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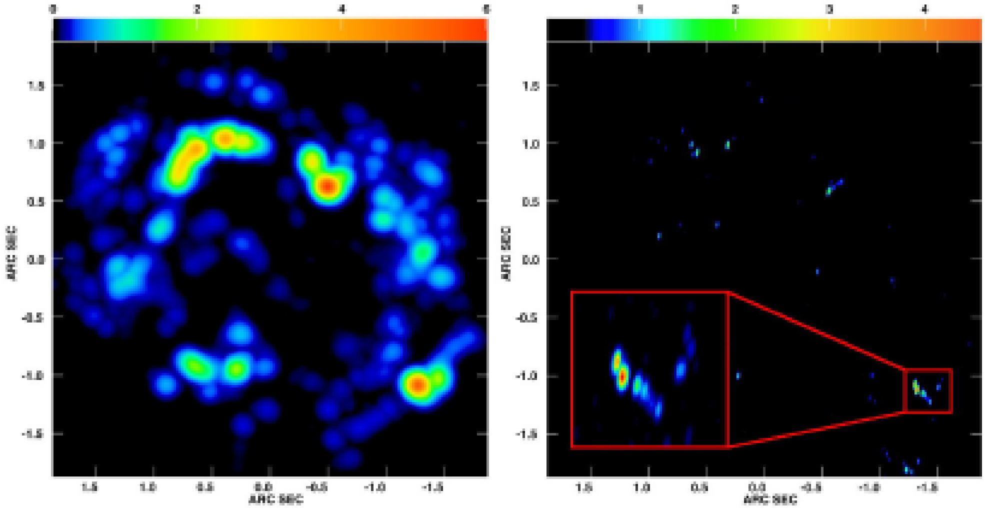

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Contents

Front cover: The first eVLBI science image, IRC+10420. See the paper by Mc Cool et al. on pp. 9-18.

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Editorial

We welcome a *Review of Radio Science* from Commission J in this issue. Roshene McCool, Ralph Spencer, Suresh Kumar, Ron Beresford, Steven Durand, Yasuhiro Koyama, Steve Parsley, Alan Whitney, and Peter Maat provide us with a comprehensive overview of the effects fiber-optic networks are having on radio telescopes. The effects are of fundamental significance. Such networks permit rapid transfer of large amounts of data among radio telescopes and to central locations, allowing *new* methods of processing the data. They allow instruments to be connected together on both local and global scales, resulting in much larger effective apertures and sensitivities. They also enable new modes for very-long-baseline interferometry (VLBI). The paper includes extensive information on where and how fiber networks are being used in radio astronomy around the world. It also provides a good introduction to the properties of high-speed fiber-optic networks.

The efforts of Ray Norris and Phil Wilkinson in bringing us this *Review* are gratefully acknowledged.

Semiconductor waveguides play an important role in integrated optoelectronic devices. A tapered, deep-ridge dielectric waveguide is an excellent example. Although there are numerical modeling tools for such waveguides, quasi-analytical techniques can permit a better understanding of the physics involved. In their paper, N. Cinosi and J. Sarma describe a quasi-analytical technique for the tapered, deep-ridge waveguide problem. It is an efficient method, requiring much less computational time than purely numerical techniques, and it is sufficiently general to be applicable for a variety of integrated optical devices. The method divides the problem into spatial regions, and applies an appropriate set of expansion functions to represent the fields in each region. The fields are then matched at the boundaries. After deriving the method, the authors use it to study the propagation of optical fields in tapered dielectric waveguides. They are able to illustrate a number of important effects associated with such propagation. In addition to presenting a new, useful design technique, this paper provides a very nice, understandable introduction to how such optical waveguides work.

At the XXVIIIth General Assembly of URSI in New Delhi, India, the attendees were treated to many special experiences. Two of these involved presentations by the President of India, Dr. A. P. J. Abdul Kalam, and both of these are included in this issue.

Dr. Kalam is an aeronautical engineer, and was Project Director for the development and deployment of India's first indigenous satellite launch vehicle. He went on to develop India's defensive missiles, and to play a major role in Indian defense development. He was Principal Scientific Advisor to the Government of India, with the rank of a Cabinet Minister, and was a Professor of Technology and Societal Transformation at Anna University, before becoming President of India in July, 2002. As a scientist, he has received over 30 honorary doctorates.

Dr. Kalam made a presentation at the Opening Ceremony of the General Assembly on the topic of the importance of the electromagnetic spectrum to humanity. His comments included a number of personal recollections of how radio science affected his own career, and some ideas of how radio science could be used to benefit mankind.

Dr. Kalam also presented one of the General Lectures at the General Assembly. This dealt with the ways in which information-network connectivity, in various forms and for various purposes, could transform India in a variety of ways. While the ultimate vision presented is some years away, many of the programs and part of the infrastructure to support them are already in place and being pursued. Remember, India represents almost one-sixth of the world's population: connecting that many people represents tremendous challenges and great opportunities.

After reading these two presentations, I urge you to take a look at Dr. Kalam's Web site: http://presidentofindia.nic.in/. I think you will find it interesting.

In his Radio-Frequency Radiation Safety and Health column, Jim Lin takes a look at the new IEEE standard for human exposure to RF radiation. He notes that the values in the new standard aren't the same as those in the standard used by the International Commission on Nonionizing Radiation Protection, and examines the differences. Some of these are potentially quite significant.

I recently had the opportunity to tour the venue for the 2008 URSI General Assembly in Chicago. It is really nice! We will have ample room for all of the sessions and lectures, for all of the needed offices, and for all of the committee meetings that go on during a General Assembly. There is a great area for poster papers and exhibits, as well. Essentially all of this is located together, with the sessions and offices on one floor of the Hyatt Regency Chicago, and the posters and exhibits on the floor below. The hotel itself is in a great location, right on what is referred to as the "Miracle Mile," with some of the best restaurants and shopping all within easy walking distance. I think you will really enjoy this venue.

We're now completely back on schedule for the *Radio Science Bulletin*. You have absolutely no excuse to not use these pages to share your work with the radio science community! I hope you'll do so: we're actively looking for contributed papers.

W. Ross Stone

The Records of the New Delhi General Assembly are now available and may be downloaded free of charge. A paper copy can be obtained via the URSI Secretariat.

URSI Accounts 2005

The URSI balance per 31.12.2005 shows a substantially increase compared to the previous year.

This is entirely the result of the favorable developments on the stock market; the value of the investments increased by almost 80 k€.

Income from the contributions from national Members was substantially higher than the year before. The latter is, however, only due to the fluctuations in payment dates and periods over which membership dues are paid; it does not reflect a trend.

The rise in total expenditure shows clearly the cost of the General Assembly. As a result, expenditures exceeded income in 2005. In 2006 this should be offset by the share of the fees of the GA to be received from the host country.

Overall, the URSI finances are sound and we are making a healthy start into the new triennium.

Gert Brussaard
Treasurer

BALANCE SHEET: 31 DECEMBER 2005

ASSETS	EURO	EURO
Dollars		
Merrill Lynch WCMA	139.05	
Fortis	773.80	
Smith Barney Shearson	10,906.55	
		11,819.40
Euros		
Banque Degroof	1,389.55	
Fortis	200,734.00	
		202,123.55
Investments		
Demeter Sicav Shares	22,681.79	
Rorento Units	111,414.88	
Aqua Sicav	63,785.56	
Merrill-Lynch Low Duration (305 units)	3,268.17	
Massachusetts Investor Fund	250,011.32	
Provision for (not realised) currency differences	(38,844.47)	
	412,317.25	
684 Rorento units on behalf of van der Pol Fund	12,414.34	
		424,731.59
Short Term Deposito		0.00
Petty Cash		889.82
Total Assets		639,564.36
Less Creditors		
IUCAF	14,676.70	
ISES	9,807.73	
		(24,484.43)
Balthasar van der Pol Medal Fund		(12,414.34)
NET TOTAL OF URSI ASSETS		**602,665.59**

The net URSI Assets are represented by:	EURO	EURO
Closure of Secretariat		
Provision for Closure of Secretariat		90,000.00
Scientific Activities Fund		
Scientific Activities in 2006	45,000.00	
Publications in 2006	40,000.00	
Young Scientists in 2006	0.00	
Administration Fund in 2006	85,000.00	
I.C.S.U. Dues in 2006	3,600.00	
		173,600.00
XXIX General Assembly 2008 Fund:		
During 2006-2007-2008		15,000.00
Total allocated URSI Assets		278,600.00
Unallocated Reserve Fund		324,065.59
		602,665.59

Statement of Income and expenditure for the year ended 31 December 2005

I. INCOME	EURO	EURO
Grant from ICSU Fund and US National		
Academy of Sciences	0.00	
Allocation from UNESCO to ISCU Grants Programme	0.00	
UNESCO Contracts	0.00	
Contributions from National Members	247,235.00	
Contributions from Other Members	0.00	
Special Contributions	0.00	
Contracts	0.00	
Sales of Publications, Royalties	0.00	
Sales of scientific materials	0.00	
Bank Interest	1,189.21	
Other Income	35,289.62	
Total Income		**283,713.83**

II. EXPENDITURE

A1) Scientific Activities		123,308.17
General Assembly 2005	113,021.76	
Scientific meetings: symposia/colloqiua	9,268.01	
Working groups/Training courses	0.00	
Representation at scientific meetings	1,018.40	
Data Gather/Processing	0.00	
Research Projects	0.00	
Grants to Individuals/Organisations	0.00	
Other	0.00	
Loss covered by UNESCO Contracts	0.00	

		EURO	EURO
A2)	Routine Meetings		13,334.00
	Bureau/Executive committee	13,334.00	
	Other	0.00	
A3)	Publications		45,929.43
B) Other Activities			10,530.23
	Contribution to ICSU	3,530.23	
	Contribution to other ICSU bodies	7,000.00	
	Activities covered by UNESCO Contracts	0.00	
C) Administrative Expenses			97,423.81
	Salaries, Related Charges	64,947.34	
	General Office Expenses	9,496.79	
	Office Equipment	911.35	
	Accountancy/Audit Fees	4,567.75	
	Bank Charges	6,783.56	
	Loss on Investments	10,717.02	
	Total Expenditure:		**290,525.64**
Excess of Income over Expenditure			(6,811.81)
	Currency translation difference (USD => EURO) - Bank Accounts		1,334.67
	Currency translation difference (USD => EURO) - Investments		78,980.90
	Currency translation difference (USD => EURO) - others		0.00
	Accumulated Balance at 1 January 2005		529,161.83
			602,665.59

