearly not true now and a range of techniques is available to improve the linearity of transmitters and hence pave the way for the use of more spectrally-efficient modulation formats.

Introduction

Cartesian loop linearized transmitter designs have been deployed in a number of radio systems, including TETRA and GEONET FH-CDMA system. The former design requires very high degrees of transmitter linearity (>60dBc) and the latter requires both wide range and high accuracy power control combined with fast frequency hopping. Together they form a difficult requirement for any transmitter and yet both have been achieved using a high-linearity, but still relatively simple, design technique. Both of these designs are now in commercial production.

Future developments currently underway aim to improve the power efficiency or channel bandwidth capability (or both) of a linearized transmitter and considerable research is underway to achieve these goals. High-efficiency use of feedforward, RF, IF and baseband predistortion, LINC (linear amplification using non-linear components), CALLUM (a derivative of LINC) and new forms of EE&R (envelope elimination and restoration) are all at varying stages of practicality, with some being available already for a restricted range of systems (e.g. a CALLUM system has been designed for TETRA base-station applications by Wireless Systems International Ltd.). These techniques are all being developed in a number of companies world-wide and that development would certainly be advanced by the definition of spectrally-efficient air interfaces which would require their use, rather than merely potential applications where their use would be beneficial but not essential.

This paper will examine the state-of-the-art in these various technologies and highlight practical niche applications where they currently exist. Awareness of the commercial availability of such techniques is clearly essential in enabling regulators to define air-interface standards capable of exploiting their advantages to the benefit of the radio spectrum as a whole. Further details on the schemes described can be found in [1].

Cartesian Loop Linear Transmitter

1. Introduction

The Cartesian loop [2-6] is an example of a linearisation scheme, i.e. a system in which a conventional linear or non-linear RF amplifier is improved, in terms of its distortion performance, in order to meet a given specification. This is achieved with minimal impact on the overall power consumption and power efficiency of the system, and with a minimum of added complexity.

The technique forms a complete linear transmitter, as opposed to simply a linear power amplifier, and is shown in Figure 1. It takes baseband signals, in I and Q format, and translates these signals to an RF carrier frequency at a high power level. Thus, the upconversion and power amplification processes are combined and the whole is subject to the distortion improvement of the linearising feedback.By this mechanism, non-linearities in the upconverter and driver amplifier chain are linearised, in addition to the RF power amplifier. If an intermediate frequency is employed in the upconversion process, then non-linearities in this block are also removed (to a degree determined by the amount of feedback).

As with all feedback systems, its performance is limited by the delay around the loop and hence the linearity improvement which can be obtained depends upon the bandwidth over which the feedback must operate. This bandwidth is usually limited to a single RF channel or a number of closely-spaced channels; it will also depend

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upon the type of amplifier employed. Smaller loop gains are usually necessary with class-C power amplifiers due to the large phase-shift which occurs when the active device turns on, in this type of amplifier.

Practical amplifiers have been constructed at a variety of frequencies between 150 MHz and 1.8 GHz, with commercial designs being incorporated in TETRA, iDEN (formerly MERS), GEONET and other (mostly PMR) applications. Linearity improvements of between 25 and 45dB have been achieved for various channel bandwidths.

incorporate an IF within the Cartesian loop, however this is generally undesirable due to the additional delay this introduces.This additional delay in turn reduces the maximum gain available within the feedback loop and hence the ultimate correction which can be achieved.

2.3 Ramping

Although power ramping and power control may be performed in a similar manner within the Cartesian transmitter as is employed at present in PDC and DAMPS designs, there are benefits which can be obtained by making use of the inherent linearity of the up-conversion and transmission system.

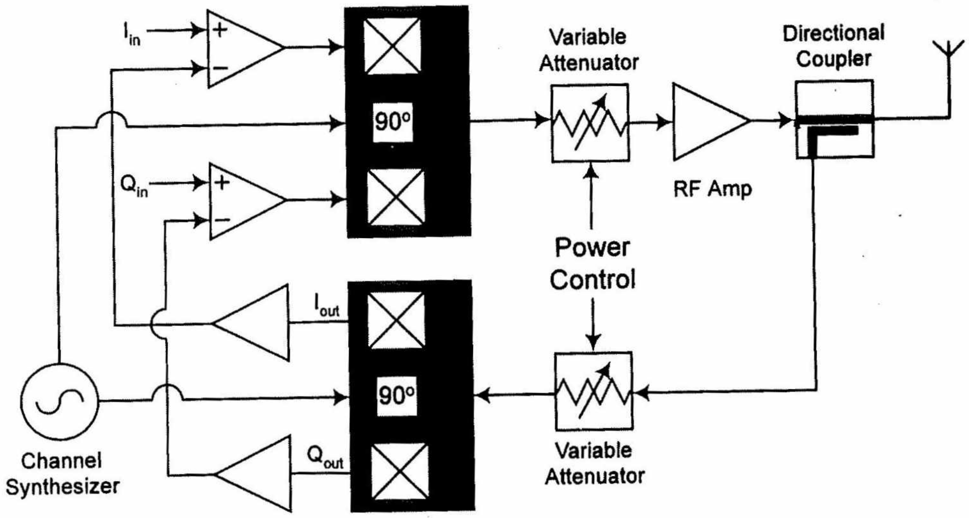


Figure 1: Cartesian loop linearised transmitter

Power ramping (or TDMA pulse-shaping) may be performed at baseband, independently of the final power level to which the amplifier must settle. This is most easily achieved by means of a look-up table implemented in software within the baseband processing. The final output signals from the baseband processing can then be scaled by the appropriate ramp profile (stored in the look-up table) immediately prior to D/A conversion. The up-conversion and amplification process is linear and hence the output ramp is a faithful reproduction of that generated at baseband. This is achieved without any calibration of the RF parts of the system, and no set-up or calibration of this aspect of performance is required on manufacture.

2.4 Power control

The function of the power control circuitry is now merely to set the ultimate power level to which the signal will ramp. Again, due to the action of the loop, this can be determined to a very high degree of accuracy without calibration. Since the power control is now only required to set a finite number of fixed power steps, it can be achieved by switched attenuation within the loop, resulting in high accuracy and no requirement for calibration.

2. - Example: Incorporation within DAMPS and PDC Architectures

The basic requirements of the Cartesian loop transmitter, in terms of external interfaces and signals can be easily met by current DAMPS (US digital cellular) and PDC (Japanese digital cellular) transmitter architectures. The only major changes required are in the methods used for handling power ramping and power control, both of which use largely the same mechanism in current designs, but can benefit from being treated separately when implemented using a Cartesian loop.

2.1 Baseband Input Signals

The baseband interface is a simple I/Q arrangement of exactly the same form as that used for quadrature upconversion at present (indeed the same upconverter devices are used in a number of discrete implementations of the loop). No changes should therefore be required in this part of the circuitry (or software).

2.2 Local Oscillator

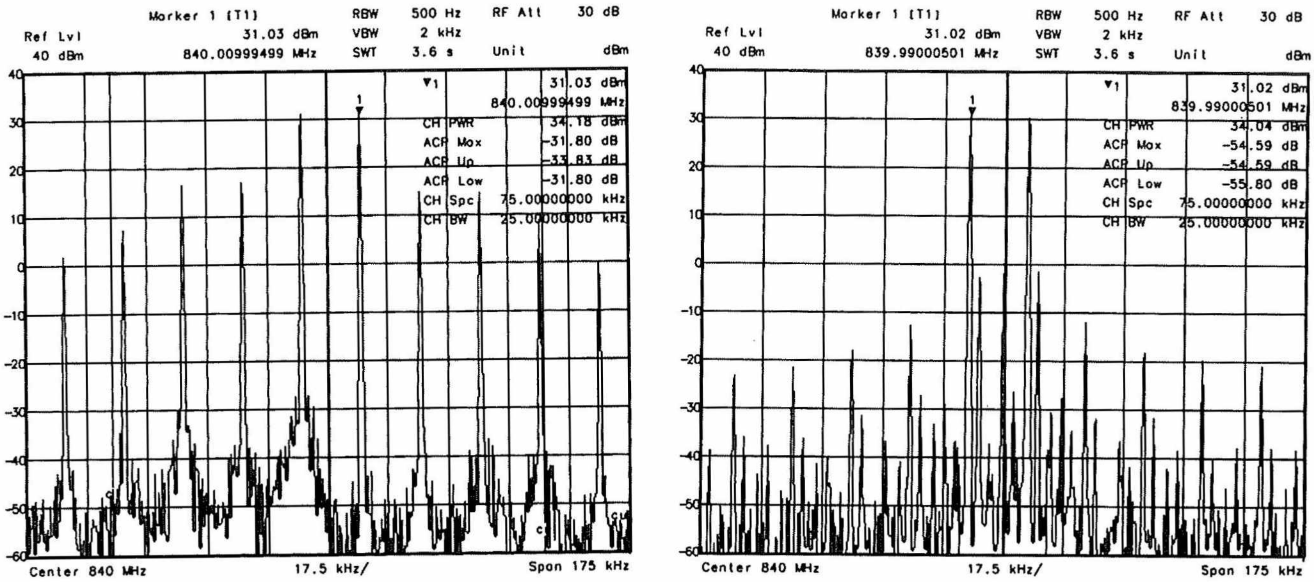
The local oscillator can either be supplied on-frequency, or can be formed by mixing two off-frequency signals (this is compatible with a number of architectures currently employing IF-based up-conversion). It is also possible to

2.5 Calibration

The only calibration required within the loop is that necessary to set the maximum output power level. This can be calibrated once upon manufacture and the value stored as a 'fine control' setting used each time the handset is turned on. This is a quick and simple calibration and does not need to be performed over a range of temperatures, operating modes etc. Its purpose is to compensate for errors in the output directional coupler value (usually around 2dB) and for small gain errors in the downconversion chain.

2.6 Phase control

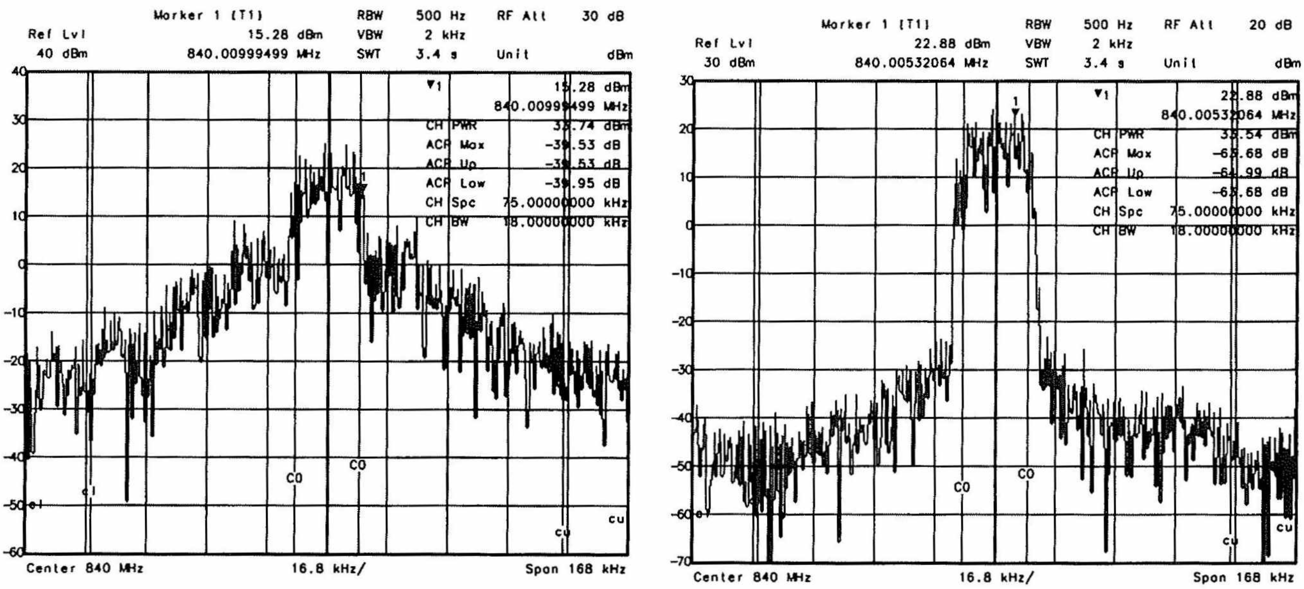
Phase control is usually required within the loop to allow operation across a wide range of channels (i.e. a wide operational bandwidth as defined earlier). This usually takes the form of a small number of 'bands' within which a given phase setting is adequate and this can be indexed by the synthesiser channel number (e.g. channels 1-100 = phase setting 1, channels 101-200 = phase setting 2 etc.). A typical number of bands would be 3-5, although a single setting is adequate in many cases. This setting only needs to change when the transmission frequency changes.



2(a)

Figure 2: Two-tone results from an 840MHz Cartesian loop: (a) Uncorrected response of the RF amplifier chain; (b) Response of the complete Cartesian loop transmitter.

2(b)



3(a)

Figure 3: pi/4-QPSK results from an 840MHz Cartesian loop: (a) Uncorrected response of the RF amplifier chain; (b) Response of the complete Cartesian loop transmitter.

3(b)

2.7 Instability detection

An instability detector is often included as a 'fail-safe' mechanism to guard against oscillatory behaviour of the loop. Under normal circumstances, this will not be used, however given the wideband-jamming consequences of an unstable transmitter it is usually desirable to have a mechanism to detect this type of fault, to allow the transmitter to be shut down. This will appear as a 'go/no-go' signal to the baseband processor or CPU controller, which can then take appropriate action (e.g. to shutdown the PA).

2.8 Signal vector error (SVE)

The signal vector error of the transmitter is dominated by the quadrature performance of the downconverter stages. This typically achieves around -35dBc of image rejection, which is more than adequate to meet the required SVE performance.

2.9 Noise performance

Noise performance of the loop is a complex question and cannot adequately be covered here. Loops have been designed recently which meet the stringent noise specifications of the European TETRA system, proving that high levels of performance are achievable. There is, however, significant scope for incorrectly-designing the loop in this area (it could well be working perfectly in all other respects). This aspect of performance must be given careful thought, and the correct design procedures followed.

3. - *Practical Results*

Some practical results from a 900MHz Cartesian loop transmitter are shown in Figures 2 and 3.

The RF amplifier chain used in this design culminated in a class-C stage and the open-loop performance of this system is shown in Figure 2(a). It is evident that the two-tone linearity performance of this arrangement is very poor (around 13dBc), as would be expected from an efficient class-C amplifier.

When the Cartesian loop system is added, the linearity of the system improves dramatically, as can be seen in Figure 2(b). The third-order IMD (Inter-Modulation Distortion) products are now at approximately 43dBc (dB below carrier), indicating an improvement of some 30dB. The same techniques have been applied to many amplifier systems, with two-tone linearity results of up to 75 dBc being achieved at a variety of frequency bands in VHF, UHF and SHF.

Figure 3 shows the results for the pi/4-QPSK modulation, using a root-raised cosine filter with a roll-off factor of 0.35. The intended channel spacing is 25kHz, with the first, second and third adjacent channels being shown on the plots. The adjacent channel power levels before and after linearisation are shown in Table 1. This indicates an improvement of 35dB for the first adjacent channel power (ACP), taking it well within both DAMPS and PDC specifications. The second and third adjacent channel performance is also well within specification.

Adjacent Channel	Open loop ACP (dBc)	Closed Loop ACP (dBc)	Reduction (dB)
1rst	-18	-53	35
2nd	-28	-62	34
3rd	-39	-64	25

Table 1: Adjacent channel power measurements for the unlinearised and linearised class-C power amplifier.