Rates of exchange:

January 1, 2005	$ 1 = 0.7540 EUR
December 31, 2005	$ 1 = 0.8500 EUR

	EURO
Balthasar van der Pol Fund	
684 Rorento Shares: market value on December 31, 2005/2004	
(Aquisition Value: USD 12.476,17/EUR 12.414,34)	29,323.08
Market Value of investments on December 31, 2005/2004	
Demeter Sicav	59,736.60
Rorento Units (1)	557,310.00
Aqua-Sicav	80,524.49
M-L Low Duration	2,592.50
Massachusetts Investor Fund	170,391.12
	870,554.71

(1) Including the 684 Rorento Shares of the van der Pol Fund

APPENDIX: Detail of Income and Expenditure

	EURO	EURO
I. INCOME		
Other Income		
Income General Assembly 2002	5,440.00	
Income General Assembly 2005	29,832.03	
Revenu Taxes	17.59	
		35,289.62
II . EXPENDITURE		
General Assembly 2005		
Organisation	75,356.34	
Vanderpol Medal	1,474.90	
Expenses officials	0.00	
Young scientists	36,190.52	
		113,021.76
Symposia/Colloquia/Working Groups:		
Commission A	0.00	
Commission B	0.00	
Commission C	2,500.00	
Commission D	1,500.00	
Commission E	0.00	
Commission F	0.00	
Commission G	1,268.01	
Commission H	1,000.00	
Commission J	3,000.00	
Commission K	0.00	
Central Fund	0.00	
		9,268.01
Contribution to other ICSU bodies		
UNESCO-ICTP	5,000.00	
IUCAF 2005	2,000.00	
		7,000.00
Publications:		
Printing ‘The Radio Science Bulletin’	14,431.73	
Mailing ‘The Radio Science Bulletin’	23,091.91	
Ursi Leaflet	8,405.79	
		45,929.43

Enhancing the Sensitivity of Radio Telescopes Using Fiber-Optic Networks

R. McCool, R. Spencer
S. Kumar, R. Beresford
S. Durand, Y. Koyama
S. Parsley, A. Whitney
P. Maat

Abstract

Optical fibers are key components of current and future radio telescopes. They enable the transmission of the large bandwidths required for high-sensitivity radio astronomy. Fiber-optic connectivity can increase the sensitivity of a radio telescope 10-fold, due to its ability to carry large amounts of data over long distances. This means that distant galaxies, only glimpsed by extended observations today, will routinely be available to the astronomers of tomorrow, in a fraction of the time. This paper will give an overview of optical-fiber technology and its related transmission characteristics, and will describe current fiber-related activities taking place in radio-astronomy observatories across the globe.

1. Introduction

Aperture Synthesis for large-scale instruments was a technique developed in the 1970's. It involves the transfer of signals from separate antennas to a central location, where the radio signals are correlated and a cosmic-source signal is extracted. Radio-frequency interferometers use aperture-synthesis techniques to enhance the resolution of the astronomical images they produce by using an array of antennas to simulate a very-large-diameter telescope. The sensitivity of this type of radio interferometer is proportional to the square root of its bandwidth, while the resolution is proportional to the separation of the antenna. The ideal method of signal transfer in this type of instrument is therefore one that can carry large bandwidths over long distances.

Methods of signal transfer in radio-frequency interferometers originally used coaxial cable or microwave links. Whilst modern, cryogenically cooled radio receivers are near the limit of their physical performance, the method of signal transfer has often been the limiting factor in the sensitivity of these instruments. Advances in fiber-optic communications over the past two decades mean that fiber-optic networks are capable of carrying very high bandwidths over very long distances. Radio astronomers have therefore looked to fiber-optic technology to release the potential sensitivity in their existing instruments. Fiber-optic networks can increase the sensitivity of a radio telescope 10-fold, due to a 100-fold increase in bandwidth to the correlator. This means that distant galaxies, only glimpsed by long observations today, will routinely be available to the astronomers of tomorrow, in a fraction of the time.

2. Optical Fiber

An optical fiber is a strand of silica-based glass, with dimensions similar to those of a human hair, surrounded by a transparent cladding. The relative differences in the refractive indices of both materials support a waveguide structure suitable for the transmission of light by the process of total internal reflection [1]. The geometry and differences between the refractive indices of the materials used in the production of an optical fiber can be manipulated to produce many varieties of specialized fiber, used in applications

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This is one of the invited Commission J *Reviews of Radio Science*.

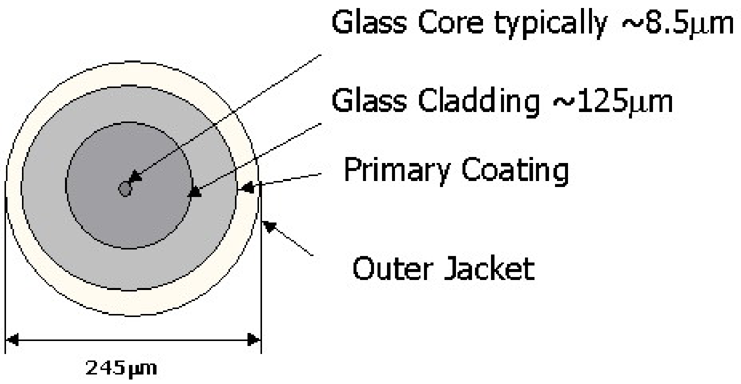

Figure 1. The geometry of a standard single-mode fiber.

from telecommunications to civil engineering. In telecommunications and computing applications, two main forms of fiber are used:

- Standard single-mode fiber. Figure 1 shows the typical structure of a fiber used for communication links. It has an inner glass core with an outer cladding. This is covered with a protective buffer and an outer jacket. Its small-diameter core allows the propagation of only one transverse electromagnetic mode (hence the term "single-mode fiber"). It has low loss in the 1550 nm window, and a dispersion minimum in the 1310 nm window.
- Multimode fiber. This type of fiber has a much larger core size, typically of 50 ìm and above. The large core size means that many electromagnetic modes can propagate through the fiber at the same time. The large core size used in multimode fibers also means that it is much easier to couple a light source into the fiber. It is therefore used in many short-distance data-transport applications.

3. Transmission Characteristics of Optical Fibers

Optical fibers provide a low-loss medium for the transport of light over a large frequency range (~25 THz). The ability to transmit light over great distances at very high data rates makes optical fiber an ideal medium for the transport of information. The light propagates along the fiber by the process of total internal reflection, and is contained within the glass core and cladding by careful design of their geometry and refractive indices. The loss along the fiber is low, and the signal is not subject to the electromagnetic interference that plagues other methods of signal transmission, such as radio or copper-wire links. However, the signal is degraded by other mechanisms, such as dispersion and nonlinear effects (resulting from a high power density in the fiber core).

3.1 Loss

The loss, or attenuation, in fiber depends on the glass material and the wavelength of the light propagating within it. There are three main bandwidth "windows" of interest in the attenuation spectrum of fiber. The first window is at 800-900 nm: here, there are many inexpensive silicon based sources and detectors. The second window is at 1260-1360 nm: here, there is low fiber attenuation coupled with zero material dispersion. The third window of interest is at 1430-1580 nm, where fiber has its attenuation minimum. Typically, the telecommunications industry uses wavelengths in the third window, which coincides with the gain bandwidth of optical-fiber amplifiers. Optical amplifiers are used to compensate for the loss within the fiber.

Optical amplifiers (mostly erbium-doped fiber amplifiers, or EDFAs) are important components in long-distance fiber links, where fiber and component attenuation will degrade the transmitted signal. When the signal power becomes too low, errors will occur at the optical receiver as it struggles to distinguish the transmitted signal from received noise. Erbium-doped fiber amplifiers provide the means to optically amplify the signal enroute, without converting the signal from the optical domain back to the electrical domain. This component works by the principle of stimulated emission. A laser at high power pumps a piece of fiber, doped with erbium ions. The excited erbium ions release their energy when the data signal is passed through the fiber. The process is such that the energy they release exactly matches the signal, thus amplifying the signal. Like most amplifiers, the optical amplifier will induce noise on the output signal. In the case of the optical amplifier, this comes predominately from the spontaneous emission that takes place alongside the stimulated emission within the amplifier.

3.2 Chromatic Dispersion

Dispersion in fibers causes pulses to spread during transmission. This spreading affects the bit-error rate at the receiver as the pulses interfere with one another, creating noise called inter-symbol interference [3]. Chromatic dispersion is caused by small differences in the path length taken by different modes or wavelengths within the fiber. The pulse broadening due to dispersion increases linearly with fiber length. It follows that dispersion therefore imposes a limit on the bandwidth of information that can be carried over a specified fiber distance. In multimode fibers, the many modes within the fiber will induce high dispersion. Multimode fiber is therefore only used in short link lengths. For many applications with high bit rates and long distances, single-mode fiber is the medium of choice, due to its low dispersion properties. The dispersion is characterized by a dispersion curve that changes with wavelength. Typically, for standard single-mode fibers, the dispersion will be ~17 ps/nm km at 1550 nm, with a dispersion minimum at 1310 nm.

It is possible to compensate for the effects of dispersion in optical-fiber links. Since the dispersion is linear and stable across the fiber, techniques have been developed to compress a dispersed pulse back to its original shape. The most popular method for achieving dispersion compensation is dispersion-compensating fiber, although other methods, such as fiber Bragg grating dispersion compensators, do exist. Dispersion-compensating fiber consists of a reel of fiber the properties of which have been manipulated to induce a negative dispersion slope in the transmission window of the system (usually in the 1550 nm range). The negative dispersion compresses a spread pulse to compensate for the transmission dispersion. This type of dispersion compensation is not exact, and dispersive effects will eventually prevail, but it is used widely in today's high-speed long-distance networks.

3.3 Nonlinear Effects

Nonlinear effects occur in fiber links when the transmitted power along the link reaches a threshold power [4]. This is only likely to happen at the output of an optical amplifier. These effects will degrade the performance of an optical-transmission system. Nonlinear effects include:

- Scattering effects

Stimulated Raman scattering (SRS): Stimulated Raman scattering affects multi-channel systems. The power is lost from shorter-wavelength channels into longer-wavelength channels. Coupling occurs only if both channels are transmitting a logical one. The effect is therefore reduced when dispersion is present in the system, since the probability of overlap between pulses at different wavelengths at any point in the fiber is reduced in a dispersive system.

Stimulated Brillouin scattering (SBS): Stimulated Brillouin scattering is a backscattering effect, and power of the transmitted light is lost to a scattered beam traveling towards the transmitter. This phenomenon is independent of the number of channels. Stimulated Brillouin scattering is caused by interaction with acoustic phonons in the fiber structure and has a very long lifetime. High modulation rates produce broad optical spectra, and a reduction in the stimulated Brillouin scattering effect can be expected.

- Kerr Effect

The refractive index of a fiber varies with the intensity of incident light upon it: this is the Kerr effect. In data transmission systems, the Kerr effect can induce additional frequency products (described as four-wave mixing), or phase fluctuations on the transmitted signal (described as self-phase or cross-phase modulation).

Four-Wave Mixing (FWM): Four-wave mixing is the interaction between three transmitted channels at different frequencies ω_i, ω_j, ω_k, producing a fourth product frequency, $\omega_{ijk} = \omega_i + \omega_j - \omega_k$. The effect of four-wave mixing depends on the phase relationship among the interacting signals. When the phase of the signals is the same, the effect is reinforced. In the presence of dispersion, the phases of the transmitted signals are more likely to be different, and therefore the effect of four-wave mixing is reduced. The effect of four-wave mixing on the optical system is that energy in the transmitted channels is reduced to the advantage of the fourth product frequency. In addition, if the resulting fourth frequency product is within the bandwidth of another channel, it will cause crosstalk at the receiver.

Self-Phase Modulation (SPM) and Cross-Phase Modulation (XPM): In self-phase modulation, the power fluctuations in the transmitted pulse are converted into phase modulations, leading to chirp on the pulses. Cross-phase modulation affects multi-channel systems in a similar way, where power fluctuations in one channel lead to phase fluctuations in another. For channel spacing above a few tens of GHz, the power penalty due to cross-phase modulation is considered negligible (assuming an externally modulated source).

4. Overview of Existing and Proposed Fiber-Optic Networks

Despite the various potential loss mechanisms described in Section 3, high-speed fiber-optic networks are in everyday use, and the radio-astronomy community is working to bring the benefits of fiber optics into its instruments. The introduction of fiber-optic connectivity to radio interferometers will result in reliable networks that support the large bandwidths required for modern, highly sensitive radio telescopes. Many facilities have already been upgraded to include fiber-optic connectivity, with most major facilities scheduled for upgrade in the next few years. The following examples are just a few of the projects successfully completed to date, and other, planned projects that would not have been possible without a mature fiber-optic industry. These projects range from stand-alone research facilities to international collaborations that use high-speed commercial networks to link US, European, and Japanese institutions in real time.

4.1 Giant Metre-Wave Telescope (GMRT), Pune, India

The GMRT is a Y-array with 12 antennas in a central square and six antennas in each Y arm [5]. The GMRT is the first radio telescope of its kind to use analog fiber-optic links for an interferometry application. The 64 km analog fiber-optic network of the GMRT is built with 60 individual links, having link distances of 200 meters to 22 km. The links use single-mode optical fiber, buried at a depth of 1.5 m to reduce the effect of temperature on the phase stability of the link. A forward and a return analog fiber-optic link [6] connect each antenna to the central electronics building, which houses a correlator, located in the central square. The forward link carries telemetry and local-oscillator (LO) reference signals from the central electronics building to the remote antenna. The return links bring in two intermediate-frequency (IF) signals of 32 MHz bandwidth each, together with return telemetry and LO signals from the antenna, to the central electronics building. Direct intensity modulation is used to modulate the optical carrier using the subcarrier-multiplexed signals. The analog fiber-optic system simplifies the electronics required at the remote antenna, and enhances the reliability, maintenance, and upgrade potential of the telescope. The bandwidth required for the analog fiber-optic system is much less than a digital system, giving a lower system cost.

4.2 EVLA, ALMA, and e-MERLIN Fiber Networks

The basic design principles for the fiber signal-transfer system of the EVLA, ALMA, and e-MERLIN telescopes are very similar. This section will describe these three instruments in overview and give details of the data-transmission design, as well as highlighting variations in the way they operate.

4.2.1 Expanded Very Large Array (EVLA), Socorro, New Mexico

The Very Large Array (VLA) consists of 27 radio antennas, configured in the shape of a 35-km diameter "Y," located on the plains of San Agustin, 50 miles west of Socorro, New Mexico, USA. Each antenna is 25 m in diameter and operates from 1 GHz to 50 GHz. The data from each antenna are combined electronically to give the resolution of an antenna 36 km across with the sensitivity of a dish 130 meters in diameter.

The VLA is in the process of being upgraded, with a scheduled 2010 completion date. This is a major capital upgrade, which involves replacing the narrowband radio receivers, increasing the system sensitivity by a factor of ten, and replacing the analog waveguide system with a wavelength-division-multiplexed (WDM) fiber link [7].

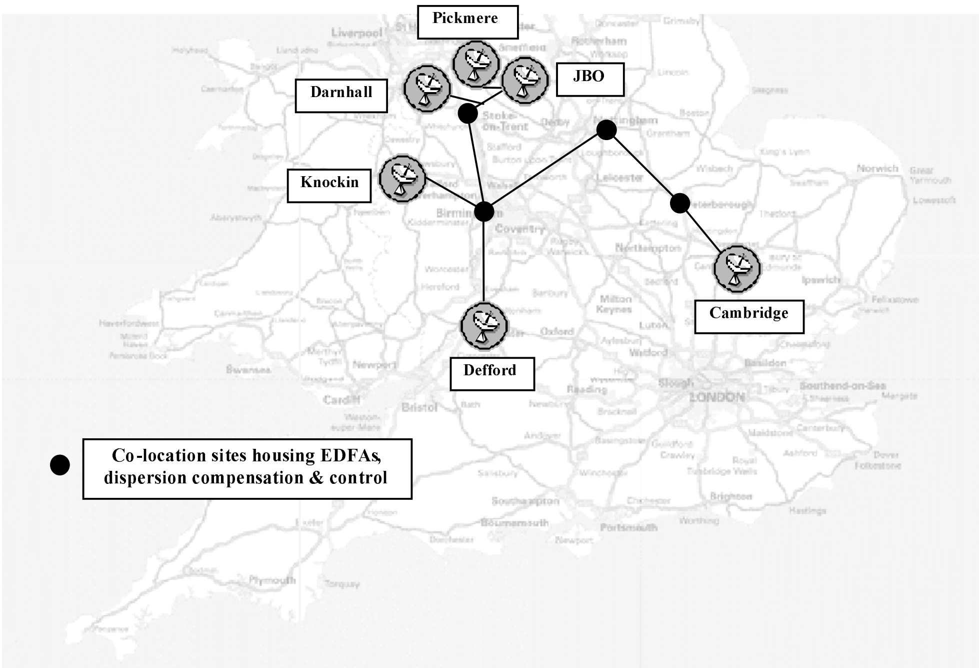

Figure 2. The eMERLIN network topology.

4.2.2 Atacama Large Millimetre Array (ALMA), Atacama Desert, Chile

The ALMA telescope is an ongoing project, made up of 64 12-meter antennas, spread across a site located at an elevation of 5000 m in the Chajnantor Plateau, Atacama, Chile. Each of the 64 antennas can be moved to one of 250 possible locations on the site to produce a reconfigurable array. The longest link from an antenna location to the center of the site will be 15 km.

ALMA is funded by an international consortium of research councils from the USA, Europe, and Japan, and developed by astronomers located across the globe. When completed, it will be a prestigious instrument that will benefit the astronomy community with new science. The wavelength-division multiplexed fiber-optic data-transfer system is an important part of the instrument. Over the whole site, the data-transfer system will transport 7.68 Tb/s of data [8].

4.2.3 e-MERLIN, Jodrell Bank Observatory (JBO), UK

MERLIN [9] is the UK's national imaging facility for radio astronomy. The instrument combines seven radio antennas with an overall array size of 217 km. The long baseline of the MERLIN array means that MERLIN can achieve resolutions of sub-arcseconds at centimeter radio wavelengths. Whilst high angular resolutions require long baselines, this restricts instrument sensitivity because of the difficulties in transferring large amounts of data over long distances [10]. The signals from each antenna are currently returned to the Jodrell Bank Observatory for correlation over microwave links with a bandwidth of 30 MHz. The addition of a fiber-optic data-transmission system to the MERLIN array will mean that all the information detected by the radio receivers at the antennas can be transferred to the correlator. This represents a bandwidth increase of 100 times the current instrument capacity. This will result in a 10-fold increase in instrument sensitivity whilst maintaining resolution. With additional upgrades to the Lovell telescope and radio receivers, e-MERLIN will be up to 40 times more sensitive than the current MERLIN design. Figure 2 shows the topology of the fiber network connecting the antenna to the Jodrell Bank Observatory. The co-location sites are used to amplify and dispersion compensate the optical signals, as the link distances require.

4.2.4 Fiber Link Design for the EVLA, ALMA, and e-MERLIN Telescopes

The basic design principles for the fiber signal-transfer system of these three telescopes are very similar. They all use digital encoding [11] of the astronomical data bands and wavelength-division multiplexing techniques to utilize components that are mass-produced for the telecommunications markets.