4. - *Power Efficiency*

Power efficiency is a key requirement in any handset transmitter and is one of the key benefits of the Cartesian loop technique when used in conjunction with a non-linear power amplifier (such as one operating in class-C).
If it is assumed that the main elements of the loop are implemented in an integrated circuit (the only sensible format for use in a DAMPS or PDC handset) and that the power consumption of this IC is small, then it is possible to base an estimate of the power efficiency of a handset transmitter purely on the DC power consumption of the power amplifier IC and on its mean output power, when supplying the relevant (DAMPS or PDC) signals into a 50 ohm load. Based on the above assessment of power efficiency, the figures shown in Table 2 are obtained.

Cellular Scheme	Supply Voltage (V)	DC Input Power (W)	RF Output Power	Efficiency (%)
NADC	6.0	2.04	1.26 W (+31 dBm)	62
NADC	4.8	1.25	0.776 W (+29 dBm)	64
PDC	6.0	2.07	1.26 W (+31 dBm)	61

Table 2: Power efficiency of a Cartesian loop linearised transmitter when operating with DAMPS and PDC modulation formats.

Polar Loop Linear Transmitter

The polar loop transmitter [1,7] is, in many respects, similar to the Cartesian loop discussed above; the main difference lies in the form of the feedback applied, which is now in amplitude and phase (polar) co-ordinates rather than I and Q (cartesian) form. The invention of the polar loop pre-dates that of the Cartesian loop, however it is generally poorer in terms of its achievable linearity performance. This occurs for two reasons:

1) The required feedback bandwidths for the amplitude and phase components are different with the majority of modulation formats. The available loop gain is therefore

limited in one or other of the amplitude and phase paths (usually the phase path). This results in either the AM-AM or AM-PM distortion (usually the latter) being corrected to a lesser degree, thus limiting the overall IMD performance.

2) The operation of the phase-feedback path relies on what is effectively a phase-locked loop, and this can suffer locking problems at low amplitude levels. It can also have problems tracking abrupt changes in phase, such as those occurring at the envelope minima in a two-tone test.

For this reason, the polar loop technique has seen little practical application and no commercial product implementations are known.

Adaptive Baseband Predistortion

This form of predistortion [8-10] can almost be viewed as a hybrid of the RF predistortion and Cartesian loop schemes described above. In this system, predistortion is applied at baseband, generally in some form of digital signal processing, before upconversion to RF, usually by quadrature methods. A feedback path is typically provided to allow the predistortion coefficients to be adapted, in real-time, in order to maintain a high level of linearity. The basic form of the system is shown in Figure 4.

In many respects this solution is similar to Cartesian loop in terms of component complexity, particularly given that in a typical flexible radio architecture the baseband modulation would be supplied from a DSP in that system. It has, however, proved less popular than Cartesian loop due to the additional signal processing required (together with a not insignificant memory requirement in some cases) and the addition of one or more A/D converters for the feedback path. These factors can greatly add to the power consumption of the technique and it is primarily this factor which has led to its unpopularity to date.

Custom solutions to some of the digital signal processing problems are now beginning to appear, however, and these have the potential to greatly reduce power consumption. The technique may therefore become more popular in the future.

Envelope Elimination and Restoration (EE&R)

The EE&R technique [11] can be implemented in a number of different ways, either as a complete transmitter (Figure 5), or as a power amplifier linearisation technique (Figure 6). In either guise it has the potential, theoretically at least, to achieve 100% DC to RF power conversion efficiency at all envelope levels of the modulation signal. This is clearly a major benefit of this (and the following LINC) technique.

The potential for high levels of efficiency stems from the fact that the RF power amplifier is freed from the requirement to amplify envelope varying signals and can thus be implemented by one of the switching RF power amplifier classes (e.g. class-D, E or F). Similarly the AF amplifier which is effectively supplying the 'DC' power to the RF amplifier (and thereby applying high-level amplitude modulation) can be implemented by a switching audio amplifier technique (e.g. pulse-width modulation, class-S) [12]. As both of these types of amplifier are theoretically 100% efficient, and as there are (ideally) no other loss mechanisms (e.g. couplers or delay-lines) in the high-power RF path, the overall amplifier or transmitter could be 100% efficient.

Clearly a practical realisation will fall short of this goal, but a 20% implementation margin (in efficiency terms) would still result in an 80% efficient linear amplifier or transmitter - a highly-desirable result.

Practical EE&R transmitters have been built for a number of applications, most notably for military HF SSB transmitters [13], however there are a number of practical

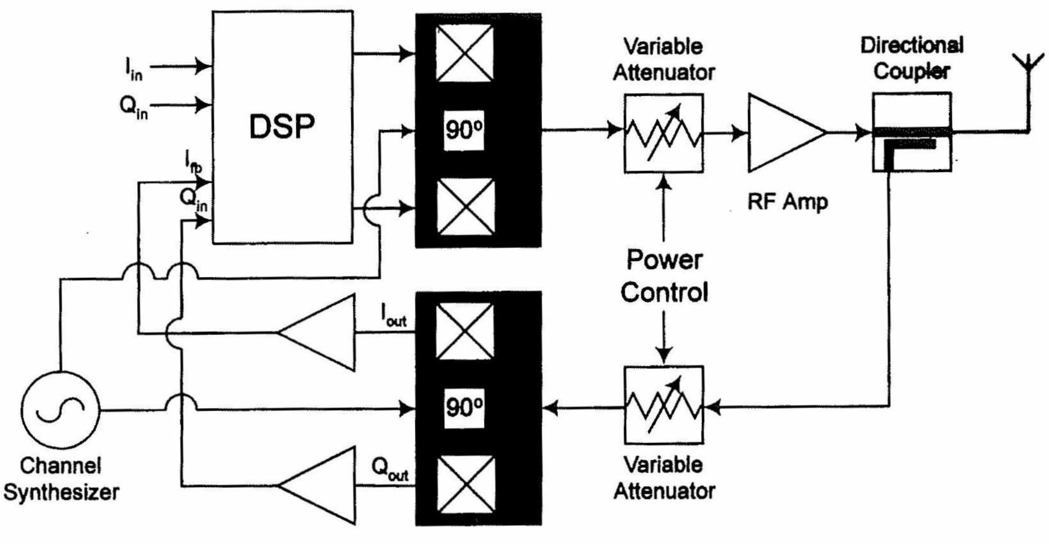


Figure 4: Adaptive baseband predistortion linearisation scheme

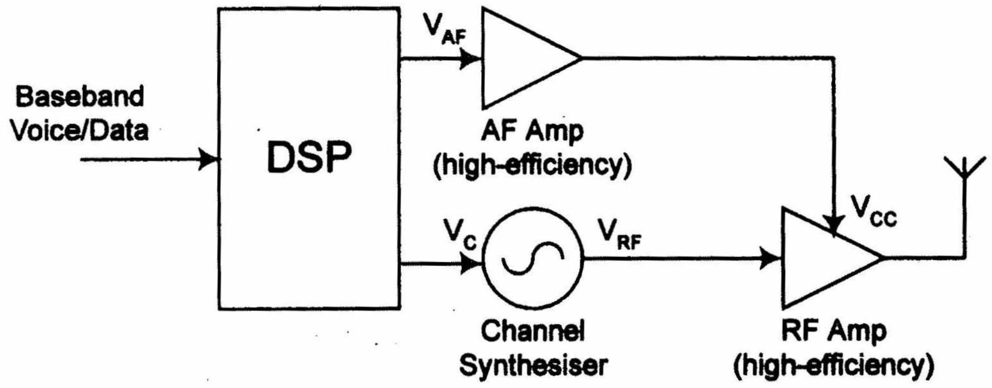


Figure 5: EE&R scheme as a linear transmitter technique

problems which limit, in particular, the linearity available from the system. The use of high-level modulation of the power supply is not a particularly linear method of modulating an RF carrier, especially at low envelope levels, where the RF power transistor will cut-off introducing significant distortion. The technique does, however, have good potential for systems involving relatively modest levels of envelope variation. Examples of this type of scheme include filtered pi/4-DQPSK.

LINC\CALLUM

The LINC (Linear Amplification using Non-linear Components) technique [14] and its derivative, CALLUM (Combined Analogue-Locked Loop Universal Modulator) [15] are both linear transmitter techniques involving RF synthesis. This means that the linear RF waveform is only created at the output of the transmitter with all of the internal processes within the transmitter being effectively non-linear (in amplitude terms). The EE&R technique (described above) could also be placed under this heading.

The basic format of the LINC technique is shown in Figure 7. The modulating signal is generated in the DSP, from the input baseband information, as two constant-envelope phase modulated signals. These are formed in such a way that after RF upconversion and non-linear power amplification (again using e.g. class-D, E or F power amplifiers), the two signals will add to produce the required linear output signal (with unwanted elements appearing in anti-phase in the two channels and hence cancelling).

The use of high-efficiency switching amplifiers again results in the potential of achieving 100% DC to RF power conversion efficiency and this is a major attraction of the technique.

There are, however, a number of problems. First, the requirement for a cancellation process at the output of the transmitter results in stringent control requirements for the gain and phase matching of the two RF paths. This is one of the problems which the feedback mechanism employed in the CALLUM technique attempts to solve.

Secondly, the cancellation process itself, occurring as it does at the output of the amplifier, results in a potential loss of efficiency of up to 50%! This occurs if a hybrid power combiner is used in the summation process, as the cancelled power is then wasted in the 50ohm load connected to the difference port. The amount of power wasted will depend upon the modulation scheme in question, but this is

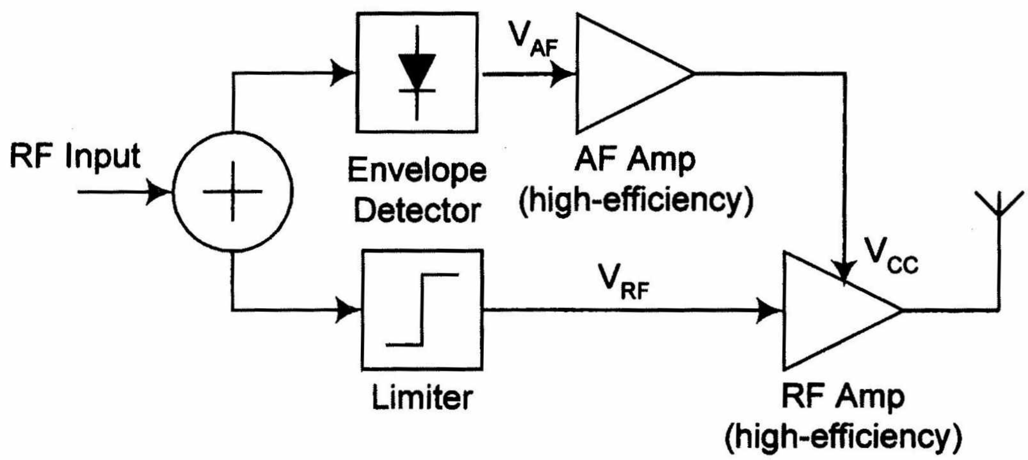


Figure 6: EE&R scheme as a power amplifier linearisation technique

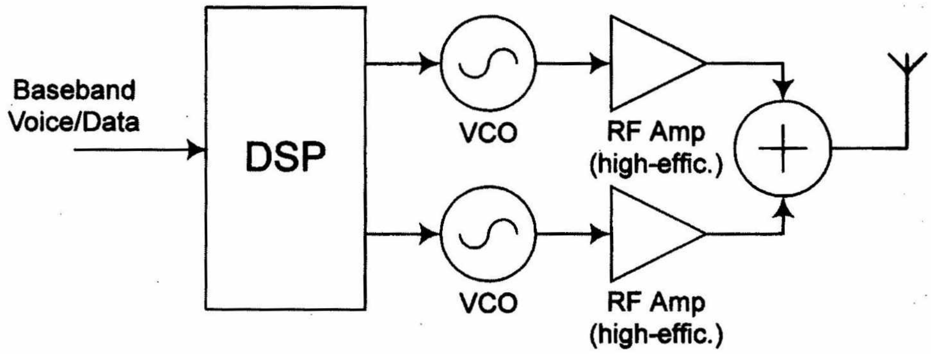


Figure 7: Basic form of the LINC technique

still a significant problem with the technique. Some prototype designs have been produced for both the LINC and CALLUM techniques, but no commercial transceiver designs employing either method are currently known to exist.

Conclusions

The Cartesian loop technique has been highlighted as a method of allowing high-efficiency class-C amplifiers to be used in second-generation cellular handsets for applications such as DAMPS and PDC. The interface of this type of transmitter to existing handset designs has been shown to be simple to achieve and to have advantages in terms of ramping accuracy, power control accuracy and simplicity of calibration, in addition to the obvious efficiency gains. The use of an IC implementation of many of the key elements of the loop makes the use of Cartesian feedback a viable handset option for current and future generation cellular equipment.

A number of other techniques also exist, at varying degrees of development, which are capable of improving upon the performance of the Cartesian loop system. Improvements in channel bandwidth, power efficiency or both are possible with varying degrees of risk and cost penalty. These techniques provide an evolutionary path for spectrally-efficient linear modulation formats and the practical implementation of the transceiver hardware.

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Software Radio Techniques to Enable a Smooth Migration to Spectrally-efficient Modulation Formats

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ABSTRACT - The migration from inefficient older modulation formats (e.g. AM, FM, FSK etc.) to high data-rate multi-level modulation formats is a major issue in ensuring better use of the radio spectrum. Modulation formats in which both the amplitude and phase of the carrier convey information provide inherently greater data rates for a given occupied bandwidth and therefore are highly desirable in the quest to ease spectral congestion. Software radio techniques are also applicable in the base-station and this allows greater flexibility in the use of spectrum, with different modulation formats or data rates being allowed to occupy adjacent channels, thus giving the ultimate in radio system flexibility.

Introduction

The use of spectrally-efficient high data-rate systems has a number of obvious attractions in a variety of applications. Such systems are not currently in widespread use, however, and the reasons for this must be addressed before their spectral-efficiency benefits can be realised in a mass marketplace. There are generally two objections to their use:

1. The hardware complexity required in the transmitter and receiver render them technologically risky or too expensive.

2. The changeover from an older modulation format to a newer one would require the system operator and system users to dispose of their 'old' equipment and replace it with newer equipment in one abrupt transition. Given the considerable investment usually involved in this process, most operators are understandably reluctant to do this.

The use of software radio techniques can clearly overcome the latter problem, as they allow a gradual transition from an old system to a newer one, a few channels at a time, with replacement of the mobiles occurring as and when they become obsolete or unreliable. This changeover can therefore be achieved without loss of revenue or capacity for the operator and without loss of service for the customer.

The former objection can only be overcome by example. Such examples are now beginning to appear in niche applications and the radios being produced are gradually going into volume production at prices comparable with existing equipment. One example is in a seismic survey application in which up to 1000 remote units can transmit data at 60kbps each (i.e. 60Mbps total data rate) in a 20MHz bandwidth (i.e. 20kHz per channel). This represents a practical spectral efficiency of 3bits/s/Hz in a production radio which is also capable of FM voice transmission. This type of modulation (16-QAM) requires an entirely different philosophy for the radio design and hence can meet with entrenched views from traditional radio engineers. These views are gradually being overcome, as larger numbers of niche applications are now using this technology in the field.

In the base-station area, software radio techniques are now emerging due to the reduced constraints on both size and power consumption in this area of application. A key enabling technology is, however, a high-linearity multi-carrier power amplifier and these are now available [1].

16-QAM Radio Modem Design

Very high data-rate bandwidth-efficient modem designs are now both common and cheap; the only remaining hurdle is in enabling the same techniques to be used over radio channels. Personal computer modems currently provide data rates of 56kbps over a 3kHz channel using QAM (quadrature amplitude modulation); the 'channel' does not suffer the fading associated with wireless transmission, but is nevertheless poor both in terms of bandwidth and signal to noise ratio. The challenge is therefore to enable the same basic techniques to be employed over a fading radio channel in a low-cost, small and power-efficient product.