2 GHz IF bands in two polarizations are digitized to three-bit precision. The digitized signal is then encoded to produce three 10.24 Gb/s channels for each band. The encoding occurs at transmitter/formatter hardware located at each antenna. It uses a field-programmable gate-array device (FPGA) to format the data into 16 serial data streams at 640 MHz. These data are then transferred to an integrated optical transmitter module, containing a 16:1 multiplexer, a laser, a modulator-driver amplifier, and an electro-absorption (EA) optical modulator. The transmitter module converts the 640 MHz electrical signals to a 10.24 Gb/s modulated optical signal that is launched into the fiber at discrete wavelengths. These discrete wavelengths are combined onto a single fiber, using a passive wavelength-division multiplexed fiber multiplexer with 200 GHz channel spacing. The signals propagate along a fiber network until they reach the central electronics building, which houses a correlator. Optical amplification and dispersion compensation is used where required within these links to overcome loss and chromatic dispersion in the fiber network. A passive wavelength-division multiplexed fiber de-multiplexer splits the optical signals coming in from each antenna. Each optical signal is fed to an OC192 optical receiver module that contains a PiN diode, a trans-impedance amplifier, and a limiting amplifier. The recovered 10.24 Gb/s electrical data stream is fed to an OC192 de-multiplexer. This device performs all clock and data recovery functions, and de-multiplexes the data back into 16 serial data streams at 640 MHz. The data are then transferred using low-voltage differential signaling (LVDS) to a field-programmable gate array. The field-programmable gate array performs the synchronization, error checking, and re-clocking functions. The data output to the correlator is a 48-bit-wide low-voltage differential signaling word at 256 MHz.

There are small variations in design among the three telescopes:

- The EVLA and ALMA have four bands per antenna, making a total of 12 wavelength channels, whereas e-MERLIN has only one, making up three wavelength channels per antenna.
- The EVLA and e-MERLIN telescopes both use 10.24 Gb/s modulation as described here, but ALMA uses slightly different clocks, resulting in a 10 Gb/s channel data rate.
- The e-MERLIN telescope has much longer links than the current EVLA and ALMA fiber-network designs. It therefore uses optical amplification much more than the ALMA or EVLA links; it is the only network that requires the use of dispersion compensation.

4.3 Australian Telescope Compact Array (ATCA), Narrabri, Australia

The Australian Telescope Compact Array is made up of six 22 m antennas connected by fiber. The original fiber connections at the array were commissioned in 1988 using multimode fibers. A subsequent upgrade, starting in 1997, provided single-mode fiber transmission lines up to a maximum distance of 4.5 km to all antennas.

At each antenna four down-converted IFs (128 MHz wide, centered at 192 MHz) are digitized to two-bit precision and Manchester encoded, resulting in an output data rate of 1024 Mb/s [12]. Directly modulated laser diodes transmit the 1024 Mb/s data streams at 1310 nm to a central correlator location. Extensive use has been made of 1310 nm gigabit Ethernet devices and base-100 Ethernet transceivers. Directly modulated 1310 nm and 1550 nm lasers are used to provide the LO reference, and wavelength-division-multiplexed 1310/1550 nm paths are utilized for timeframe synchronization signals.

The compact array broadband upgrade scheme is now in full swing, and expected to run until 2007. Each antenna IF will be upgraded to 4 GS/s at eight-bit resolution, using interleaved analog-to-digital conversion techniques, giving a composite single antenna data rate of 160 Gb/s, or an array data rate of 1 Tb/s, with framing overhead. For each antenna, a field-programmable gate array in the digitizer module will drive a bank of four electro-absorption laser assemblies in the 1550 nm band, which are then wavelength-division multiplexed onto a single fiber. As part of the upgrade, a new FX style correlator, with input capability for eight antennas, will allow for real-time VLBI application.

Recent experiments have also been performed using wideband 4-12 GHz RF-over-fiber transmission with lithium niobate Mach-Zender modulators and distributed-feedback 1550 nm lasers. This method allows almost an entire single-polarization receiver output to be transmitted from the antenna to the central site and inputted to a wideband analog correlator. In this novel application, there is no variable tracking delay (no suitable variable optical delay line); therefore, the astronomy is limited to observations at the meridian.

4.4 Upgraded Very-Long-Baseline Interferometer (eVLBI)

Very-long-baseline interferometry is conducted by a collection of large telescopes located across the globe, which collaborate to produce the world's highest-resolution instrument for radio astronomy. In the past, very-long-baseline interferometer (VLBI) observations were restricted, because the data had to be recorded onto tape and then shipped to a central processing facility for analysis. Consequently, radio astronomers were unable to judge the success of their endeavors until many weeks, even months, after the observations were made. VLBI telescopes can now be linked in real time, due to two recent advances:

(1) high-bandwidth network connectivity is a reality via national fiber networks, and
(2) digital data interfacing equipment is widely used in participating observatories (e.g., Mark 5 recording equipment).

This real-time connectivity enables astronomers to analyze the data immediately, and to react much more swiftly to transient events. The technique, called eVLBI, is predicted to revolutionize the way VLBI observations are organized. As well as the operational benefits that fiber connectivity can bring to eVLBI, with further developments in digital data-recording technology, expansion of high-speed network availability, and powerful new correlators, it has the potential to increase the sensitivity of the instrument in the future. eVLBI is a global effort, with work ongoing in Japan, Australia, Europe, and the US.

4.4.1 eVLBI Development in Japan

Early success in the field of eVLBI was obtained in Japan, where real-time VLBI observations at 256 Mbps were conducted daily from June, 1997.

Further developments by the National Astronomy Observatory of Japan (NAOJ) mean that currently antennas in Usuda, Nobeyama, Tsukuba, Gifu, and Kashima are connected by high-speed research networks. The overall system is capable of correlating a single-channel 1 Gbps data stream, and supports a maximum data rate of 2 Gbps at each station by using two data channels.

At the National Institute of Information and Communications Technology (NICT), developments of the Internet-protocol-based eVLBI system started as a result of developments in an early program, "project keystone." The system, K5, utilizes the conventional PC systems running on the *FreeBSD* or a *Linux* operating system, and newly developed PCI interface boards. The observed data at VLBI observing stations can be recorded as data files on the local hard disks of the PC systems. The development of the software programs that enable the real-time data transfer from the observing stations to the correlation site over the Internet-protocol-based high-speed network is also underway. A software correlation program has been developed to enable distributed correlation for real-time or near-real-time eVLBI operations. The K5 system was used along with the Mark 5 system to demonstrate rapid turnaround of the universal time estimation using the Kashima-Westford baseline in June, 2004. From this session, it was possible to estimate universal time to coordinated universal time within about 4.5 hours after the one-hour session [13].

In the near future, there is a plan to extend the high-speed network connection to the Tomakomai and Yamaguchi antenna stations. In the Asia-Pacific region, the Seshan and Urumqi stations in China, and three new VLBI sites of the Korean VLBI Network, are also being connected to the high-speed research network. Collaborations on eVLBI development work are underway among these groups.

4.4.2 eVLBI in Europe

The VLBI correlator used for eVLBI is located at the Joint Institute for VLBI in Europe (JIVE), in the Netherlands. A real-time connection between the JIVE correlator and European telescopes involves crossing many country borders and many national fiber networks. This process has been simplified by the existence of GEANT, a pan-European network for research and education networks. GEANT, established in 1993, pre-dates the conception of eVLBI, and was set up and is owned by a group of national research and educational network operators (NREN). The home observatory for each of the participating European telescopes will manage the funding and installation of a "last-mile" high-speed fiber connection between the telescope and the local national research and educational network. These connections use standard protocols, such as gigabit Ethernet, so that they can interface with their local national research and educational network equipment. So far, last-mile connections exist for JIVE and Westerbork in the Netherlands, Medicina in Italy, Cambridge and JBO in the UK, Torun in Poland, and Onsala in Sweden. Real-time observations have been carried out at speeds of up to 256 Mb/s between two telescopes within Europe. For large observations involving many telescopes, speeds of 64 Mb/s are more routinely achieved.

Figure 3 shows the first science image obtained using eVLBI data from telescope connections in Westerbork, Onsala, Jodrell Bank-Cambridge, and Torun, running at 32 Mb/s [14]. A low-resolution image taken with the MERLIN array (left) shows the shell of maser emission. The corresponding high-resolution eVLBI image (right) shows the much finer structure and detail of the masers. In March, 2005, a proposal, called "EXPReS," was submitted to the European Commission Research Infrastructure Call. "EXPReS" will collect into one coordinated project all actions and developments needed to create a real-time eVLBI network, transparently connecting together an array of up to 16 telescopes, operating reliably at data rates of up to 1 Gb/s per telescope. The project will also include research activity that will look forward to the next-generation eVLBI system, enabled by evolving network capacity and emerging GRID technologies.

4.4.3 eVLBI in the US

The first eVLBI experiment in the US using shared Internet-protocol networks was conducted in October, 2002, when data were transferred from the Westford, Massachusetts, and GGAO, Maryland, telescopes to the Haystack Observatory Mark 4 VLBI correlator in near-real-time at 788 Mbps. Since that time, eVLBI has been rapidly developing to include stations in Europe and Japan, as well as real-time correlation. These developments have been enabled by the Mark 5 VLBI data system, developed at Haystack Observatory, which allows interfacing of VLBI data to standard high-speed-network facilities.