The constellation diagram for a 16-QAM signal is shown in Figure 1. It is clear that the signal contains a number of amplitude levels in addition to the range of phase

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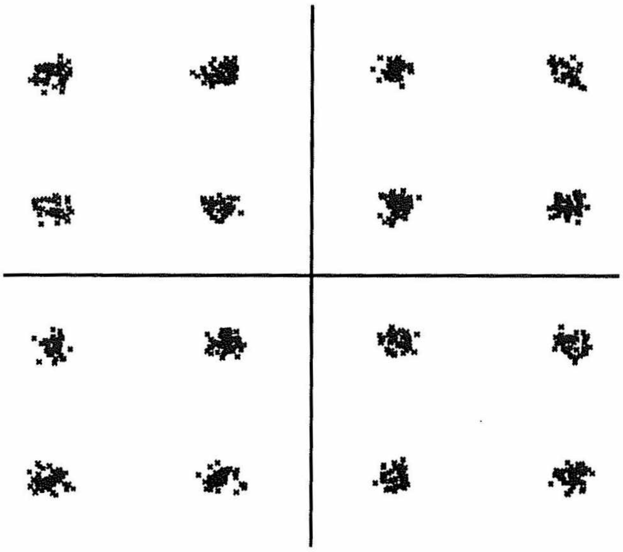

Figure 1: 16-QAM constellation (measured)

states. This places a stringent requirement on the linearity of the radio transmitter, as this can no longer remain constant envelope (as typically used in FM and FSK systems). The effect of a class-C (constant-envelope) power amplifier on a 16-QAM constellation is illustrated in Figure 2. It can clearly be seen that the constellation has been severely affected and that the resulting signal vector error would be extremely poor. These effects alone would be unacceptable in a good system design, however the non-linearity in the amplifier also causes significant spectral spreading, and this is usually a much more important problem. This spectral spreading causes interference in adjacent channels, or places a minimum restriction on channel spacing, hence negating the spectral efficiency benefits of the technique. Clearly, amplifier non-linearity is a key problem in QAM systems.

The basic format of a QAM modem is shown in Figure 3, with the areas of functionality provided within a DSP device being highlighted. Note that the same DSP device is typically employed in both transmit and receive parts of the system (even for full-duplex operation), hence helping to maintain a relatively low level of complexity for the modem.

The transmitter consists of a serial to parallel converter which splits the incoming data stream in to two channels. These two channels are each converted from two to four levels before root-raised cosine filtering to generate the digital I and Q channel waveforms. These I and Q channels are then converted to analoge by the D/A converters and directly upconverted to RF, using a quadrature local oscillator. Finally, the two quadrature paths are combined and linearly amplified, before being fed to the transmit antenna. The linear amplification process is clearly very important to the successful implementation of a QAM modem and is dealt with in a separate paper in this issue and in more detail in the literature [2,3,4].

The receiver consists of a front-end filter and LNA, similar to those in a conventional receiver; the LNA must be highly linear in all radio systems for reasons of strong-signal handling, and hence does not require special modification for linear modulation formats. Following these, a quadrature demodulator converts the signals directly to baseband I and Q channels for A/D conversion and supply to the DSP. The DSP provides symbol and timing recovery, followed by the inverse of the transmit processes of level conversion and parallel to serial conversion.

The complete radio is therefore a direct-conversion transmit and direct-conversion receive system, with all of

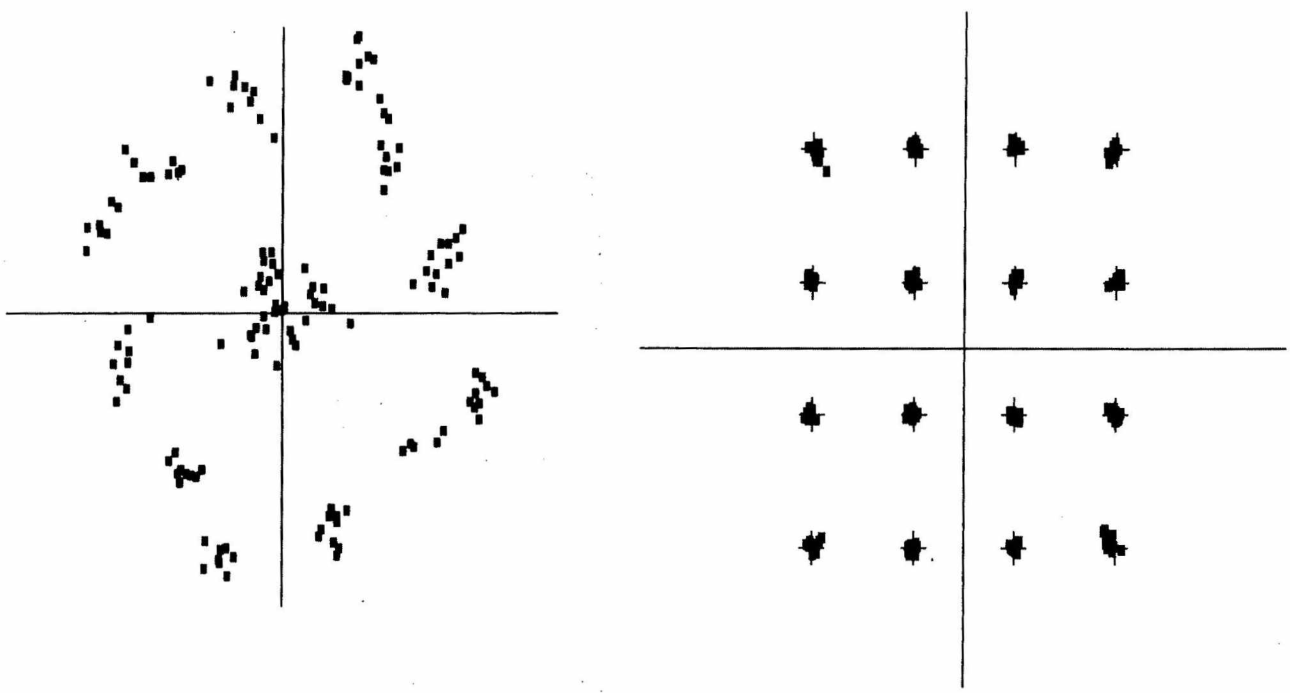

Figure 2: Effect of non-linear amplification on a QAM signal, together with the improvement obtained by linearisation :
(a) Unlinearised Class-C amplifier
(b) Cartesian linearised class-C amplifier

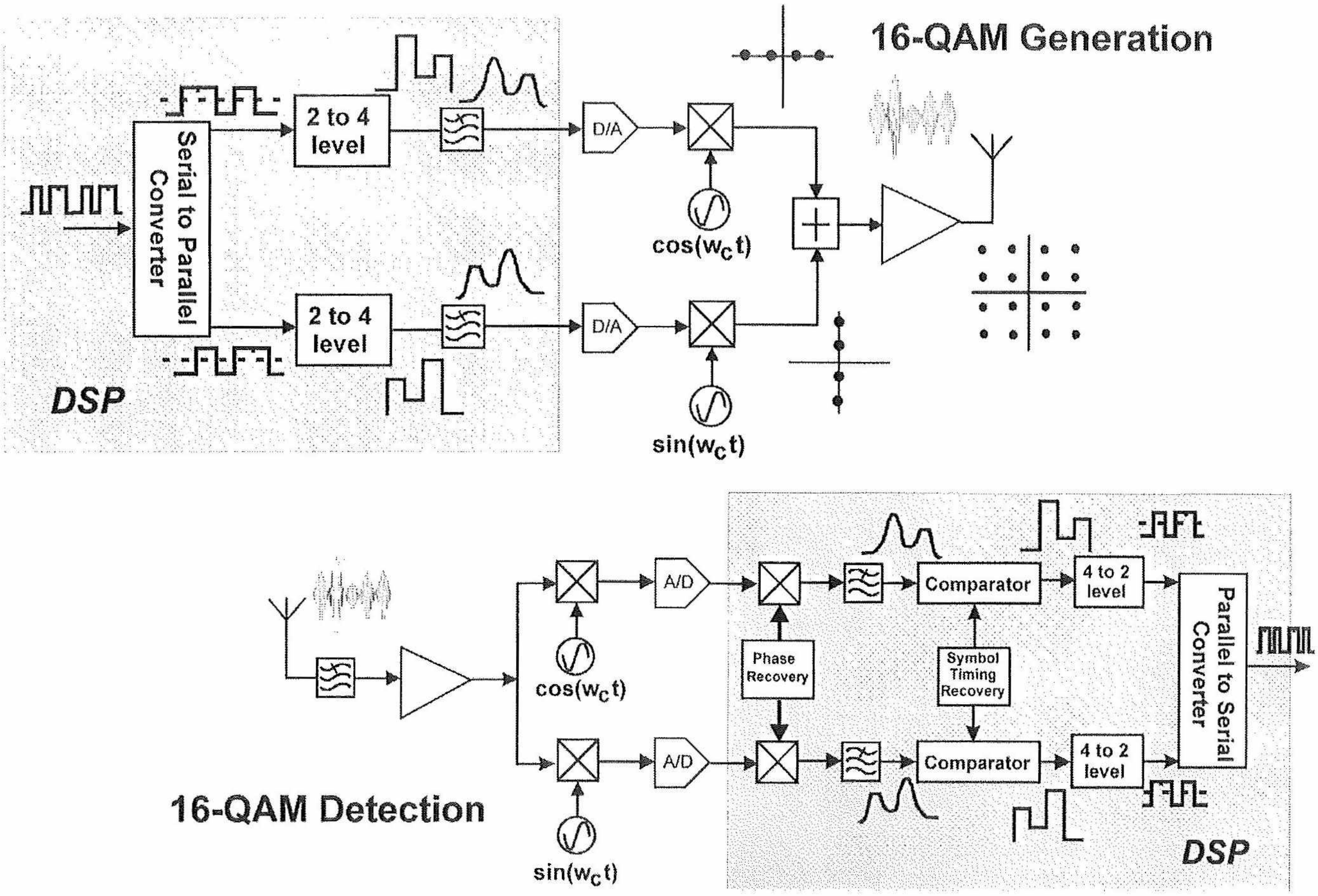

Figure 3: QAM radio modem architecture

the modulation scheme-specific functionality being contained within the DSP (and hence is fully reconfigurable).

The above description has shown that a QAM transceiver is a realistic technical proposition, however this is only part of the question. For such a solution to be acceptable, it must also be cost-effective both in component terms and in manufactured cost. Table 1 and Figure 4 show the component cost breakdown for a volume-manufactured half-duplex 16-QAM radio modem. The cost can be seen to be very competitive with existing solutions, despite the radically different technological approach. This may seem surprising at first, however many of the high performance components required are already used in high-volume applications outside of the radio marketplace (e.g. high-resolution A/D and D/A converters used in the PC multimedia market). These parts are therefore already at a low cost and are not awaiting a high-volume radio application in order for their costs to drop to an acceptable level. This is a major advantage of the techniques and architectures adopted in this system.

Software Radio Platform

A key requirement in the design of spectrally-efficient radio systems is the cost of the mobile and portable equipment. The design goal is to achieve a volume price similar to that of current FM systems, and hence the transmitter and receiver technology must be kept simple. The ideal technology to employ is a true software radio, with all aspects of the modulation format, data-rate, channel bandwidth and fading correction performed within DSP software. This means that the terminal may be reconfigured to satisfy any of a very wide range of different applications (e.g. TETRA, DAMPS, FM, APCO25 etc.) and is very easily customisable to other uses outside of the system in question. This is a key benefit to a volume manufacturer as he could make physically the same radio for all of these applications and simply load different software into these 'standard' radio products, to satisfy the different system requirements.

Subsystem	Cost (USD)
PA	10
TX chain	15
RX chain	20
Synth	12
Switch	7
Codec	12
DSP/FPGA	25
Misc	15
PCB	8
Total	**124**

Table 1: Approximate costs (1000's-off) for the main components of a narrowband software radio

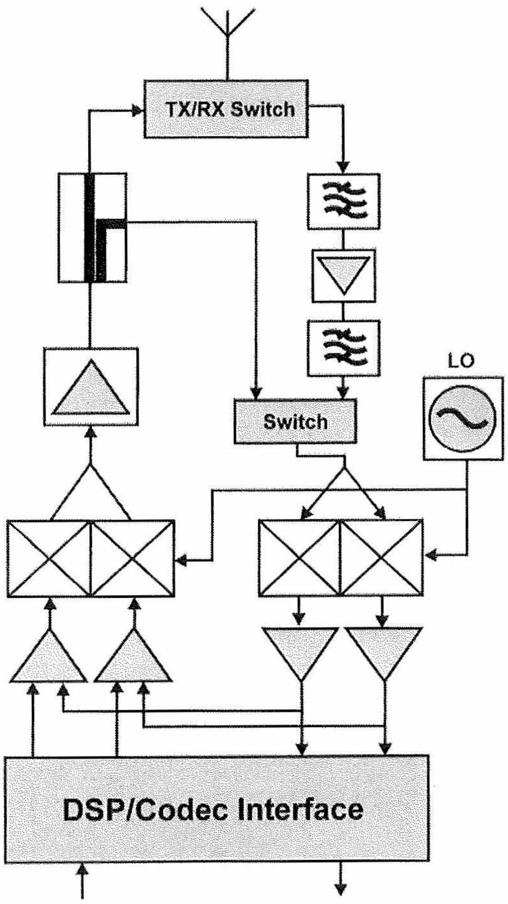

Fig 4: Main component breakdown for half-duplex 16-QAM modem

In addition, the platform can then easily support custom high data-rate modem applications, thus extending the benefits and application of the technology outside of traditional radio markets. It allows custom solutions to be developed, prototyped and manufactured in much shorter timescales than would previously have been possible and at a much lower cost. Further details on the design and use of software radios are provided in [5].

WSIL have produced such a platform and this is now being applied in a growing range of applications. An illustration of the range of capabilities of this platform is provided in Table 2.

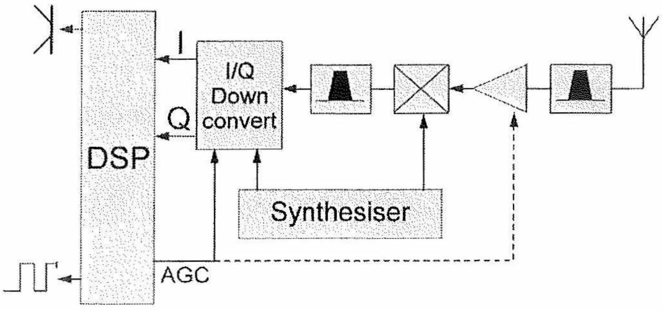

Figure 6: Mobile Receiver Architecture

'Mobile' TX Power (max)	0.5-30 W
Power control range (max)	70 dB
Channel bandwidth	5-50 kHz
Operating frequencies available (by customisation)	100 MHz – 2.5 GHz
Data Rate (16 QAM)	64 kbps in 25 kHz

Table 2: WSIL Linear Radio Platform Capability

Figure 5 illustrates, in block-diagram form, the basic transmitter architecture employed in the radio. The transmitter employs Cartesian loop technology, which is now an established linear transmitter technique, and is already available in an integrated package for some frequency bands. It is employed in a number of areas, including iDEN, TETRA (Trans-European Trunked Radio), 220MHz in the USA and in the Geonet FH-CDMA System (USA). The DSP used in the transmitter is also employed for the receiver, and so a single device only is required in any given radio.

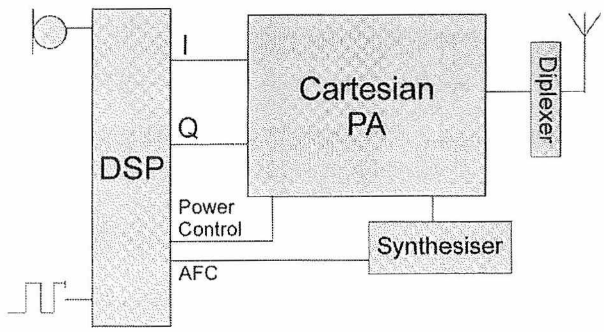

Figure 5: Mobile Transmitter Architecture

The synthesizer is a standard 12.5 or 25kHz-spaced type (depending upon the application), operating on-frequency. There is therefore no IF involved in the up-conversion process, and hence no requirement for two synthesized local oscillator frequencies. This also helps in maintaining a simple design philosophy and minimising the cost of the radio unit.

Finally, the receiver is illustrated in Figure 6. This employs the same DSP and synthesizer used in the transmitter and is of relatively conventional design. Most of the 'hard work' in the receiver signal processing is performed in the DSP, with fading correction, fine frequency control and tracking and much of the AGC functions being performed using the FFSR technique (see Figure 7). It is the use

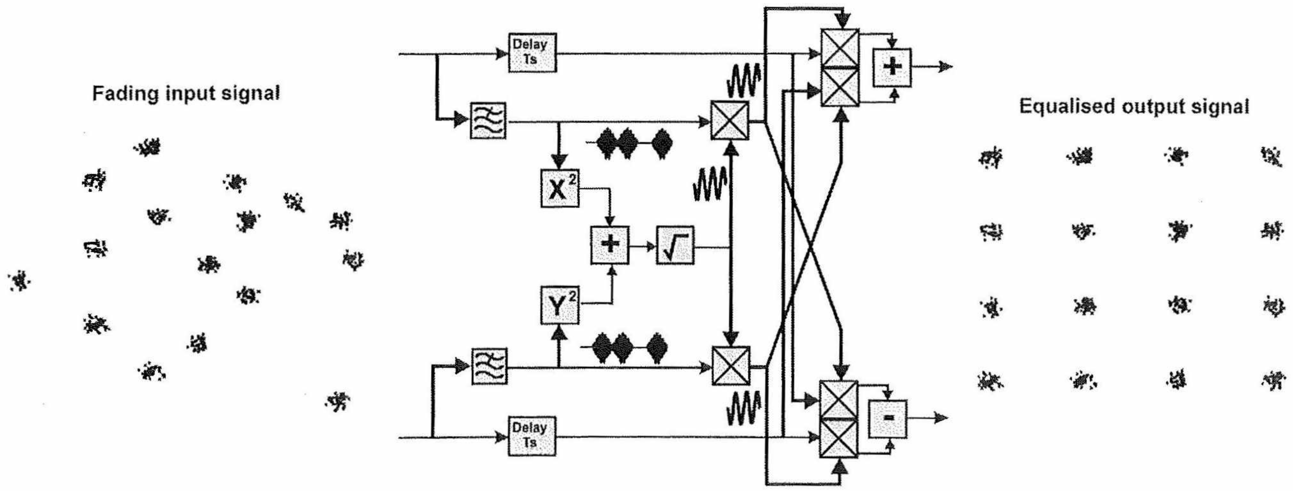

Figure 7: Feedforward signal regeneration for mobile fading correction in an RF modem

of a DSP at the heart of the transmitter and receiver which allows conventional FM to be provided (for backwards compatibility) at no extra cost.

Conclusions

This paper has presented a methodology for improving spectral efficiency for high data-rate systems involving the use of linear radio technology. It has demonstrated that the use of software radio is now a realistic commercial proposition and is currently being used in medium volume applications in niche market areas. Finally it has analysed the true cost of this form of radio technology and has shown that the application of off-the-shelf volume-manufactured components allows the cost of this technology to be highly competitive.

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The Effect of the August 11th Total Solar Eclipse on radio propagation at 1440kHz

R.A.Bamford
L. Farr

ABSTRACT - Some initial results are presented showing the change in signal strength of 1440kHz radio emissions from Luxembourg received at seven different sites in Southern England during the total solar eclipse on 11th August 1999. Changes of 20 to 40 dBm were recorded on calibrated receivers, a return to approximately 60% of the normal nightime signal level. For each of the different propagation paths the maximum signal rise occurred when the 100% lunar shadow was closer to the transmitter than the receiver.

Introduction

On the morning of the August 11th 1999, a total eclipse of the sun plunged parts of Europe into darkness during the middle of the day. The localised "night" created as the moon's shadow travelled across the earth produced a noticeable change in medium frequency (MF) radio reception across Europe.

Many radio frequency bands from 30kHz to 30MHz show different propagation effects at night compared to during the day [1]. Range, signal strength and spectrum availability can all show a diurnal variation on sky-wave propagation [2]. This is mainly due to changes in the D-layer of the ionosphere when the sunsets. The D-layer at an altitude of 50-90km, is the lowermost layer of the ionosphere and actively requires the radiation from the sun to sustain it. With the disappearance of the D-layer ionisation at night the main source of signal absorption for MF band disappears. As a consequence MF skywave signals signal strengths increase at night [1,2].

The technique used to investigate the changes in signal strength during the temporary darkness of the 1999 total solar eclipse was the classical A3b method [3]. This is where the continuous wave (CW) emissions from a remote station are monitored in time on a calibrated radio receiver. Although results from many bands from VLF to HF were collect the results presented here show the changes in signal strength of the carrier frequency at 1440 kHz (±1.4kHz) from the 1200 kW Radio Luxembourg broadcast station [4]. Seven receivers were distributed across the South of the UK. One was located, like the transmitter, directly below the path of totality while the rest were located north of the path of totality in the >90% partial eclipse region. The map in Figure 1 shows the locations of the transmitter and receiver stations relative to the 100% eclipsed path. Table 1 lists the latitude, longitude and distance from the transmitter of each of the receiver locations.

Receiver Station Rx	Lat.	Long.	Distance (km) Tx- Rx
Baldock	52.00N	0.13E	505.14
Birmingham	52.49N	1.89E	636.37
Bristol *	51.4N	2.64E	641.50
Bury St Edmunds	52.25 N	0.72E	471.30
Canterbury	51.28N	1.07E	394.68
Chilton	51.56N	1.3 E	558.17
Helston	50.1 N	5.27E	808.31

Table [1] The latitude and longitude of the receiving stations and the great circle ground range between the transmitter and each receiver. The Marnach transmitter is located at 49.62N, 6.0 E.

The receivers used were ICOM/IC-PCR1000 programmable LF/MF/HF radio receivers controlled by PC with a 10 second sampling interval. Each receiver was calibrated into dBm before deployment at a range of spot frequencies from 250kHz to 15MHz. A variety of antennas were used from low noise, broadband active whip antennas (SONY AN-1) to 60m long wire dipoles.

Results

Figure 2 shows a typical signal strength variation of 1440kHz carrier emanating from Radio Luxembourg based at Marnach (6.0E, 49.62 N) as received in the UK (a) for the morning of the eclipse (11th August) and (b) the day after. The receiving station was in Birmingham (-1.89E, 52.49 N) and the time interval shown is between 3am and 11:30am UT . The path from Marnach to Birmingham was show as the dashed line in the map in Figure 1.

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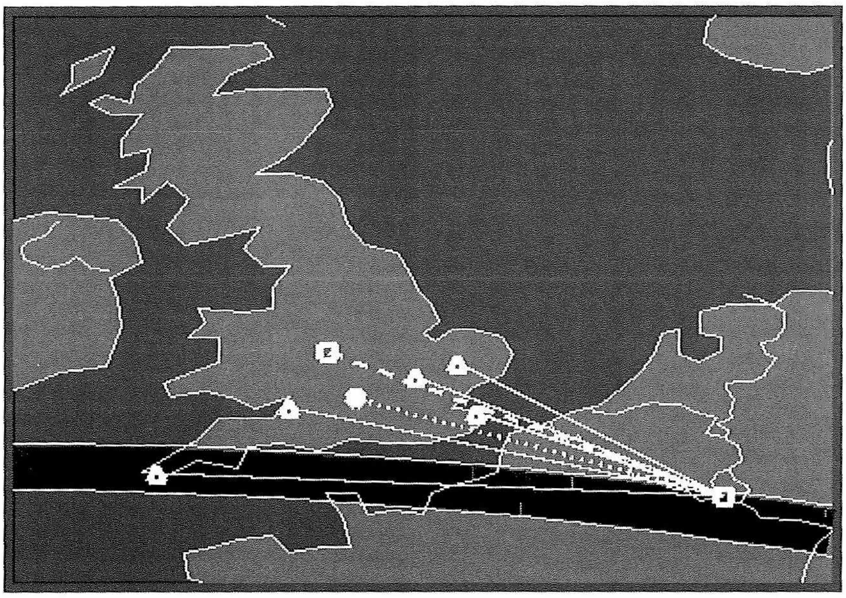

Figure [1]. A map of Europe with the path of totality (at ground level) of the solar eclipse and the location of the 1440kHz Marnach transmitter in Luxembourg at the northern edge of the eclipse path of totality and the receiving stations in the U.K.

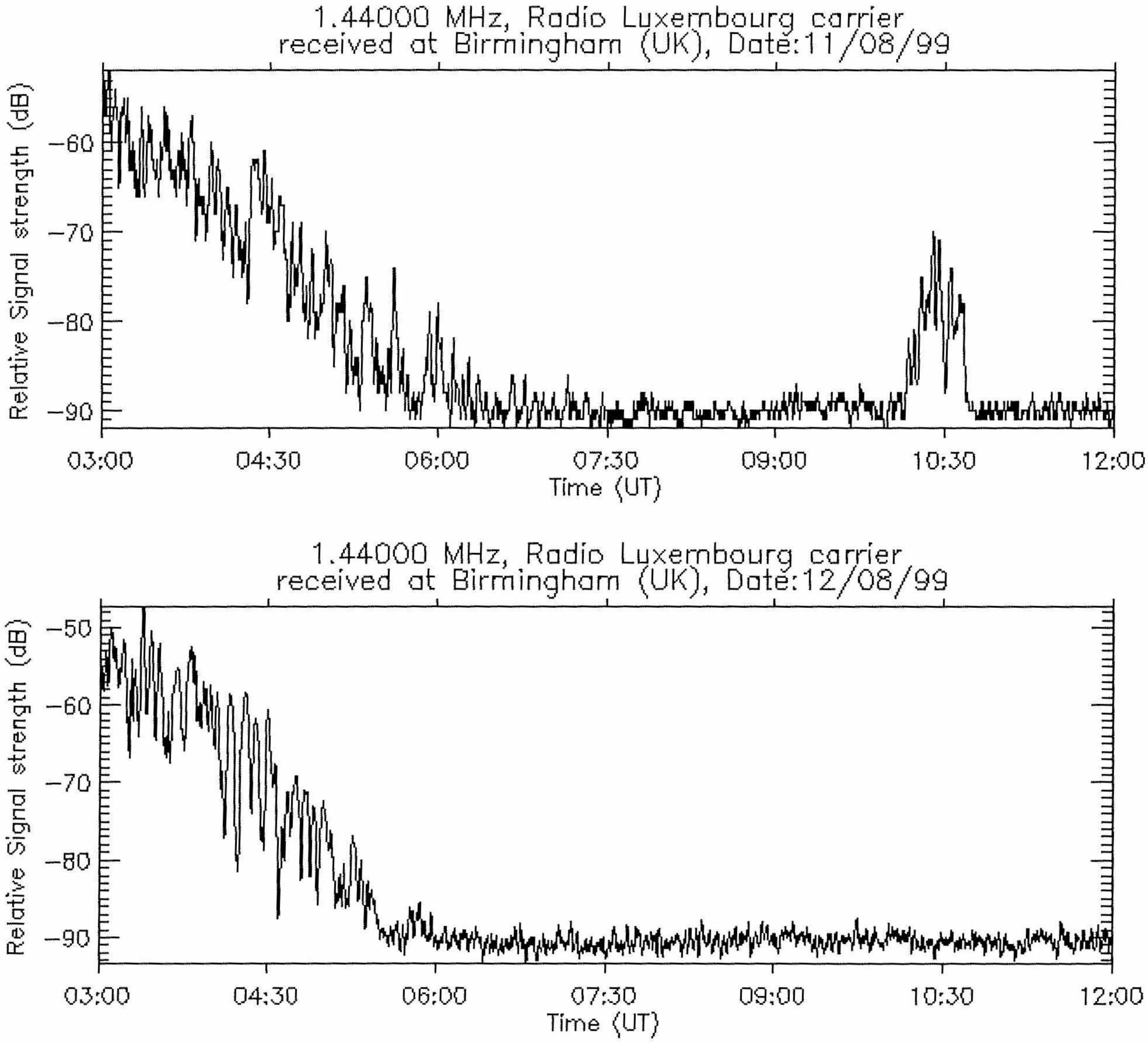

Figure [2]. A plot of the variation in the received CW radio signal as recorded in Birmingham in the UK of the 1440kHz (±1.4kHz) carrier emanating from Radio Luxembourg at Marnach (a) for the morning of the total solar eclipse and (b) the day after the eclipse. A 60 second smoothing has been applied.

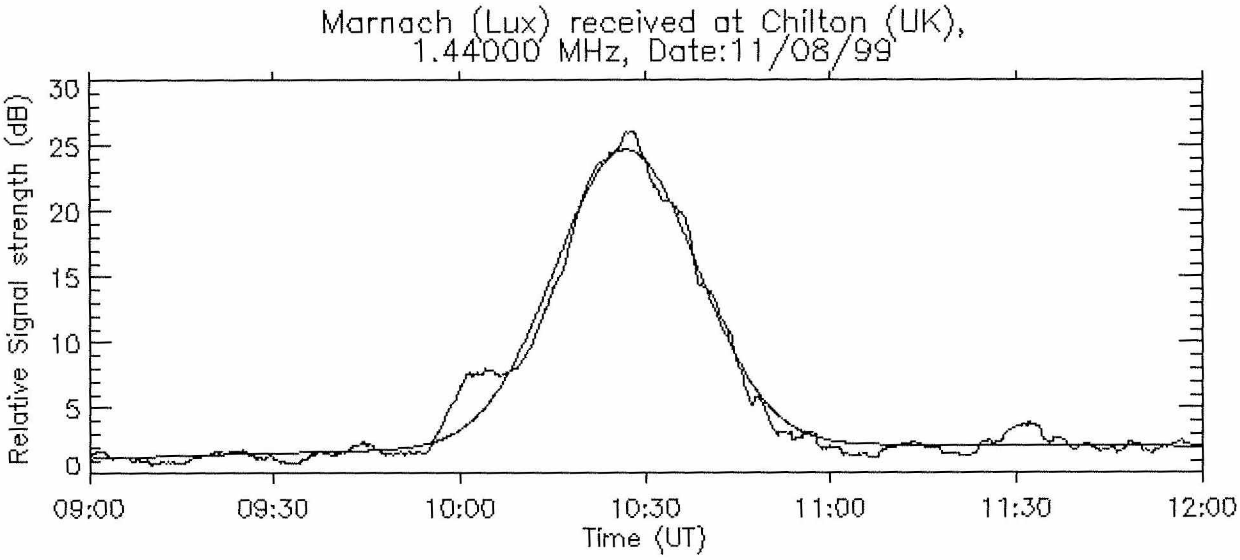

Figure [3]. Variation in received signal at Chilton in the UK of the 1440kHz CW Radio Luxembourg carrier broadcast from Marnarch (Luxembourg). Here a 5 minute smoothing has been applied.

The increased signal strength during the night, due to the lower levels of ionospheric absorption, is clear on both the eclipse and the control day (at 03:00 am). As the sun rises at dawn the signal absorption steadily increases reducing the signal strength (03:00 am to 05:30 am).

The difference made by the eclipse passage is very clear in Figure 2 (a) between 10 to 11 am. The 1440 kHz signal strength makes a brief, partial return to the night-level before returning to normal daytime levels. At the maximum, the passage of the lunar shadow across the ionosphere allowed the signal strength to recover to 60% of it's night-time level for this station.