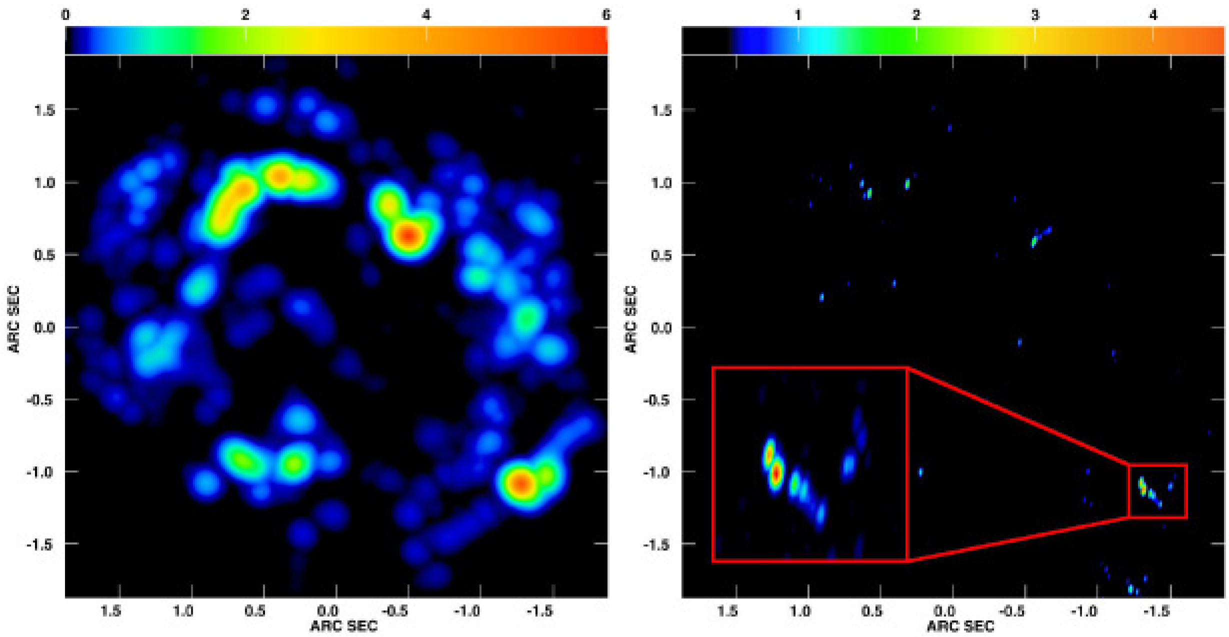

Figure 3. The first eVLBI science image, IRC+10420. It is a super-giant star located in our own galaxy, with a mass about ten times greater than the sun. The OH maser shell is 15000 astronomical units in diameter, with an expansion velocity of about 40 km/s, implying that the matter was ejected from the star about 900 years ago.

The eVLBI development program at Haystack Observatory is primarily focusing on three objectives:

1) Development of an internationally agreed-upon standard eVLBI data format and transmission protocol that will allow easy interoperability between heterogeneous VLBI data systems.
   An eVLBI-specific protocol, based on RTP/RTCP with extensions for eVLBI, has been developed and is being evaluated by the international community. This protocol, a part of the VLBI Standard Interface (VSI) specification, is designed to support data flows up to 100 Gbps per telescope, in anticipation of future global-network capabilities.
2) Development of algorithms and protocols specifically suited to the unique characteristics of eVLBI.
   This is being addressed by a project called "Experiment-Guided Adaptive Endpoint," which seeks to allow VLBI investigators to tailor eVLBI data-delivery specifications to the experimenter's requirements, and to dynamically adapt to network conditions to make optimal use of "scavenged" network bandwidth. Since TCP/IP is usually poorly suited to long-distance high-speed transfers, other transport protocols are being evaluated for both speed and network friendliness.
3) To bring eVLBI into routine use on a global scale.
   Unfortunately, few US antennas or correlators are currently well-connected to global high-speed networks. The Westford and GGAO antennas are connected at 2 Gbps, and Arecibo is connected at 150 Mbps. A few other antennas are connected a rates below 10 Mbps. The Mark 4 correlator at Haystack Observatory is connected to the global network at 2.4 Gbps, with plans to expand to 10 Gbps in the near future. Commitments to connect other major antennas and correlators have not yet been made.

Many real-time and near-real-time eVLBI experiments are now conducted in cooperation with US, European, and Japanese institutions. Real-time correlations with no disk buffering at 512 Mbps per telescope have been conducted at Haystack Observatory, with efforts now underway to push to 1024 Mbps. Routine eVLBI data transfers are now conducted among US, Japan, and Europe.

4.4.4 eVLBI in Australia

The networking of a number of widely spaced Australian radio-astronomy antennas in real time using broadband fiber-optic networks has been proposed for eVLBI observations. The initial phase is likely to connect the Mopra antenna (Coonabarabran), and Parkes and Tidbinbilla (Canberra), to the Australian Telescope Compact Array correlator. The Australian Telescope Compact Array correlator will network with the Australia Telescope National Facility (ATNF) headquarters in Sydney, with access to the trans-Pacific Southern Cross Network to the USA. At present, negotiations are in progress with the Australian Academic Research Network (AARNet) to facilitate the connectivity, largely on the transcontinental fiber backbone infrastructure provided by fiber-optic network carrier NEXTGEN. The "last mile" costs of connecting telescopes into the backbone are significant.

Short-term developments for 2005/2006 will enable 1 Gb/s between individual sites and the Australian Telescope Compact Array, with disk storage and software post-correlation. Beyond 2007, it is expected that dedicated 10 Gb/s or greater wavelength-division-multiplexed-based architectures will be available between sites, with full real-time on-the-fly correlation for eVLBI made possible by utilization of the new Australian Telescope Compact Array FX correlator. Figure 4 shows the proposed eVLBI connections for Australia.

One notable contribution of eVLBI observations in Australia was made in January, 2005, when the Huygen European spacecraft was observed by the Mopra and Parkes telescopes. The data, stored on disk, were flown to the Australia Telescope National Facility in Sydney. From there, they were delivered to the Joint Institute for VLBI in Europe over high-speed networks via Seattle, New York, and Amsterdam. The Australian Academic Research Network provided the coordinating role for setting up the dedicated link between Australia and the Joint Institute for VLBI in Europe. Two thirteen-minute scans from Mopra and Parkes were transferred at a data rate of about 450 Mbps. They were then reformatted and correlated to show fringes, giving strong confirmation that the Huygens VLBI observation had been successful.

4.5 Low-Frequency Array (LOFAR), Netherlands

At present, a large radio telescope is being constructed in the Netherlands. It is designed to perform astronomy observations at radio frequencies below 250 MHz, and is known as the LOFAR telescope [15]. LOFAR is the first of its type, using as it does an array of simple omni-directional antennas, instead of mechanical signal processing with a dish antenna. The electronic signals from the antennas are digitized, transported via an optical data-transport network to a central digital processor, and combined in software to emulate a conventional antenna.

The LOFAR antennas are grouped in clusters or antenna stations, which contain about 100 antennas. Fifty percent of all stations are located in the LOFAR central core, an area of 2 km × 3 km. The remaining antenna stations are positioned along a number of curved arms. In total, 25000 antennas are spread out over an area of 350 km in diameter, resulting in a data rate at the input side of the central processor of ~1 Tb/s. The stations along the arms of the telescope produce a data stream of 2 Gb/s, although the central-core stations have an output data rate of 20 Gb/s. The receiver data streams are transported via unidirectional

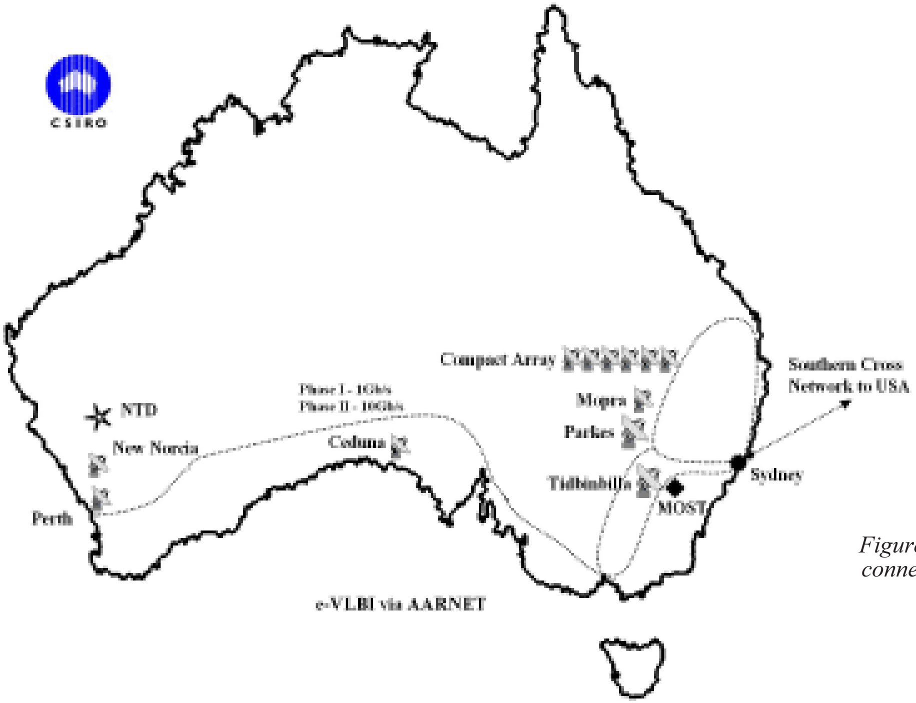

Figure 4. Proposed eVLBI connections for Australia.

point-to-point links to a single central processor. The required synchronicity in the data is obtained by time-tagging the data packets.

1 Gb/s and 10 Gb/s pluggable Ethernet transceivers are employed to transmit the data (SFP, the small form factor pluggable interface, and XFP, the standard for serial fiber-optic pluggable interfaces, respectively). This technology is preferred over other types of communication technology because of its low cost, commercial availability, and low complexity. The present-day costs of SFP technology are much lower than the XFP costs, so that SFP is used where possible. Since the costs of Ethernet equipment change rapidly, this has to be regularly reviewed.

The large amounts of LOFAR data can, in principle, be transported via a great number of parallel 1 gigabit Ethernet steams over separate fibers. However, in the case where the transmission distance becomes larger than about 10 km, the application of coarse wavelength-division multiplexing techniques becomes economically viable [16] at high data rates. With the use of coarse wavelength-division multiplexing, eight to sixteen 1 gigabit Ethernet (wavelength) channels can be multiplexed onto a single fiber.

4.6 Square Kilometer Array (SKA)

The SKA [17] is a revolutionary radio telescope, being planned by an international consortium of astronomers and engineers. It will have a collecting area of the order of a million square meters, giving it unprecedented sensitivity for studies including the early universe, the evolution of galaxies and quasars at high redshift, stars, star formation, the interstellar medium, and high-energy astrophysics [18].

Receiving elements of the SKA will be distributed into a hierarchy of array stations, probably made up of several antenna types. Each array station will have an effective diameter of up to 400 m. Various antenna designs are being considered, including aperture tile arrays, focal-plane arrays, and from medium-size dishes through to large circular flux concentrators. The requirement of angular resolution better than 0.1 arcseconds means that the stations will need to be spread over an area up to 3000 km in extent for the operating frequencies being considered (0.15 GHz to 20 GHz).