In Figure 3, a polynomial fit has been overlaid to the plot of the 1440kHz carrier as received at Chilton (51.7N, 1.3W) for the 11th August. A broken line in the map in Figure 1 highlights the path from Marnach to Chilton. The signal level for the control day in Figure 3 has been subtracted from that of the eclipse day to highlight the difference made by the eclipse.

It takes approximately one and a half hours from when the moon first starts to appear to encroach on the face of the sun until it reaches the maximum obscuration at any particular location whether it is a partial or a total eclipse. The time for the sun's disk to be returned to normal takes a similar length of time. However Figure 3 shows how the effect on the radio propagation is much shorter than this. The full width half maximum (FWHM) of the curve fitted to the data in Figure 3 corresponds to a time of 21 minutes 42 seconds centred on a time of 10:27:53UT.

The peak signal strength received at Chilton occurred 1 minute 5 seconds before the eclipse totality at ground level was directly over Luxembourg at 10:28:58 UT and 9 minutes 24 seconds after maximum partial eclipse at Chilton. Totality lasted 1 minute 26 seconds at Luxembourg [5]. The effect of the eclipse on the signal strength continues well after the lunar shadow has passed overhead of the transmitter site. At the FWHM point of the signal response received in the UK, which is more than 10 minutes after the maximum, the eclipse totality has moved on to southern Germany.

This general tendency for the peak signal strength to occur when the eclipse shadow was much closer to the transmitter than either the path mid-point or the receiver was found to be the case for all but one of the propagation paths. The times and the peak values for the all the receiving stations are listed in Table 2. The precision of the receiving station clocks was checked manually before and after the time of the eclipse and corrected for.

Receiver Station Rx	Time of max eclipse Rx	%Max eclipse Rx	Time of signal maximum (UT)	Rise (dBm)
Baldock	10:19:37 ¥	95.3	10:28:24	23.8
Birmingham	10:17:57	93.5	10:26:44	25
Bristol *	10:16:25	97.3	10:28:07	39.9 *
Bury St Edmunds	10:21:54 §	94.3	10:28:30	20.3
Canterbury	10:21:31	97.0	10:26:08	21
Chilton	10:18:24¨	95.9	10:27:53	23.9
Helston	10:12:00	100.0	10:24:33	28

* Uncalibrated receiver, ¥ Local circumstances for Luton, § for Ipswich, ¨ Oxford [5].

Table 2. The results from the UK receivers monitoring the carrier frequency from the Marnach transmitter. The 100 % passed over the Marnach transmitter at 10:28:58 UT [5].

The magnitude of the responses for the different paths ranged from 21dBm to 40dBm. The table also includes the time and % maximum obscuration for each of the receiving stations, or the nearest large town. The general bias towards the transmitter could be expected given that the 100% eclipse passed closer to the transmitter site than to most of the receiver sites. However in the case of Helston, which was also under the path of totality, the maximum signal occurred at a time closer to the time the eclipse shadow was at the mid-point between Marnach and Helston.

Conclusions

Significant increases of 20 to 40 dBm on the received signal strength radio waves propagating at 1440 kHz from Luxembourg to the UK were observed during the 1999 total solar eclipse at several sites across the UK. Six of the seven propagation paths were from a source directly under the path of totality to receiving station in the partial eclipse. In each of these cases the maximum received signal occurred when the lunar shadow was closer to the transmitting station than the receiving station. This suggests that the loss of absorption directly over the transmitter had a more significant effect than the loss of absorption at any other region of the path. A full analysis of these propagation effects requires proper account to be taken of a number of factors not covered here. These include determining the probable location that the radio signals passed through the D-layer of the ionosphere using ray tracing, making the corrections in time and position of the lunar shadow to allow for ionospheric altitudes and estimation of the influence of the proximity to the gyro-frequency. A fuller analysis would also include considering different frequencies and propagation paths.

Acknowledgements

This work was funded by the U.K. Radiocommunications Agency (RA). Thanks is due to David Eden & Ray Wiltshire of RA and Pete Mahy for adapting the PCR1000 control software.

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A Case for the Luneburg Lens as the Antenna Element for the Square Kilometre Array Radio Telescope

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ABSTRACT - For the proposed square kilometre array (SKA) radio telescope, the Luneburg lens is one of the few configurations for the antenna element that offers the multiple advantages of optical beam forming, inherent wide bandwidth, and very wide field of view. The Luneburg lens is capable of placing simultaneous beams across a large portion of the visible sky for multiple observations or interference mitigation reasons. Furthermore, it provides an almost ideal solution to many of the other technical demands placed on the antenna element for a large array radio telescope such as the SKA. In the past, the most significant challenge associated with the use of Luneburg lenses has been that of construction. This is especially the case here for the so called mid-band SKA, intended for operation over a wide frequency range at centimetre wavelengths, where several thousand large lenses would be implemented over a large geographical area. In this paper the primary challenges of the mid-band SKA are identified and considered. To meet these challenges, two options for the SKA antenna element, designed around the Luneburg lens, are proposed as possible solutions to the specifications.

Introduction

The square kilometre array (SKA) is a new radio telescope proposed for the next century with, as the name implies, an effective collecting area of a square kilometre [1]. Planned for construction around 2010, the main scientific justification for this enormous array is to study the early universe at centimetre wavelengths and to complement next generation telescopes operating at other wavelengths. To date, the major contenders for the SKA antenna element have been based on either phased array or reflector antenna technology. Both have their advantages and limitations with no one obvious solution emerging. As an alternative solution to meet the ambitious specifications for the SKA, we propose here two alternatives based around the Luneburg lens [2]. As we shall show, the Luneburg lens is in many ways an ideal solution to meet the demands of the SKA, with the primary difficulties in realising the lens being in the areas of fabrication and material characteristics. These problems are highlighted and possible ways of overcoming them are shown to exist or can be developed.

The SKA Specifications

While the final and detailed specifications for the SKA are still under discussion and development, the main features of this array with an overall collecting area of a square kilometre are as follows.

1. A wide frequency range: While there is interest in frequency coverage from 0.03-22 GHz, it is recognised that a single instrument is unlikely to cover this range effectively. Three instruments are a possibility with a mid-band SKA covering centimetre wavelengths over at least a frequency range of 0.2 GHz to 2 GHz.
2. Sky coverage: Ideally full sky coverage is required, and an effective design must be able to access most of the visible sky.
3. Instantaneous beams: A major and determining feature of the SKA is the requirement for multiple instantaneous beams on the sky. Although up to 100 beams have been specified, it is likely that a steerable cluster of beams for imaging, together with a few independently steerable beams for interference mitigation and other science purposes, will suffice for most observations.
4. Dual polarisation: Detailed imaging requires the use of either dual linear or dual circular polarisation for a complete characterisation of the field of view.
5. Clean beam dynamic range: An imaging clean beam dynamic range $> 10^6$ is required, especially at the lower frequencies, and this demands that the antenna element radiation pattern be characterised accurately.
6. Beam forming: A hierarchical beamforming arrangement is envisaged. A number of antenna elements are grouped together and the signals combined to form an array station. The signals from these array stations will then be correlated to produce an image within the primary beam or combined directly to form one or many pencil beams within the primary beam. The number and layout of the array stations are yet to be fully determined, but the initial considerations suggest

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at least 100 array stations spread over a distance of up to 1000 km, in a manner consistent with the desired uv-plane coverage, will be required.

The Luneburg Lens

The Luneburg lens is a spherical lens characterised by an inhomogeneous but spherically symmetric refractive index η given by

$$\eta = \sqrt{2 - r^2}$$

where r is the normalised radial coordinate of the unit sphere. The basic action of the lens is illustrated in Figure 1. Energy from a plane wave incident on the lens is focussed to a point on the opposite side of the sphere. Given the spherical symmetry of the lens, perfect focussing is obtained from all feed positions on the surface. Multiple beams may be produced by increasing the number of feeds, or the beam may be scanned by simply moving the feed. By varying the refractive index profile, the focus can be moved to any point inside or outside the lens, the latter being important for practical feeds. Another important variation is the 'virtual source' Luneburg lens [3] shown in Figure 2 where the lens is placed on a ground plane passing through its equator. In this case the ground plane also acts to support the lens.

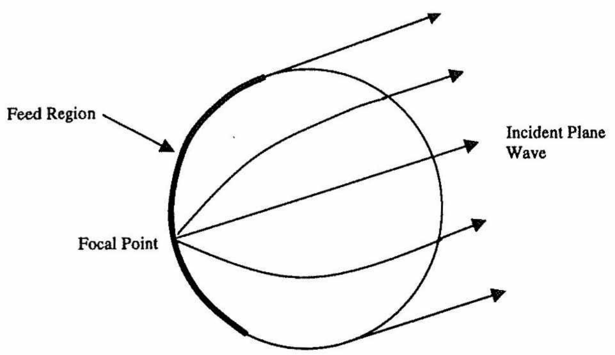

Figure 1: Basic focussing action of Luneburg Lens

The Luneburg lens has the dual advantages of optical beam forming and a very wide field of view. This gives a number of attractive features for use as the antenna element for the SKA:

1. for each lens there is a single beam per feed;
2. by symmetry, the beam shape is invariant with scan angle, and, by implication, no gain loss on scan;
3. because of the continuous aperture, frequency dependent scan blindness (a phenomenon common in phased arrays) does not occur;
4. the optical beam forming is inherently wide band, giving true time-delay beam forming throughout;
5. multiple beams and beam steering are simply achieved as outlined above.

The primary potential disadvantage of the Luneburg lens from an electromagnetic point of view is the loss through the lens. However, given the availability of materials with very low loss tangents and the likely maximum limit on the size of each lens in the array imposed by mechanical and structural constraints, this issue is not anticipated to be a serious one.

More serious objections to the Luneburg lens relate to total mass of material required for its manufacture and the implications for cost and weight. In the past, Luneburg lenses have been built with graded refractive index and with stepped approximations, from both rectangular "building-blocks" and concentric spherical shells of uniform material. The spherical shell design seems the most attractive for accurate control of the lens, and some designs of this type have been built with as few as three layers and others with many more. Thus, in principle, manufacture appears to be feasible. However, for the SKA to operate at the lower frequencies, a lens of at least 5m in diameter is likely. Even with the lightest of materials, the mass will be considerable. However, lenses of this size and larger have been considered and built in the past [4]. If the lens were to be much larger than 8 metres in diameter, then the self supporting 'virtual source' Luneburg lens configuration of Figure 2 would appear to be the most practical solution. This, together with issues associated with provision of multiple beams, is described later.

Contenders, Challenges and Comparisons

Given the specifications in Section 2, several technologies have been proposed for the SKA antenna element. Reflector antennas in the form of spherical reflectors with scanning feeds compatible with geographical features [5], a large adaptive reflector with an aerostat mounted feed [6], a cylindrical doublet [7], and planar phased arrays [8] are among those that have received attention from various groups. Of these, the extremes are represented by the traditional reflector technology and modern phased array technology and, therefore, used as a basis of comparison with the Luneburg lens. Their key features are now summarised.

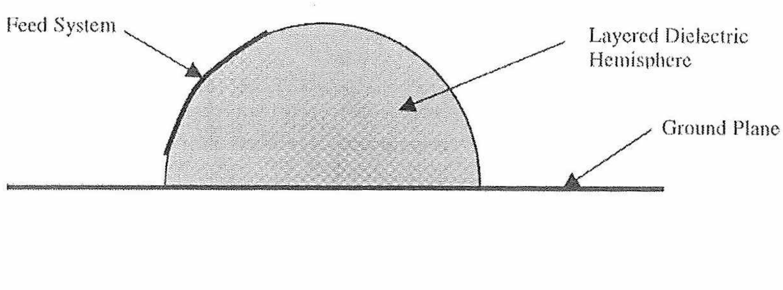

Figure 2: Virtual Source Luneburg Lens

1. Reflector Technology

Reflector technology has traditionally been used for radio telescopes due to the availability of constant collecting area over a wide bandwidth. For the SKA, however, the very large collecting area requires either a moderate number of large reflectors or a very large number of small reflectors; the latter suitable only for the higher frequencies of interest. Moreover, the emphasis on simultaneous multi-beaming capability across the visible sky effectively precludes conventional reflectors. Doublet configurations with scanning line feeds [7] go some way to providing coverage of a proportion of the sky, but do not fully satisfy the requirements. Finally, complex mechanical steering arrangements may be necessary to move heavy antenna structures, requiring considerable infrastructure at each array element site.

2. Phased Array Technology

Modern electronic components at centimetre wavelengths are increasing in performance and decreasing in cost, leading to proposals for the use of a phased array as the SKA antenna element. The advantages cited by proponents of the phased array technology are multi-beaming and flexible beam forming opportunities. Phased arrays, however, require complex interconnections and architecture, especially for the many thousands of antennas required for each array station. There remains the inherent gain loss on scan and significant bandwidth and scanning limitations with closely packed arrays.

3. The Luneburg lens and basis of comparisons

In order to compare the Luneburg lens with reflector and phased array technology it is necessary to have a well reasoned basis for making such comparisons. The following four factors are identified as forming this basis.

1. Compatibility with scientific objectives. The SKA will have agreed scientific objectives which must be accounted for in the design of the radio telescope hardware. Moreover, the next generation of radio telescopes must exhibit the capability to mitigate the effect of interference in an increasingly populated spectrum in order to achieve their scientific objectives. It must be shown, therefore, that a given technology has a reasonable probability of meeting the scientific objectives.
2. Realisability. The anticipated performance limitations with realistic components must be assessed for each technology to ensure that the hardware can be realised in practice with performance compatible with the scientific objectives.
3. Cost. The chosen technology will need to be realised within the constraints imposed by projected funding. This inevitably drives the need for low cost hardware, low cost manufacture and low cost infrastructure.
4. Reliability/Maintainability. The SKA will need to be operated and maintained over more than a decade of usable life, dictating the requirement for reliable and easily maintainable hardware.

Against these criteria, reflector hardware is seen to be incompatible with the scientific objectives (as currently stated) due to its lack of widely-spaced multi-beaming capability. Complex phased array hardware, while potentially meeting the scientific requirements, would appear to rely to some extent on both the continued extension of Moore's law for high speed signal processing and the continuing development of cheap low loss combining and switching hardware over the next decade to bring the cost in line with expected funding. In addition, it is has not yet been demonstrated that the scanning performance of a planar phased array can be maintained over the wide bandwidth required. From the foregoing discussion the Luneburg lens would seem to meet the scientific objectives and electromagnetic performance requirements best. With its few, if any, moving parts, reliability and maintainability are not seen to be major concerns. The key issues associated with realisation of the Luneburg lens are therefore the cost of materials, the manner of manufacturing the lens and the feed design requirements. These issues are addressed in the next Section.

Addressing the Challenges of the Luneburg Lens

In addressing the challenges of the Luneburg lens for the SKA antenna element under the various sub-headings of this Section, we consider two possible solutions; one based around a 5m diameter spherical lens and another around a larger 16m hemispherical lens.

1. Lens Size and Dielectric Loss

The minimum size of each Luneburg lens in the SKA will be determined mainly by the lowest operating frequency and, for the hemispherical case, the feed blockage that can be tolerated given the requirement for widely-spaced multiple beams across the visible sky. The maximum size will be set mainly by the mass of the lens and on the allowable loss through it.

One proposal for the SKA is for 100 array stations where each array station consists of 400 5m diameter Luneburg lenses as shown in Figure 3. Each array station is roughly equivalent in collecting area to a 100m diameter reflector. For a 5m lens constructed from low loss materials having loss tangents ~ 0.0001, the loss is predicted to be < 0.1 dB at 21cm wavelength (1.4 GHz) rising to about 0.5 dB at 10 GHz, corresponding to receiver noise loadings of < 7K and 35K. The estimates depend somewhat on the distribution of available materials throughout the lens and any structural materials required to fabricate the lens. Nevertheless, these values show that operation is possible to quite high frequencies with acceptably low values of noise temperature prior to the feeds. The feeds will be located underneath the lens and most likely fixed in place. They will provide an unblocked aperture down to an elevation angle that is a function of the f/D of the lens with elevation angles down to at least 30° possible in a practical design. A concern with the 5m diameter lens is that it may be too small to operate effectively at the lowest band edge. (The magnitude of this, and other concerns, will become clearer with further study.)

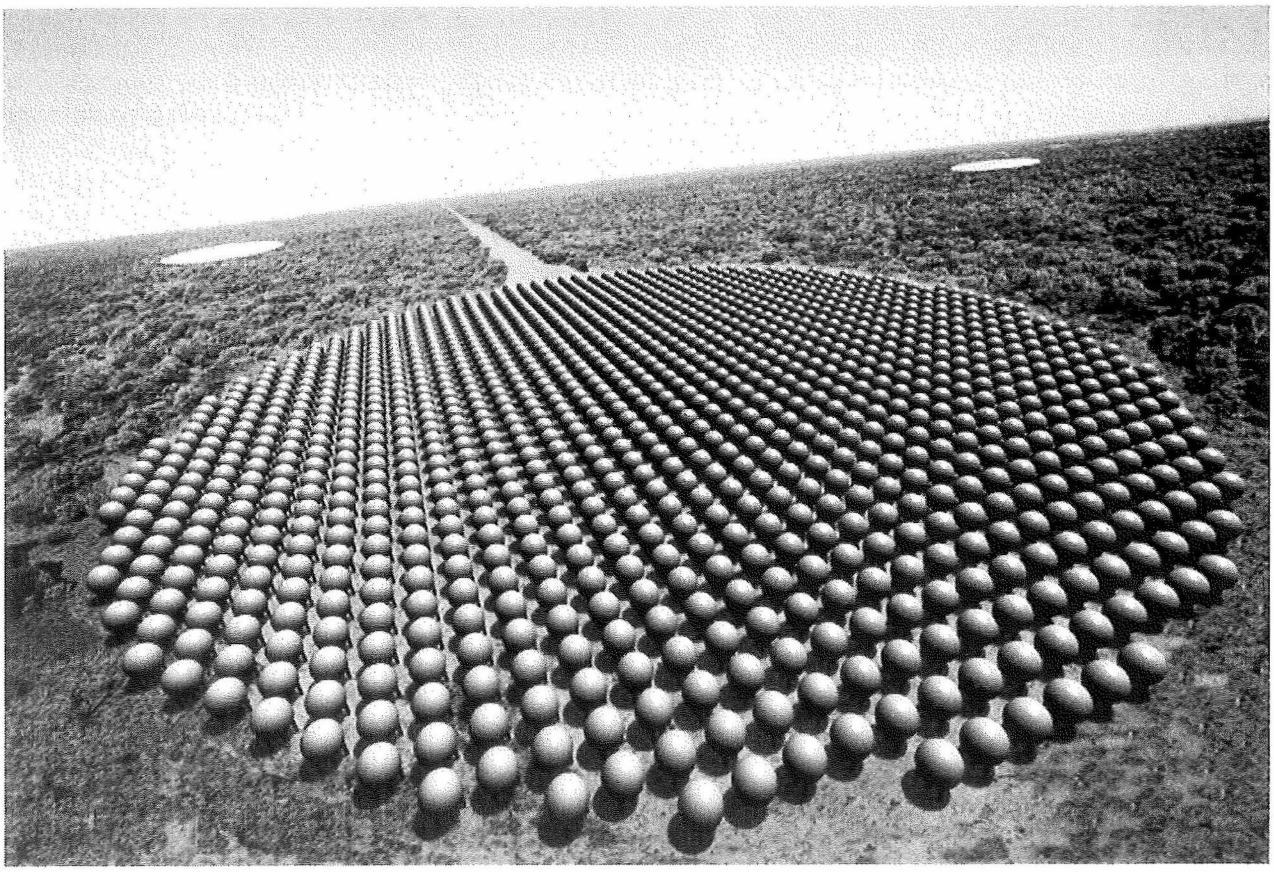

Figure 3: Artist's impression of SKA stations composed of 5m diameter Luneburg lenses

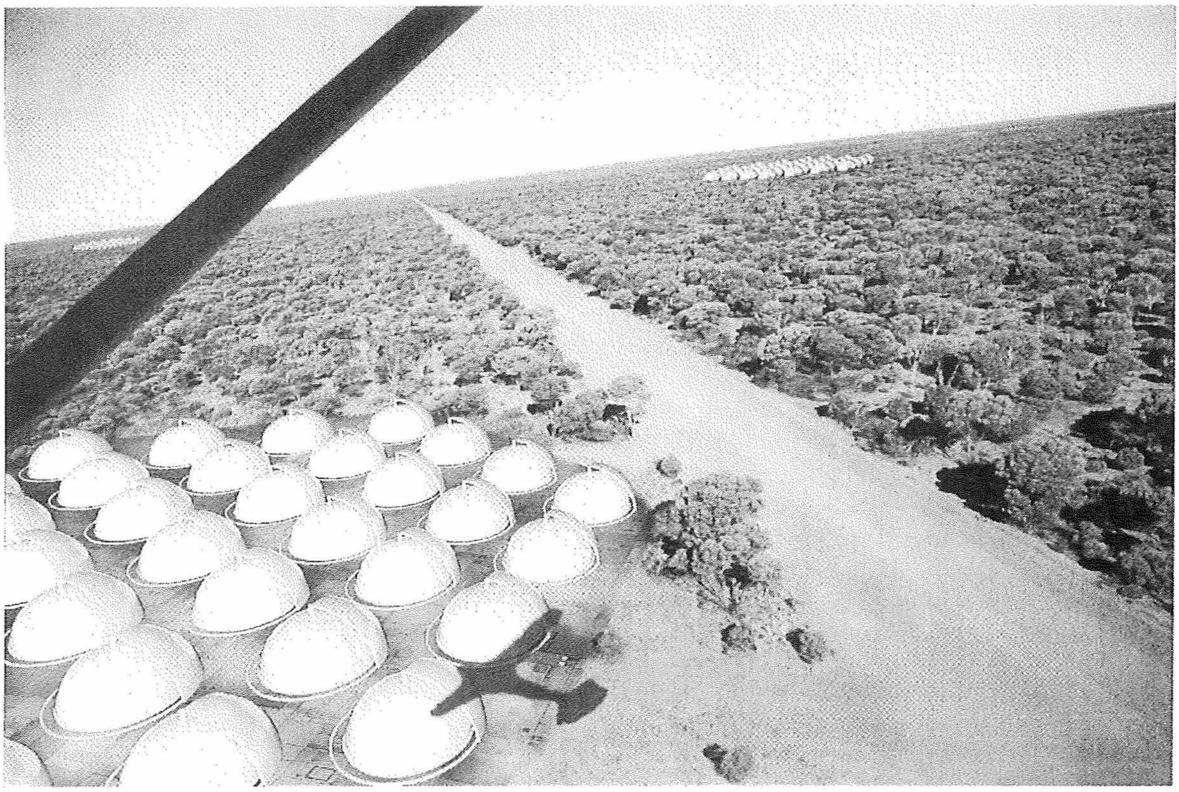

Figure 4: Artist's impression of SKA stations where 16m diameter virtual source Luneburg lenses are supported on a ground plane and fitted-out with a rotating feed arm

An alternative proposal is to use a much larger lens of around 16m diameter in the virtual source Luneburg lens configuration of Figure 3. Assuming, as before, 100 array stations, we would need to have 40 such lenses to form a single station. Such an array station, designed to operate down to 30° elevation, is illustrated in Figure 4 where, on each lens, we show a possible rotating feed arm configuration (to be discussed later). Indeed a number of feed configurations are possible. With respect to loss, a 16 metre lens constructed from low loss materials (again, with a loss tangent ~ 0.0001) gives a predicted loss of 0.25 dB at 1.4 GHz. While at higher frequencies this larger lens will not operate as effectively as the previous example due to increased loss, its beam shape at lower frequencies will be superior. The disadvantage compared to the spherical Luneburg lens is the need for some feed movement.

2. Material Characteristics

Various options are available for the lens material having refractive indices in the required range. The main types of material are foamed natural dielectrics, either plastics or inorganic materials, or artificial dielectrics made from inorganic or metal particles embedded in a low-density foam. The actual choice of material will depend on the trade-off between factors such as loss, total mass, cost, isotropy and uniformity.

3. Structural Design and Strength

Predictions of the mass indicate that the weight of a 5m Luneburg lens will be at least 50 tonnes and a 16m diameter virtual source Luneburg lens would lie in the range of several hundred to several thousand tonnes, depending on the dielectric material used. With the virtual source Luneburg lens, however, the weight of the lens is supported directly on the ground plane. Studies [4] show that it should be possible to produce a self-supporting hemispherical Luneburg lens of this diameter.

In order to operate at higher frequencies, 30 to 40 layers or more may be required to minimise problems with scattering from dielectric discontinuities. To form the layers a number of options exist: the lens could be built from preformed blocks of dielectric and, in the case of the large 16m lens, transported to the site and assembled against a moulded internal hemisphere of approximately 2m in diameter. Alternatively, material could be formed on site by mixing and spraying, using the future feed assembly temporarily fitted-out to act as a guide for the process.

Although the structures, being volumetric in nature, are inherently heavy, it is not anticipated that the mass alone will prohibit assembly. Note that a 5m spherical lens takes about 66 cubic metres of low-loss dielectric whereas a 16m diameter hemispherical lens requires just over 1000 cubic metres of material.

4. Ground Plane for the Hemispherical Lens

The virtual source Luneburg lens requires a ground plane extending beyond the diameter of the lens. The extent of the ground plane, R, will determine how low in elevation a beam can be scanned. To a first approximation

$$R = a / \tan\alpha$$

where α is the elevation of the beam and a the radius of the lens. For a typical minimum of 30° elevation the ground mat must extend to just under twice the lens radius, the case shown in Figure 4, whereas for 10 degrees elevation 6 lens radii is required. The shape of the ground plane can be selected to allow lower elevation where it is of most interest, and the ground plane can be shared by several lenses in a single station if shadowing is not produced by close spacing of the lenses. Compared to the spherical lens design in Figure 3, low elevation angles (viz. < 30°) are probably easier to realise with the hemispherical lens. Finally, the quality of the ground plane, particularly its surface roughness and porosity, will determine how good the image of the lens is in its resemblance to a full Luneburg lens and to how much additional noise is introduced into the system. Meshes that have been used for ground mats at lower frequencies could be adapted to form a suitable low maintenance ground plane providing acceptable performance over the required range of elevation angles.

5. Feed Structure and Feed Elements

One of the attractions of the Luneburg lens design is the considerable flexibility it provides to the feed designer to cater for the many astronomical needs, both now and in the future. This is an important attribute given the critical nature of the feed configuration generally in any radio telescope. A problem particular to the Luneburg lens is the inherent edge brightness of the collimated beam [9] which, without correction, leads to reduced gain and higher sidelobes. The edge brightness effect reduces significantly in designs where the focus is displaced away from the lens surface. This not only allows easier realisation of a uniform beam by appropriate feed design but also results in a smaller range of permittivity of dielectric in the lens leading to easier manufacture.

For the full spherical lens design in Figure 3, the feeds will ideally remained fixed. At low elevation angles these feeds will block the signal path. For observation down to an acceptable 30° in elevation, the f/D of the lens needs to be around 0.7. A larger f/D will provide still lower elevation angles at which observations are possible, with diminishing returns for f/D > 1 where the unblocked elevation angle is 15°.

In the case of the hemispherical lens design, some feed movement will be necessary. The simplest approach is to provide azimuth rotation only and have some form of feed array provide the elevation coverage. This could be in the form of several "arch" line feeds to image different portions of the sky independently and simultaneously. Indeed, calculations have shown that for the 16 metre diameter lens, up to 200 feeds with a size compatible with the effective *f/D* of the lens can be accommodated before blockage becomes severe. Consequently it is possible for there to be three or four small cross-section arms having almost independent movement (subject to mechanical blockage) providing line fields-of-view on the sky. Elevation coverage would be available from just under zenith down to an elevation angle limited by the extent of the ground plane. Alternatively it can be shown [10] that up to 140° of azimuthal coverage can be accommodated simultaneously by a large array without blockage. This "shell array" is the option illustrated in Figure 4 where the f/D of the lens is 0.7. While the "shell" rotates to view different parts of the sky as required, it does not offer full simultaneous sky coverage.

Either the full operating frequency range is covered by a single feed or else several feeds for different frequency bands must be used. Moreover, dual polarisation is required to fulfil the SKA specifications. For cost reasons, printed circuit antenna technology is desirable, and focal plane arrays with integrated low-noise amplifiers and digital receivers may be considered. It is worth re-emphasising that phasing is not required for an array feeding the Luneburg lens unless some correction to the phase due to lens imperfections is envisaged or unless there is a particular need for a fully- or over-sampled multi-beam array. For signal routing, optical signal combining and distribution after digitisation provides the most flexibility.

6. Analysis and Design of the Luneburg Lens and Feeds

Electromagnetic scattering by a lens constructed of uniform spherical shells has an exact analytic solution in terms of spherical waves, and techniques exist to implement this solution numerically for lenses up to at least 100 to 200 wavelengths in diameter [11] which would cover the range of lenses considered here. Interaction with the feeding network, and the effects of deformation of the lens due to gravity or manufacturing tolerance would require a different approach. Computational electromagnetism techniques such as finite difference time domain and boundary element methods provide the highest degree of flexibility in this regard, and computing resources exist to permit detailed design studies to be undertaken. It should be possible to provide a full characterisation of the electrical performance of the two Luneburg lens systems subject to mechanical constrains and tolerances, a feature that is also true for reflector antenna technology but not yet available in a reliable way for phased arrays.

7. Infrastructure Requirements

The possibly remote location of the SKA array stations makes the infrastructure requirements an important consideration in the choice of antenna element. The infrastructure requirements relate firstly to the construction of the SKA, and secondly to its operation. For construction, transportation of materials, support structure for the lens, assembly of the feed structure, assembly of the lens itself and, in the case of the hemispherical lens, a ground mat, will require an infrastructure compatible to the construction of a reflector antenna and its mount. However, given that the structure can be weatherproofed and only in the case of the hemispherical lens is there a small number of lightweight moving parts, the electrical power and other support required for operation is minimal. Power requirements should be compatible with solar and battery operation, which is highly desirable for the large number of SKA antenna elements envisaged.

8. Cost of Materials

The primary cost of materials is in the construction and forming of the dielectric layers of the lens. Given the large quantity of material and the number of lenses required, as well as the potential of the Luneburg lens design for many other applications, it is in the area of manufacture that effort is required to minimise the cost and hence feasibility of the Luneburg lens for the SKA antenna element.

Concluding Remarks

We have identified the major advantages and challenges of designs based around the Luneburg lens for the antenna element of the SKA. In almost all regards the Luneburg lens offers attractive performance features. Many of the major material and structural challenges have been addressed and solutions proposed. It remains to ascertain the parameters governing the cost, and the impact on SKA funding given the potential benefits of the structure to the astronomical objectives of the project.

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CONFERENCE REPORT

MST9 - COST76

Toulouse, France, 13-18 March 2000

The Ninth International Workshop on Technical and Scientific Aspects of MST Radar – MST9 - combined with the COST-76 Final Profiler Workshop – COST76 – was held at the International Conference Centre of Meteo France in Toulouse March 13-18, 2000. The merging of these two workshops was a natural consequence of the evolution of mesosphere-stratosphere-troposphere (MST) radars into wind profiler applications. It was a major event drawing together experts from all over the world, engaged in research and development of these radar techniques to study the troposphere, stratosphere, mesosphere and the ionosphere as well. It offered excellent opportunities to young scientists, research students, operators and meteorologists for close interactions with experts on technical and scientific aspects of MST radar and wind profilers and the corresponding operational applications, governed by COST (Cooperation on Science and Technology, a European Union project).