Signals from the stations may be combined at beamformers and sent to a central processor for correlation. The high (up to 4 GHz) bandwidth at the higher frequencies implies huge data rates and high-capacity optical-fiber links [19]. Within individual stations, it should be possible to use developments of current local-area-network techniques (e.g., 10 GE or its successors). Research into inexpensive short-range RF-over-fiber is also being considered, such as the fiber links used in the Allen Telescope Array [20]. The longer 100s km to 1000s km links will need many dense wavelength-division multiplexing systems with 40 Gbps or higher data rate devices. A number of design studies are currently underway in Europe, the USA, and Australia to find the most cost-effective solutions while meeting the demanding scientific requirements.

5. Conclusion

Optical fibers are key components of current and future radio telescopes, enabling the transmission of large bandwidths required for high-sensitivity radio astronomy. Radio telescopes utilizing this technology are operational today, but in the future, telescopes such as the SKA will push the boundaries of optical transmission beyond bandwidths currently used, and may become a driving force for development in the field of optical communications. Fiber-linked eVLBI networks will bring operational improvements to existing instruments, as well as sensitivities unimagined at their conception. The eVLBI project is testing the bandwidth capacity of present-day commercial telecommunications networks and equipment. The arrival of high-bandwidth applications such as radio astronomy will drive development and understanding in both the fields of radio astronomy and optical-network engineering.

6. Glossary

AARNet	Australian Academic Research Network
ALMA	Atacama Large Millimetre Array
ATNF	Australia Telescope National Facility
DFB	distributed feedback (laser)
EA	electro-absorption (modulator)
EDFA	erbium doped fiber amplifier
EVLA	Expanded Very Large Array
FPGA	field-programmable gate array
FWM	four-wave mixing
GbE	gigabit Ethernet
GGAO	Goddard Geophysical and Astronomy Observatory
GMRT	Giant Meter Wave Radio Telescope
IP	Internet protocol
JBO	Jodrell Bank Observatory
JIVE	Joint Institute for VLBI in Europe
LO	local oscillator
LOFAR	low-frequency array
LVDS	low-voltage differential signaling
MZ	Mach-Zender (modulator)
NREN	national research and education networks
OC192	optical carrier denomination used in the telecom industry, equivalent to 9.952 Gb/s
PCI	peripheral component interconnect
PiN	a photodiode having a large intrinsic layer sandwiched between p-type and n-type layers.
SBS	stimulated Brillouin scattering
SFP	small-form-factor pluggable interface
SKA	Square Kilometer Array
SPM	self phase modulation
SRS	stimulated Raman scattering
TCP/IP	transmission control protocol, Internet protocol
VLA	Very Large Array
VLBI	very long baseline interferometer
WDM	wavelength-division multiplexing
XFP	standard for serial fiber-optic pluggable interfaces
XPM	cross-phase modulation

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Three-Dimensional Analysis of Optical Propagation in Tapered Deep-Ridge Dielectric Waveguides

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J. Sarma

Abstract

This paper presents a method that is fast, reliable, and easy to implement for analyzing the optical propagation inside three-dimensional nonuniform semiconductor waveguides. The method suggested has been developed by following a quasi-analytic approach and, hence, it is general enough to be applied to a large class of photonic devices. It is particularly suitable as a computer-aided design tool for assisting in the analysis of and for studying the feasibility of novel devices. It is preferable to computationally expensive, purely numerical techniques. Because of its generality, the method can be used for the investigation of integrated circuits, where uniform and nonuniform optical components are combined together, residing on the same chip.

The method subdivides the device into spatial sub-regions and uses functional expansion techniques, with an appropriate set of functions chosen according to the type of spatial sub-region. The different expressions of the optical field in such sub-regions are then matched together by applying physical electromagnetic boundary conditions.

1. Introduction

The increasing demand for multifunctional optoelectronic integrated devices requires the development of complete computer-aided design (CAD) tools to assist component designers in rapidly and reliably exploring the feasibility of novel devices. With this aim in mind, quasi-analytical techniques for modeling are more desirable than the more-often-used purely numerical methods. Quasi-analytical techniques enable understanding of the links between the physics of the device and the parameters of the model.

The work presented in this paper focuses mainly on a specific class of multifunctional devices, namely planar rib waveguides with a large refractive-index step (a deep ridge) between the guiding (core) and the surrounding (cladding) regions. Examples of such devices are those based on silicon-on-insulator technology [1]. An important property often required for an integrated optical system is to enable optical propagation and routing along the various components of the system. The propagation can occur either along a (longitudinally) uniform device, such as a straight planar rib, or through a non-uniform device, such as a signal splitting from a tapered rib waveguide into the two branches of a Y junction (i.e., a Mach-Zender interferometer, or a Y junction/switch [2-4]).

Optical propagation along the uniform sections can be studied as an eigenvalue problem. There are established quasi-analytic three-dimensional techniques, such as the Spectral Index Method (SIM), for solving this problem [5]. In the case of nonuniform waveguides, the propagation cannot be described with an eigenvalue formulation, but it must be treated as an initial-value problem. The most commonly used numerical techniques for solving for the optical propagation inside nonuniform devices are the Finite Element Method (FEM) and the Beam Propagation Method (BPM) [6-7]. Although a few quasi-analytical methods exist, their application is limited to two-dimensional analysis and to rib waveguides with a small refractive-index step between the guiding and the surrounding regions [8] (a shallow ridge).

It is often common practice to separately analyze each part of an optical integrated system by applying a different technique for each component. As an alternative, it is the intention of this paper to suggest a single (quasi-analytical) method that does apply to both the uniform and nonuniform parts. Since the Spectral Index Method has been shown to be an accurate method for determining the three-dimensional propagation inside a longitudinally uniform waveguide, it is suggested and demonstrated here that a common modeling platform, capable of solving even a tapered ridge waveguide quite satisfactorily, can be obtained by adapting the Spectral Index Method to a nonuniform geometry. The method presented is general, and, although introduced for a single linear taper, can be easily extended to a larger class of devices, such as rib-waveguide couplers, a Y-junction splitter, etc.

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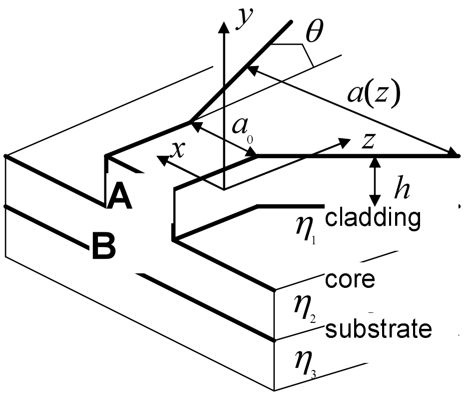

Figure 1a. An isometric view of the geometry of a linearly tapered rib waveguide.

The paper is organized in four parts. Section 2 introduces the geometry of the device investigated, together with the corresponding modeling equations. Section 3 reviews the fundamentals of the Spectral Index Method for the analysis of three-dimensional uniform waveguides. Section 4 illustrates the method proposed for the analysis of three-dimensional nonuniform waveguides. Section 5 presents and discusses the results obtained.

2. Optical Propagation in Tapered Dielectric Waveguides

2.1 Description of the Device

A typical tapered waveguide is illustrated in Figure 1. The width of the tapered rib changes linearly along the (longitudinal) z direction, varying from an initial aperture, a_0, at one edge of the taper, to a value of $a(z)$ at any distance z:

$$a(z) = a_0 + 2z\tan\theta, \tag{1}$$

with θ being the half-angle of the taper.

The vertical multilayer stack (along the y axis) enforces the optical confinement inside the central core region, Figure 1, while the etched ridge provides the horizontal confinement, mostly within the spatial region underneath the ridge [9].

Three-dimensional tapered structures have been extensively studied, although many of the methods applied are purely numerical. There exist a few quasi-analytical methods, such as the Effective Dielectric Constant (EDC) [10], but they are suitable for solving only for shallow waveguides. Typical shallow waveguides are those with a small refractive-index step between the central core and the surrounding cladding regions, or, equivalently, those with a small ridge etch depth, i.e., $h/a \ll 1$, Figure 1.

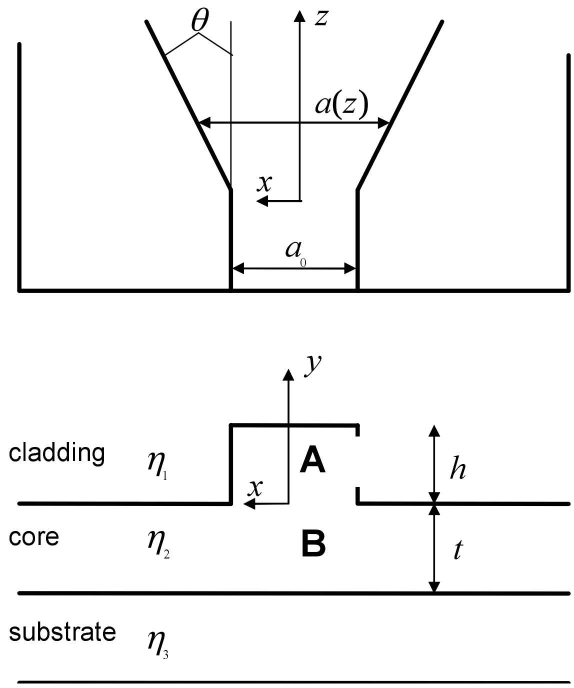

Figure 1b. Top and front views of the geometry of a linearly tapered rib waveguide.

In the case of deep-ridge waveguides, there is an evident gap in quasi-analytical methods for studying the optical propagation. Typical examples of deep-ridge waveguides are silicon-on-insulator (SOI) optoelectronic devices – characterized by a large refractive-index step between the silicon core ($\eta = 3.5$) and the silicon oxide cladding ($\eta = 1.5$) [1, 11-12] – and current-injected III-V type gallium-nitride visible-light sources, characterized by a deep etch of the ridge [13].