The workshop was prepared by the International Steering Group (J. Röttger, S. Fukao, M.F. Larsen, C.H. Liu, A.P. Mitra and W. Monna), the Programme Committee (L. Alonso, K.S. Gage, E. Legrand, G. Nastrom, G. Peters, M. Piringer, P.B. Rao, R.A. Vincent, and R.F. Woodman) and the Local Organizing Committee (J.P. Aubagnac and V. Klaus). It was sponsored by the International Union of Radio Science (URSI), the Scientific Committee on Solar Terrestrial Physics (SCOSTEP), COST/European Union, the Universite de Midi Pyrenees and Meteo France.

The workshop was attended by 156 participants from 27 countries and 6 continents. A total of 195 papers were presented, whereof 76 were poster papers. The opening session was held in attendance of the Director of the Research Division of Meteo France, Dr. Daniel Cariolle. The participants were invited by the Lord Major of Toulouse for a reception in the town hall, and enjoyed a banquet in a country-side restaurant. The workshop ended with a plenary session and a tour of the Meteo France facilities on Saturday.

The scientific and technical part of the workshop was held in 8 major sessions; each of these highlighted by one or two review papers.

In Session 1 (11 oral / 10 poster papers) on Scattering Processes and Refractive Index Irregularities in the Neutral Atmosphere the high resolution interferometer and imaging techniques played a dominant role, since these help to improve the understanding of the atmospheric structures causing the radar scatter.

Session 2 (20 / 19) was devoted to the Mesosphere, Lower Thermosphere and the Ionosphere, where the latter essentially concentrated on coherent scatter from electron density irregularities. The VHF radar studies of meteors, of Polar Mesosphere Summer Echoes (PMSE) and Quasi-Periodic (QP) Echoes from the mid-latitude E-region were the highlights of this session.

Session 3 (26 / 7) on Waves and Turbulence covered planetary and gravity wave climatology and momentum flux measurements with radars. Simulations of turbulence generation and development and the observations by radar and RASS (radio acoustic sounding systems) were a particular topic.

Boundary Layer Meteorology was the topic of Session 4 (9 / 9), where it was shown that UHF and VHF profilers are particularly useful observing instruments, and RASS and SODAR are most suitable complements.

The studies of Precipitation and Clouds were presented in Session 5 (7 / 5). It was highlighted that profiler observations provide suitable ground truth calibration for remote sensing of rainfall rates.

Synoptic and Larger-Scale Meteorology was treated in Session 6 (10 / 3). This included radar observations of thunderstorms, tropopause, fronts, hurricanes, Hadley circulation and the potential of wind profiler radars for studies of El Niño related effects.

Session 7 (25/14) dealt with Wind Profilers and Complementary Techniques. Reports from radar facilities, networks and new systems were presented. RASS and SODAR were part of this session. Many details of methods, parameter estimation and optimization and calibration procedures were discussed and evaluated.

The Operational Aspects of wind profilers, presented in Session 8 (11/9), were a final highlight of the workshop. The inclusion of wind profiler data into weather forecasting projects and models has proved as a most rational asset. It was also pointed out that wind profiler measurements have essentially the same accuracy as the radiosonde wind measurements.

The Plenary Session was held at the end of the workshop on Saturday morning. W. Monna presented a report on the COST-76 project on radar wind profiler networks. The future activities within this frame are foreseen to focus on combining various observing techniques.

Reports from the five Permanent Working Groups (PWG) of the MST radar community were given and the continuation of the groups approved.

PWG-1 on System Calibrations and Definitions (co-chaired by P. Chilson and J. Röttger) has to fulfill a most tedious task to prepare a glossary of specific terms, and this could be done together with the preparation of lecture material for future schools on atmospheric radar. Calibration procedures are required to be worked out, for instance, to allow better estimates of turbulence parameters and comparison of observations done with different radars.

PWG-2 on Data Analysis, Validation and Parameter Deduction Methods (co-chaired by D. Holdsworth and M. Yamamoto) has been divided into three distinct groups on (1) general processing, (2) analysis techniques, and (3) post-analysis techniques. It is suggested making time-series of raw data available to verify the results of different analysis techniques. The idea is also explored making libraries of analysis routines available to the community.

PWG-3 on Accuracies and Requirements for Meteorological Applications (chaired by G. Nastrom) is considering options for data distribution, archiving and the corresponding format.

The report of PWG-4 on International Collaborations (chaired by P.B. Rao) was given by S. Fukao. Several projects had been carried out and will continue, such as those on mid-latitude sporadic-E echoes, gravity waves and turbulence.

A short report on observation during the Leonid meteor shower was resulting from PWG-5 on Transient Phenomena.

A.P. Mitra gave a report on activities on international projects for atmospheric studies in the Indian region.

A proposal for a new working group on education and training was brought forward. This should preferably be handled in the context of future schools on atmospheric radars. A special school will already be held in November 2000 in Trieste for students from developing countries. In 2003 the Third International School on Atmospheric Radar ISAR3 should also take place in Trieste. To take care of these subjects, the ISAR Working Group was established consisting of the members S. Fukao, D.N. Rao, J. Röttger and R.F. Woodman.

It was also decided to intensify the interaction between the working groups and their relation to similar groups of other communities. It will also be investigated to establish a permanent MST radar web page and an e-mail discussion group.

The publication of Extended Abstracts in the Workshop Proceedings will take place as usual. SCOSTEP and Meteo France handle this business. Papers related to COST76 will be published in Zeitschrift für Meteorologie and those on MST radar in Annales Geophysicae.

The format of future workshops was discussed. It was generally agreed to emphasize the workshop aspect again more clearly on timely topics of MST radar techniques and science, whereas conclusion was not established whether to have part of the workshop in conference and the other part in a less formal working group style. It was agreed that the steering committee and the chairs of the working group should consider this evolution in more depth.

Invitations to hold the forthcoming workshop MST10 in Adelaide, Australia, or in Peru were presented. That workshop would be in late 2002.

Many further details on this workshop MST9 are found on the homepage of Meteo France:
http:/www.cnrm.meteo.fr/mst/

Jürgen Röttger

CONFERENCE ANNOUNCEMENTS

CPEM 2000

Sydney, Australia, 14-19 May 2000

Topics

Automated systems, software/firmware validation
DC and low frequency
Electromagnetic compatibility
Fundamental constants
International traceability
Lasers and optoelectronics
RF/microwave/millimetre-wave
Cryoelectronics
New sensors
Optical metrology
Power and energy
Quantum metrology
Realisation of units
Time and frequency

Which URSI Commissions are or could be involved?
Commissions A, B, C, D, E, F, J and K

Contact

CPEM 2000 Secretariat, GPO Box 128
Sydney NSW 2001, Australia
Phone: +61 2 9262 2277, Fax: + 61 2 9262 3135
E-mail: cpem2000@tourhosts.com.au
http://www.tourhosts.com.au/cpem2000

Dr Angela Samuel, Project Leader: International Metrology, APMP Work Program, CPEM 2000, and Thai National Standards National Measurement Laboratory, CSIRO PO Box 218, Lindfield, NSW 2070 Australia. Ph: 61 2 9413 7788 Fax: 61 2 9413 7383 Email: angelas@tip.csiro.au

BIANISOTROPICS 2000

Lisbon, Portugal, 27-29 September 2000

BIANISOTROPICS 2000 will be the 8th International Conference on Electromagnetics of Complex Media. The Conference will be held at the Congress Center of Instituto Superior Técnico, Universidade Técnica de Lisboa.

The meeting will cover from fundamental electromagnetic theory of complex media to applications and novel devices from the microwave to the optical regimes.

The conference will comprise 6 half-day sessions on a variety of research topics concerned with theory and applications of complex (i.e., chiral, pseudochiral, anisotropic, bianisotropic, nonhomogeneous, nonlocal, nonlinear, random) media. The programme will include special talks by key speakers, oral and poster sessions with contributed papers and discussions on hot topics bringing together applied mathematicians, physicists, engineers, material scientists from research institutes, universities and industry.

Schedule

April 22, 2000: deadline for one-page abstracts
May 22, 2000: notification of acceptance
July 5, 2000: reception of final manuscripts and registration

Contact

BIANISOTROPICS 2000
Prof. Afonso M. Barbosa (Conference Organizer)
Department of Electrical and Computer Engineering
Instituto Superior Técnico
Av. Rovisco Pais
1049-001 Lisboa, Portugal
Phone: +351-21-8418482
Fax: +351-21-8417284
e-mail: Bian2000@lx.it.pt
(e-mail should be used for all correspondence)
www.lx.it.pt/bian2000

EMC ZURICH '01

Zurich, Switzerland, 20-22 February 2001

Topics

The 14th International Zurich Symposium and Technical Exhibition on Electromagnetic Compatibility will cover the entire scope of EMC theory and technology. The topics will be identified within the following technical committees (TCs) of the symposium:

TC-1: EMC Management (including specifications and standards)
TC-2: EMC Measurement Techniques I (theory)
TC-3: EMC Measurement Techniques II (practice)
TC-4: Environment I (stationary)
TC-5: Environment II (transient)
TC-6: System-Level EMC I (modeling)
TC-7: System Level EMC II (effects)
TC-8: Chip & Package Level EMC (including PCB)
TC-9: Lightning
TC-10: EMC Innovation
TC-11: Power System EMC
TC-12: EMC Protection

Schedules for authors

July 1, 2000: Preliminary manuscript received*
September 15, 2000: Notification of acceptance and authors kit mailed
November 25, 2000: Camera-ready manuscript received*
*) Electronic submission preferred, otherwise use Air Mail.

Schedules for exhibitors

August 31, 2000: Deadline for regular exhibitor registration
October 14, 2000: Deadline for advertisements
December 15, 2000: Deadline for regular fees

Contact

Dr. Gabriel Meyer
Symposium Chairman
EMC Zurich '01
ETH Zentrum, IKT - ETF
CH-8092 Zurich, Switzerland
e-mail: emc@nari.ee.ethz.ch and
gmeyer@nari.ee.ethz.ch
Tel.: +41-1 632 27 90
Fax: +41-1 632 12 09
url: www.emc-zurich.ch/

The preliminary program is scheduled for October 2000.

2001 URSI International Symposium on Electromagnetic Theory

Victoria, BC, Canada, 13-17 May 2001

In a long tradition our Commission B on "Fields and Waves" organises a triennial series of international symposia on electromagnetic theory. The next symposium in this series is the 2001 URSI International Symposium on Electromagnetic Theory, which will be held in Victoria, British Columbia, Canada, May 13-17, 2001.

It is hosted by the Canadian Member Committee of URSI and is organised by a Local Organising Committee at the University of Victoria, in collaboration with the Canadian National Research Council. The scope of the Symposium covers all areas of electromagnetic theory and its applications. The working language of the Symposium is English. There will be a limited number of Young Scientist Awards available for application. Further information concerning these Awards will be given well in advance of the Symposium.

Suggested topics

Contributions concerning all aspects of electromagnetic theory and its applications are welcome.

Novel and innovative contributions are particularly appreciated. Authors are asked to indicate the relevant topic area for their contribution, using the list of suggested topics T1-T22 given below.

T1: New basic theoretical developments
T2: Scattering and diffraction
T3: Inverse scattering and imaging
T4: Time domain methods
T5: High frequency methods
T6: Guided waves
T7: Solutions to canonical problems
T8: Propagation and Scattering in layered structures
T9: Propagation and scattering in complex media
T10: Propagation and scattering in random media
T11: Rough surface scattering
T12: Beam and pulse propagation and scattering in lossy and/or dispersive media
T13: Non-linear phenomena
T14: Antennas: general aspects
T15: Antenna arrays, planar and conformal
T16: Antennas for mobile communications
T17: Numerical methods: general aspects
T18: Numerical methods for integral equation problem formulations
T19: Numerical methods for differential equation problem formulations
T20: Numerical methods: hybrid methods
T21: Interaction of EM waves with biological tissue
T22: Other (suggest area title)

Symposium Time Table

Sept 23, 2000 : Deadline for receipt of summaries
Dec 15, 2000 : Notification of authors regarding acceptance of papers and announcement of the Young Scientist Award program
Jan 19, 2001 : Deadline for applications for the Young Scientist Awards program
Feb 16, 2001 : Notification of the Young Scientist Awards applicants
March 15, 2001 : Deadline for receipt of final papers, pre-registration of authors

Contact

Address general questions about the Symposium and its technical program to:

Prof. Staffan Strom
Chair, Commission B of URSI
Dept. of Electromagnetic Theory
Royal Institute of Technology
SE-100 44 Stockholm
Sweden
Phone: +46-8-790 8195, Fax: +46-8-10 83 27
e-mail: staffan@tet.kth.se

Questions regarding local arrangements can be addressed to:

Prof. Jens Bornemann
Dept. of Electrical and Computer Engineering
University of Victoria
PO Box 3055, Stn CSC
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Phone: +1-250-721-8666, Fax: +1-250-721-6052
e-mail: jbornema@ece.uvic.ca

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URSI-B2001 Conference Secretariat
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e-mail: URSI-B2001@nrc.ca
http://www.nrc.ca/confserv/URSI-B2001

ISSSE'01 - 2001 INTERNATIONAL SYMPOSIUM ON SIGNALS, SYSTEMS, AND ELECTRONICS

Tokyo, Japan, 24-27 July 2001

"Questing More Significant Harmony and Integration: Systems/Devices and Softwares/Hardwares"

The ISSSE is an international symposium held once in every three years sponsored by URSI Commissions C and D. Historically, Commission C represented signal-, system-, and software-oriented technology, while Commission D represented device- and hardware-oriented technology. In recent years, however, the importance of cooperation between systems and devices, and in other words, software and hardware, has been more and more strongly recognized. In modern radio equipment, even a tiny single device can have a complex system function, and on the other hand, software gradually takes over the role of hardware. The cooperation of Commissions C and D, therefore, is quite timely and meaningful in the present and future URSI activities.

Conference Co-chairpersons
M.Akaike, *Science Univ. of Tokyo, Japan*
K.Kikuchi, *Univ. of Tokyo, Japan*
Technical Program chairperson
H.Ogawa , *CRL, Japan*

Topics

Software-oriented radio transmitters/receivers
Integrated modules and elements
Wireless channel equalization
Hardware-oriented signal processing and compression
Signal detection and interference cancellation
Advanced technologies for RF circuits
Advanced wireless radio networks
Devices for microwaves and photonics
Hardware/software cooperation in radio equipment
Microwave/photonic integrated devices/systems
Diversity/ RAKE reception
Devices modeling and design
Anti-fading techniques
Numerical and CAD techniques
Radio-frequency synthesizers
Millimeter-waves applications
Digital signal processing
Cooperation of optical and microwave guides
Smart antennas
New materials and devices and their application
Optical signal processing
Full-scale system on a single chip
Large-capacity optical transmission

Special Transactions Issue: A mini-special issue on "Signals, Systems and Electronics" based upon papers presented in ISSSE'01 will be published in IEICE Transactions.

Tentative schedule

Abstract Submission: January 15, 2001
Notification of Acceptance: March 1, 2001
Camera Ready: April 15, 2001

Contact

ISSSE'01 secretariat
Dept.of Elec. Eng., Science University of Tokyo
1-3 kagurazaka, shinjuku Tokyo 162-8601 Japan
E-mail: issse01@ee.kagu.sut.ac.jp
Home Page: http://issse01.ee.kagu.sut.ac.jp

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URSI Commission C and Commission D
Electronics Society and Communications Society, IEICE

(ICEAA01)

INTERNATIONAL CONFERENCE ON ELECTROMAGNETICS IN ADVANCED APPLICATIONS

Torino, Italy, 10-14 September 2001

The seventh edition of the biennial International Conference on Electromagnetics in Advanced Applications (ICEAA 01) will consist of invited and contributed papers, as well as workshops and short courses. The Conference is organized by the Politecnico di Torino and by IRITI - CNR, with the technical cosponsorship of the IEEE Antennas and Propagation, Electromagnetic Compatibility, and Electron Devices Societies, and of the International Union of Radio Science (URSI).

Topics

1. Electromagnetic measurements
2. Electromagnetic modeling of devices and circuits
3. Electromagnetic packaging
4. Electromagnetic properties of materials
5. Electromagnetic terrorism
6. EMC/EMI/EMP
7. Finite methods
8. Frequency selective surfaces

9. Integral equation methods
10. Inverse scattering and remote sensing
11. Microwave antennas
12. Optoelectronics and photonics
13 Plasma and plasma-wave interaction
14 Phased and adaptive arrays
15 Printed and conformal antennas
16 Radar cross section and asymptotic techniques
17 Radar imaging
18 Radomes
19 Random and nonlinear electromagnetics
20 Smart antennas
21 Statistics in electromagnetics
22 Technologies for mm and sub-mm waves
23 Wireless communications
24 Other topics

Deadlines

Submission of abstract	March 2, 2001
Notification of acceptance	April 6, 2001
Final manuscript and presenter registration	June 1, 2001

Contact

COREP - ICEAA 01
Politecnico di Torino
Corso Duca degli Abruzzi 24
10129 Torino, ITALY
http://www.polito.it/iceaa01

URSI CONFERENCE CALENDAR

June 2000

EMC Wroclaw 2000
Wroclaw, Poland, 27-30 June 2000
Contact : EMC Symposium, Box 2141, 51-645 Wroclaw 12, Poland, fax +48 71-728 878, e-mail : emc@ita.pwr.wroc.pl

July 2000

Electromagnetic Aspects of Self-Organisation in Biology
Prague, Czech Republic, 9-12 July 2000
Contact : Prof. Jiri Pokorny, Institute of Radio Engineering and Electronics, No 240 Communications Systems, Chaberska 57, Prague 8-Kobylisy, 182 51 Czech Republic, Phone : +420 2 688 1804, Fax : 420 2 688 0222, E-mail : pokorny@ure.cas.cz, http://www.ure.cas.cz

HF Radio Systems and Techniques
Surrey, United Kingdom, 10-13 July 2000
Contact : HF Radio 2000 Secretariat, Conference & Exhibition Services, Institution of Electrical Engineers, Savoy Place, London WC2R 0BL, United Kingdom, Tel. +44 171-344 5471, Fax +44 171-240-8830, E-mail hf2000@iee.org.uk, www.iee.org.uk/Conf/

33rd COSPAR Scientific Assembly
Warsaw, Poland, 16-23 July 2000
Contact : Prof. S. Grzedzielski, Executive Director, COSPAR, 51, Bvd. de Montmorency, F-75016 Paris, France, Tel. : +33 1-4525 0679, Fax : +33 1-4050 9827

Int. School of Physics "Enrico Fermi"
Varenna, Italy, 25 July - 4 August 2000
Contact : Prof. S. Leschiutta, Istituto Elettrotecnico Nazionale "Galileo Ferraris", Strada delle Cacce 91, I-10135 Torino, Italy, Tel. : +39 113919544, Fax : +39 11346384, E-mail : pres@amm.ien.it

August 2000

ISAP 2000
Fukuoka, Japan, 22-25 August 2000
Contact : Dr. Y. Karasawa, ISAP 2000, KDD R&D Labs, Inc. 2-1-15 Ohara, Kamifukuoka-shi, Saitama 356-8502, Japan, Tel. +81 492-78 7327, Fax +81 492-78 7524, E-mail karasawa@lab.kdd.co.jp

September 2000

2000 Int. Conference on Mathematical Methods in Electromagnetic Theory (MMET'00)
Kharkov, Ukraine, 12-15 September 2000
Contact : Dr. A. Nosich, MMET 2000 TPC Co-Chairman, c/o Dept. of Computational Electromagnetics, Institute of Radio Physics and Electronics, National Academy of Sciences, Ul. Proskury 12, Kharkov 61085, Ukraine, Fax : +380 572-140 738 or 441105

Bianisotropics 2000
Lisbon, Portugal, 27-29 September 2000
Contact : Bianisotropics 2000, Prof. A.M. Barbosa, Dept of Electrical and Computer Eng., Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal, Tel.: +351-21-8418482, Fax: +351-21-8417284, e-mail: Bian2000@lx.it.pt, www.lx.it.pt/bian2000

October 2000

The First S-RAMP Conference
Sapporo, Japan, 2-6 October 2000
Contact : Dr. Y. Kamide, Solar-Terrestrial Environment Laboratory, Nagoya University, Honohara 3-13, Toyokawa, Aichi 442-8507, Japan, Tel: 81-533-86-3154, Fax: 81-533-86-0811, E-mail: s-ramp@kurasc.kyoto-u.ac.jp

February 2001

EMC Zurich

Zurich, Switzerland, 20-22 February 2001

Contact : Dr. G. Meyer, ETHZ-IKT, ETH-Zentrum, CH-8092 Zurich, Switzerland, Tel. : 41 1-2562 793, Fax : 41 1-2620 943

May 2001

2001 URSI International Symposium on Electromagnetic Theory

Victoria, BC, Canada, 13-17 May 2001

Contact : Prof. S. Ström, Dept. of Electromagnetic Theory, Royal Institute of Technology, SE-100 44 Stockholm, Sweden, Tel.: +46-8-790 8195, Fax: +46-8-10 83 27, e-mail: staffan@tet.kth.se, www.nrc.ca/confserv/URSI-B2001

July 2001

ISSSE'01 - "Questing More Significant Harmony and Integration : Systems/Devices and Softwares/ Hardwares"

Tokyo, Japan, 24-27 July 2001

Contact : ISSSE'01 secretariat, Dept.of Elec. Eng., Science University of Tokyo, 1-3 kagurazaka, shinjuku Tokyo 162-8601 Japan, E-mail: issse01@ee.kagu.sut.ac.jp, http://issse01.ee.kagu.sut.ac.jp

August 2001

Asia-Pacific Radio Science Conference

Tokyo, Japan, 1-4 August 2001

Contact : AP-RASC Secretariat, c/o Dr. Y. Furuhama, Communications Research Laboratory, Ministry of Posts and Telecommunications, 4-2-1 Nukuikita-machi, Koganei-shi, 184-8795 Tokyo, Japan, E-mail : ap-rasc@kurasc.kyoto-u.ac.jp, www.kurasc.kyoto-u.ac.jp/ap-rasc/

September 2001

ICEAA'01

International Conference on Electromagnetic in Advanced Applications

Torino, Italy, 10-14 September 2001

Contact : COREP - ICEAA'01, Politecnico di Torino, Corso Duca degli Abruzzi 24, I-10129 Torino, Italy, http://www.polito.it/iceaa01

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The Guidelines and Rules for URSI Sponsorship of Meetings can be found at ***http://www.intec.rug.ac.be/ursi/Rules.html***

News from the URSI Community

NEWS FROM A MEMBER COMMITTEE

GERMANY

Kleinheubacher Tagung 2000, 25-29 September 2000

A/E. Electromagnetische Metrologie und Elektromagnetisches Rauschen und Interferenzen
A.1.: Offene Sitzung über Electromagnetische Metrologie; Sitzungsleiter: U. Stumper
A.2.: EMV Mess- und Prüftechnik; Sitzungsleiter: J. Glimm
E.1.: Offene Sitzung über Elektromagnetisches Rauschen und Interferenzen; Sitzungsleiter: J. Nitsch
E.2.: Optische Aufbau- und Verbindungstechniken; Sitzungsleiter: E. Griese
EA.1.: Elektromagnetische Einkopplung in Systeme und Schaltungen; Sitzungsleiter: G. Wollenberg
EA.2.: EMV-Testumgebungen: ein Vergleich; Sitzungsleiter: A. Enders

B. Felder und Wellen
B.1.: Offene Sitzung über Felder und Wellen; Sitzungsleiter: W. Menzel
B.2.: Transiente Quasistationäre Felder; Sitzungleiter: G. Mrozynski
B.3.: Nichtseparable Eigenwert- und Streuprobleme in der EM Theorie; Sitzungsleiter: T. Rother
B.4.: Integralgleichungsverfahren zur Lösung elektromagnetischer Randwertprobleme; Sitzungsleiter: T.F. Eibert
B.5.: Lineare und nichtlineare Inverse Beugungstheorie; Sitzungleiter: R. Marklein

C. Signale und Systeme
C.1.: Offene Sitzung über Signale und Systeme; Sitzungsleiter: D. Wolf
C.2.: Migrationszenarien hin zur Dritten Mobilfunkgeneration; Sitzungsleiter: B. Steiner
C.3.: Mobilfunksysteme der Vierten Generation; Sitzungsleiter: C. Weck
C.4.: DVB-T: Einführung, Pilotprojekte und Entwicklungspotentiale; Sitzungsleiter: C. Weck
C.5.: Digitale Rundfunksysteme Weltweit; Sitzungsleiter: G. Zimmermann
C.6.: CDMA und Multiuser Informationstheorie; Sitzungsleiter: M. Mecking
C.7.: Coded Modulation; Sitzungsleiter: R. Fischer
C.8.: Übertragung analoger und digitaler Signale in CATV-Netzen; Sitzungsleiter: H. Weissleder
C.9.: Verkehrsmonitoring und Verkehrsdatengewinnung; Sitzungsleiter: E. Michler

D. Elektronik und Optik
D.1.: Offene Sitzung über Elektronik und Optik; Sitzungsleiter: W. Schminke
D.2.: Bauelemente und Schaltungen der Nanoelektronik; Sitzungsleiter: U. Kunze

F. Wellenausbreitung und Fernerkundung
F.1.: Offene Sitzung über Wellenausbreitung und Fernerkundung; Sitzungsleiter: M. Chandra
F.2.: Fernerkundung mit direktem und synthetischem Apertur- Radar und Mikrowellenausbreitung in Funksystemen; Sitzungsleiter: U. Kühn
F.3. : Bodengebundene Fernsondierung der Atmosphäre; Sitzungsleiter: G. Peters und J. Bösenberg

GHJ. Ionosphärenphysik, Wellen in Plasmen und Radioastronomie
GHJ.1.: Offene Sitzung über Ionosphärenphysik, Wellen in Plasmen und Radioastronomie; Sitzungsleiter: G. Mann
GHJ.2.: Erzeugung energiereicher Teilchen in kosmischen Plasmen; Sitzungsleiter: W. Reich
GHJ.3.: Grenzempfindlichkeit von Radioteleskopen; Sitzungsleiter: W. Reich

K. Electromagnetics in Biologie und Medizin
K.1.: Offene Sitzung über Electromagnetics in Biologie und Medizin; Sitzungsleiter: F. Kaiser
K.2.: Wirkungsmechanismen; Sitzungsleiter: F. Kaiser
K.3.: ZNS invitro - invivo; Sitzungsleiter: U. Kullnick
K.4.: Dosimetrie; Sitzungsleiter: F. Gustrau
K.5.: ELF - EMF als Stimuli zur Zellaktivierung; Sitzungsleiter: M. Simko
K.6.: EMF effects on gene expression; Sitzungsleiter: H.-A. Kolb
K.7.: Expositionseinrichtungen und Dosimetrie bei biologischen Untersuchungen; Sitzungsleiter: V. Hansen
K.8.: Exposition durch ortsfeste Sendefunkanlagen und mobile Funkgeräte; Sitzungsleiter: Th. Weiland

http://www.copernicus.org/URSI/URSI.html

URSI Publications

Modern Radio Science 1999

Editor: Maria Stuchly
ISBN 0-7803-6002-8
List Price : USD 49.95 Member Price : USD 45.00
IEEE Product No. PC5837

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in cooperation with URSI and IEEE Press
Order 24 hours a day, 7 days a week :
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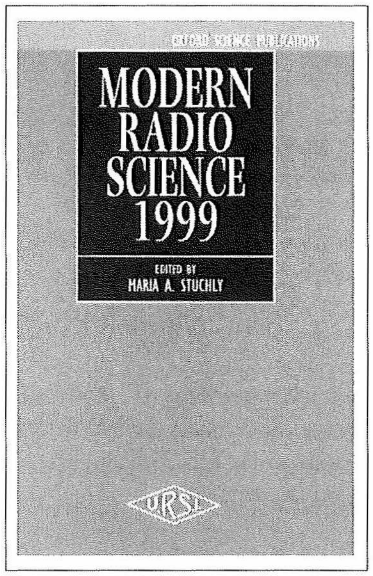

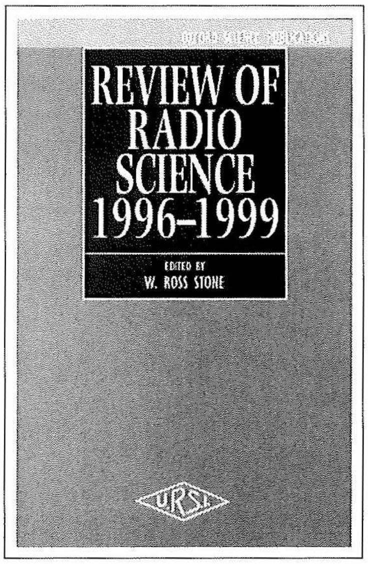

Review of Radio Science 1996-1999

Editor: W. Ross Stone
August 1999/Hardcover/1044 pp
ISBN 0-7803-6003-6
List Price : USD 89.95 Member Price : USD 81.00
IEEE Product No. PC5838

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Fax 1-732 981 9667
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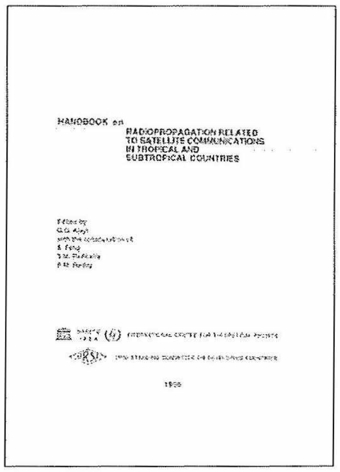
Handbook on Radiopropagation Related to Satellite Communications in Tropical and Subtropical Countries

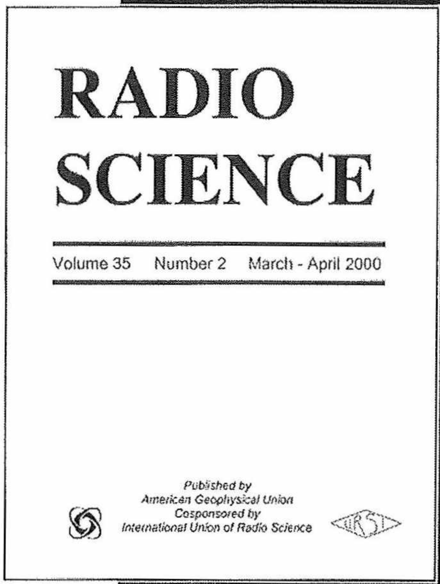
Editor: G.O. Ajayi
with the collaboration of :
S. Feng, S.M. Radicella, B.M. Reddy

Available from 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 : heleu@intec.rug.ac.be



Radio Science

Bimonthly!



Radio Science contains original articles on all aspects of electromagnetic phenomena related to physical problems. Covers the propagation through and interaction of electromagnetic waves with geophysical media, biological media, plasmas, and man-made structures. Also included, but not limited to, are papers on the application of electromagnetic techniques to remote sensing of the Earth and its environment, telecommunications, signals and systems, the ionosphere, and radio astronomy. All frequencies, including optical, are of interest.

See a recent Table of Contents on the AGU Web Site: *http://www.agu.org*

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