2.2 The Scalar Wave Equation

The general wave equations representing the optical electromagnetic field, propagating in a semiconductor device ($\mu_r = 1$), in a harmonic regime with angular frequency ω, are [10]

$$\Delta \mathbf{E} + k_0^2 \varepsilon_r \mathbf{E} = -\nabla\left[\frac{\nabla \varepsilon_r}{\varepsilon_r}\mathbf{E}\right], \tag{2a}$$

$$\Delta \mathbf{H} + k_0^2 \varepsilon_r \mathbf{H} = -\frac{\nabla \varepsilon_r}{\varepsilon_r} \times \nabla \times \mathbf{H}, \tag{2b}$$

with $k_0^2 = \omega^2 \varepsilon_0 \mu_0 = (2\pi/\lambda_0)^2$, where λ_0 is the free-space (vacuum) optical wavelength, and $\varepsilon_r = \eta^2$, with η being the refractive index of the material. Equations (2) produce six scalar equations representing the six components of the electromagnetic field, which in general are all coupled together.

In a Cartesian coordinate system, (x , y , z), the spatial variations of the refractive index, represented by $\nabla\varepsilon_r$ in Equations (2), can be highlighted as two types of terms. $\partial_z\varepsilon_r = \frac{\partial\varepsilon_r}{\partial z}$ is a term representing the longitudinal variation of the refractive index, due, for example, to longitudinally tapered geometries. In the case of a longitudinally uniform waveguide ($\partial_z\varepsilon_r = 0$), or a slowly varying structure ($\partial_z\varepsilon_r \approx 0$), this term can be neglected. $\partial_x\varepsilon_r = \frac{\partial\varepsilon_r}{\partial x}$ and $\partial_y\varepsilon_r = \frac{\partial\varepsilon_r}{\partial y}$ are terms representing the transverse variation of the refractive index. For example, the first term describes the presence of a planar rib, while the second term is used to describe a vertical multilayer stack (Figure 1).

In the case of a longitudinally uniform (or slowly varying) waveguide, e.g., $\partial_z\varepsilon_r = 0$, the vectorial wave Equation (2a) for the electric field can be rewritten as three different equations, one for each component of the field, as

$$\Delta E_x + k_0^2\varepsilon E_x = -\partial_x\left[E_x\partial_x \ln(\varepsilon_r) + E_y\partial_y \ln(\varepsilon_r)\right], \quad (3a)$$

$$\Delta E_y + k_0^2\varepsilon E_y = -\partial_y\left[E_x\partial_x \ln(\varepsilon_r) + E_y\partial_y \ln(\varepsilon_r)\right], \quad (3b)$$

$$\Delta E_z + k_0^2\varepsilon E_z = -\partial_z\left[E_x\partial_x \ln(\varepsilon_r) + E_y\partial_y \ln(\varepsilon_r)\right]. \quad (3c)$$

The terms $\left(\partial_x\left[E_x\partial_x \ln(\varepsilon_r)\right]\right)$ in Equation (3a) and $\left(\partial_y\left[E_y\partial_y \ln(\varepsilon_r)\right]\right)$ in Equation (3b) account for the effects of polarization [14], (the polarization describes the field's spatial orientation). The terms $\left(\partial_x\left[E_y\partial_y \ln(\varepsilon_r)\right]\right)$ in Equation (3a) and $\left(\partial_y\left[E_x\partial_x \ln(\varepsilon_r)\right]\right)$ in Equation (3b) imply a vectorial type of solution, since they are responsible for the coupling between the different components of the field [15].

In the case of a slab waveguide (or a vertical stack of layers) with no ribs, i.e., $\partial_x\varepsilon_r = 0$, the vertical component, E_y , is uncoupled from the other components. Equation (3b) for E_y involves only such a component and, therefore, reduces to an uncoupled Helmholtz scalar wave equation:

$$\frac{\partial^2 E_y}{\partial x^2} + \frac{\partial^2 E_y}{\partial y^2} + \frac{\partial^2 E_y}{\partial z^2} + k_0^2\varepsilon_r E_y = -\partial_y\left[E_y\partial_y \ln\varepsilon_r\right]. \quad (4)$$

It is thus possible to solve Equation (4) for E_y independently of the other field components. Moreover, if the H_y component is omitted, i.e., $H_y = 0$, it is possible to determine all the other components of the electromagnetic field by inserting the results for E_y into Maxwell's equations [10]. This solution is referred to as TM_y polarization, since the magnetic-field vector lies on a plane transverse to the y axis. In a similar manner, by starting from the wave Equation (2b) for the magnetic field, it is possible to write an independent scalar wave equation for the vertical component of the magnetic field, H_y . All the other components are then obtained from Maxwell's equations, provided that the vertical component of the electric field is omitted, i.e., $E_y = 0$. This solution is referred to as TE_y , since the electric field is transverse to the y axis.

Therefore, in a vertical-slab waveguide, the six components of the electromagnetic field can be entirely determined by solving two scalar Helmholtz wave equations separately, namely for the TM_y and the TE_y polarization:

$$\Delta E_y + k_0^2\varepsilon_r E_y = \frac{\partial^2 E_y}{\partial x^2} + \frac{\partial^2 E_y}{\partial y^2} + \frac{\partial^2 E_y}{\partial z^2} + k_0^2\varepsilon_r E_y = 0 \quad (5a)$$

$$\Delta H_y + k_0^2\varepsilon_r H_y = \frac{\partial^2 H_y}{\partial x^2} + \frac{\partial^2 H_y}{\partial y^2} + \frac{\partial^2 H_y}{\partial z^2} + k_0^2\varepsilon_r H_y = 0 \quad (5b)$$

In the more general case of a rib waveguide, the condition $\partial_x\varepsilon_r \neq 0$ applies in Equations (3). Hence, the presence of the rib introduces a coupling between the TM_y and the TE_y polarizations, and the field is characterized by a hybrid solution [10] (a combination of both polarizations). A rigorous analysis will then require that all the six components of the electromagnetic field be solved together.

2.3 Longitudinally Nonuniform Waveguides: The Paraxial Wave Equation

In the case of a waveguide uniform along the longitudinal z direction, it is possible to separate the z variable from the other spatial directions, and the propagating field can be expressed as

$$E(x, y, z) = f(x, y)g(z) = f(x, y)\exp(-i\beta z). \quad (6)$$

The scalar wave Equation (5a) can then be rewritten as

$$\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + k_0^2\varepsilon_r(x, y)f = \beta^2 f. \quad (7)$$

Equation (7) constitutes an eigenvalue equation the solutions of which, *f*, are the eigenmodes supported by the waveguide, and the values of β are the corresponding eigenvalues (propagation constants).

In the case of waveguides with a longitudinal z variation, i.e., $\partial_z\varepsilon_r \neq 0$, it would be necessary to solve for the full field vector, as the field components are coupled together. With the approximation of a slowly varying waveguide, i.e., $\partial_z\varepsilon_r \approx 0$, the full six-component vectorial analysis is reduced to the solution of the Helmholtz scalar Equations (5), even in the case of nonuniform waveguides.

However, although the analysis can be reduced to the scalar case, the field can no longer be described as in Equation (6). The field propagation thus cannot be studied as an eigenmode problem, Equation (7), but the field profile, $E(x,y,z)$, must be obtained by solving the more general Helmholtz Equation (5). Moreover, in order to determine a unique field solution, an initial distribution of the field at $z=0$ (Figure 1) must be assigned, i.e., $E(x,y,0)=E_0(x,y)$. If as an initial field profile one of the eigenmodes supported by the input uniform waveguide is given (Figure 1), then the solution of Equation (5a) will uniquely describe how such a profile propagates and evolves along the longitudinal *z* direction, inside the taper.

Although the field cannot be written in separated-variables form, i.e., $E(x,y,z)\neq f(x,y)g(z)$, for geometries with *z* slowly varying it is convenient to decompose the field into two terms:

$$E(x,y,z)=F(x,y,z)\exp(-ipz)\cdot \tag{8}$$

The exponential term represents the longitudinal fast variation, while $F(x,y,z)$ is a slowly varying term.

The analysis of the electromagnetic field with a slowly varying pattern $F(x,y,z)$ is greatly simplified by using the paraxial approximation, expressed as

$$\left|\frac{\partial^2 F(x,y,z)}{\partial z^2}\right| \ll \left|p\frac{\partial F(x,y,z)}{\partial z}\right| \tag{9}$$

and

$$\left|\frac{\partial^2 F(x,y,z)}{\partial z^2}\right| \ll \left|\frac{\partial^2 F(x,y,z)}{\partial x^2}\right|, \tag{10}$$

$$\left|\frac{\partial^2 F(x,y,z)}{\partial z^2}\right| \ll \left|\frac{\partial^2 F(x,y,z)}{\partial y^2}\right|.$$

Inserting Equation (8) into the Helmholtz Equation (5a), and by making use of Equations (9) and (10), the paraxial wave equation for the slowly varying term, $F(x,y,z)$, is obtained as

$$\left[\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}-2ip\frac{\partial}{\partial z}+k_0^2\varepsilon_r(x,y)-p^2\right]F(x,y,z)=0\,. \tag{11}$$

The paraxial approximation is particularly valid in the case of waveguides with a small longitudinal variation of the refractive index (adiabatic geometry).

3. Analysis of Three-Dimensional Uniform Waveguides: The Spectral Index Method

The Spectral Index Method (SIM) is a quasi-analytic method [5] suitable for the analysis of the field propagation along longitudinally uniform rib waveguides (eigenmode analysis) characterized by a large refractive-index step between the core guiding region and the top cladding region (Figure 1). The method can be summarized in three steps:

1. The electric field inside the rib, region A in Figure 1, is expanded in terms of metal waveguide modes;
2. The electric field underneath the rib, region B in Figure 1, is decomposed into plane waves (Fourier expansion along the *x* axis);
3. The above two expressions of the field are matched at the common interface between the two regions, A and B, i.e., at the base of the rib, $y=0$, by applying a variational technique.

As a result, the matching conditions generate an equation (a dispersion relation) the numerical solution of which yields the propagation constants, β, of the modes supported by the waveguide. The values of β are then inserted into the two field expansions, in regions A and B, to obtain the field profile.

3.1 Evanescent Boundary Conditions and Effective Rib

As introduced in Section 2.2, the electromagnetic field propagating inside a rib waveguide is characterized by a hybrid solution. The two polarizations, TE_y and TM_y, are coupled together, and all the six field components are necessary to represent the propagation. However, Robson and Kendall [5] showed that if the rib is surrounded by a cladding material with a much lower refractive index, then the coupling between the two polarizations is negligible. Therefore, the field can be represented accurately by using only five components [16], and, more importantly, the problem can be reduced to the solution of the scalar Helmholtz Equations (5). Since the waveguide is longitudinally uniform, the field can be expressed as in Equation (6). The corresponding Equation (7) is solved separately for the vertical components of the magnetic field, H_y, and the electric field, E_y, in order to obtain the TE_y and TM_y polarized modes, respectively.

The large refractive-index step between the core and the cladding, i.e., $\eta_1 \ll \eta_2 < \eta_3$ (Figure 1), produces bound (guided) modes that are mostly confined inside the core region. As a consequence, the field in the outer cladding

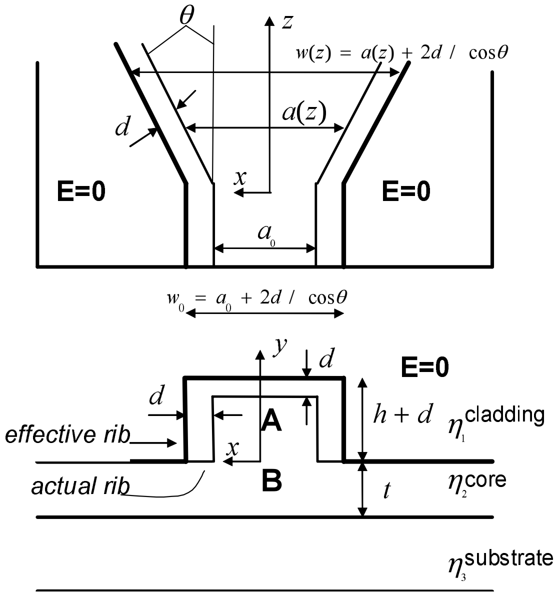

Figure 2. A linearly tapered effective rib.

region decays rapidly after a short distance from the core/cladding surface, and its value is almost negligible away from the interface.

The decaying behavior is described by the evanescent boundary conditions, which, in effect, replace the physical boundary conditions at the core/cladding interface [5]:

$$\frac{\partial E_n}{\partial n} = -\frac{E_n}{d_n}, \tag{12}$$

$$\frac{\partial E_t}{\partial n} = -\frac{E_t}{d_t}.$$

E_n and E_t are the normal and tangential components of the field at the boundary surface, respectively; $\partial/\partial n$ is the derivative along the direction normal to the surface; and the distances d_n and d_t describe the penetration depth of the field inside the cladding layer, before its amplitude becomes negligible. These distances are determined by [5]

$$d_t = \frac{1}{\sqrt{\beta^2 - k_0^2 \eta_1^2}}, \tag{13a}$$

$$d_n = \frac{\eta_1^2}{\eta_2^2} \frac{1}{\sqrt{\beta^2 - k_0^2 \eta_1^2}}. \tag{13b}$$

Because the distances d_n, d_t are, in general, small, the field is almost zero after a short distance away from the rib. It is then convenient to replace the actual rib with an *effective rib* (Figure 2) the field outside of which is assumed to be perfectly zero [17].

It is important to note that since β is the sought parameter, the penetration depths of Equations (13) can not be determined until the final solution is known: this would invalidate the use of the evanescent boundary conditions of Equations (12). However, in the case of guided modes, the propagation constant must be in the range $k_0\eta_1 \ll k_0\eta_3 < \beta < k_0\eta_2$. It is thus reasonable to approximate $\beta \approx k_0\eta_2$ in order to evaluate the distances d_n and d_t and to define the boundary conditions for the problem. This approximation has negligible effect on the final value of β [5].

3.2 Modal Expansion Inside the Rib

With the newly defined *effective rib*, the wave Equation (7) is solved first in the region $y > 0$ (Figure 2), omitting, for the moment, the layers below the base of the rib. The artifice of the effective rib, surrounded outside by zero electric field, introduces new boundary conditions similar to those applied for metal waveguides. The two vertical walls of the effective rib are de facto equivalent to two metal plates. It then seems expedient to expand the field along the x direction in terms of metal waveguide modes (a complete set of functions). Thus (within region A in Figure 2),

$$E_A(x, y) = \sum_{k=1}^{\infty} F_k(x) G_k(y), \tag{14}$$

where $F_k(x)$ is the kth-order mode of two metal parallel plates separated by a distance w_0 (Figure 2);

$$F_K(x) = \cos\left[\frac{(2k-1)\pi}{w_0} x\right], \tag{15a}$$

for symmetric modes, and

$$F_K(x) = \sin\left[\frac{2k\pi}{w_0} x\right] \tag{15b}$$

for anti-symmetric modes.

Robson and Kendall [5] showed that for the propagation of the kth eigenmode, only the kth term of the expansion in Equation (14) contributes significantly to the expression of the field, while the other terms are negligible. Therefore, each mode can be represented accurately by using only one appropriate term of the expansion: for instance, the first (symmetric) mode is expressed in region A as ($k = 1$)

$$E_A(x,y) \approx \cos(s_A x) G(y), \quad s_A = \pi / w_0 . \qquad (16)$$

Substituting this expression into Equation (7) yields

$$\frac{d^2 G(y)}{dy^2} + \left[k_0^2 \eta_2^2 - s_A^2 - \beta^2 \right] G(y) = 0 . \qquad (17)$$

The new Helmholtz Equation (17) is equivalent to that of a slab waveguide uniform along x. The expression for $G(y)$ is given analytically as

$$G(y) = A_1 \sin(k_A y) + A_2 \cos(k_A y), \qquad (18)$$

with $k_A^2 = k_0^2 \eta_2^2 - s_A^2 - \beta^2$. The constants A_1 and A_2 are determined by applying the boundary conditions at the top and the bottom of region A. At the top of the rib, $y = h + d$ (Figure 2), the electric field is zero, due to the effective rib. At the bottom of the rib, $y = 0$, the field in region A must match with the field in region B. Since the field in region B underneath the rib will be represented by a different expansion, the condition at the bottom of the rib will be imposed explicitly later, in Section 3.4, when the two expressions of the electric field are matched.

3.3 Modal Expansion Underneath the Rib

Similarly to region A, the field is expressed through a functional expansion in region B, underneath the rib (Figure 2). In region B, the waveguide is uniform along the x axis, as it extends between $x = -\infty$ and $x = +\infty$. Along the vertical y axis, it shows a sequence of layers, each one characterized by a different refractive index. The bottom layer, extending ideally to $y = -\infty$, represents the substrate of the device; the base of the rib and the core/cladding interface at $y = 0$ constitute the top of the layer stack.

Because of the uniformity, in each layer the field can be Fourier expanded along the x direction as

$$E_B(x,y) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \mathsf{E}_B(s,y) \exp(-isx)\, ds , \qquad (19)$$

where $\mathsf{E}_B(s,y)$ is the Fourier transform of the electric field, $E_B(x,y)$.

Inserting Equation (19) into the Helmholtz Equation (7) yields for each vertical layer

$$\frac{\partial^2 \mathsf{E}_B(s,y)}{\partial y^2} + \left[\left(k_0^2 \eta^2 - s^2 \right) - \beta^2 \right] \mathsf{E}_B(s,y) = 0 . \qquad (20)$$

The refractive index, η, is $\eta = \eta_2$ in the core layer, $-t < y < 0$, and $\eta = \eta_3$ in the substrate, $y < -t$ (Figure 2). Equation (20) is similar to the slab wave Equation (17), and the solutions are of the same form as in Equation (18).

The field underneath the rib is thus solved in the spectral domain, in terms of the spectral wavenumber, s. This expedient reduces the analysis to the study of a one-dimensional slab. It is important to note that in contrast to region A, the electric field, Equation (19), is now not expressed as the product of two functions with separate variables: the x variable is linked to the y variable through the spectral variable, s.

3.4 Interface Matching Conditions

In order to determine $\mathsf{E}_B(s,y)$ uniquely from Equation (20), both the continuity of the electric field and its derivative are applied at the interface between the core and the substrate region [17], $y = -t$. The continuity of the field at the spatial interface can be equivalently applied to the Fourier transform of the field in the spectral domain, s. Moreover, the continuity of the electric field is also required at the bottom of the rib, $y = 0$, between the two regions A and B, except that the fields at the two sides of this interface are represented by two different expansions. In the top part, inside the rib, the field is as given by Equation (16):

$$E_A(x, y=0) = \cos(s_A x) G(y=0) . \qquad (21)$$

Underneath the rib, the field is Fourier expanded. Thus, in order to match the profiles, it is necessary to write both of the expressions in the same domain. For convenience, the matching is constrained in the spectral domain, s, i.e.,

$$\int_{-\infty}^{+\infty} E_A(x, y=0) \exp(isx)\, dx$$

$$= \int_{-w_0/2}^{+w_0/2} \cos(s_A x) G(y=0) \exp(isx)\, dx \qquad (22)$$

$$= \mathsf{E}_B(s, y=0) .$$

Before enforcing the continuity of the derivative of the electric field, it is important to observe that because in region A the expression of the field has separated variables, while the same is not true in the bottom region, B, it is impossible to achieve an exact matching of the derivative [5]. This is due to the fact that the field inside the rib has been represented by using only one term of the expansion in Equation (14), and the approximated expression of Equation (16) does not exactly satisfy the wave equation. However, a second condition is still needed in order to uniquely determine the solution. The best option would be to minimize the mismatching between the two derivatives of the field at the two sides of the common interface, $y = 0$. This condition is achieved by applying a variational technique and allowing a small discontinuity for the derivative, $\partial E/\partial y$, but providing a stationary solution for the propagation constant, β [18] (Appendix Section 7.1).

The application of the interface conditions, together with the variational technique, yield the dispersion relation, the solutions of which are the propagation constants, β.

4. Field Propagation in Tapered Deep-Ridge Waveguides

The Spectral Index Method, originally conceived to solve longitudinally uniform waveguides, can be extended to the case of nonuniform waveguides, and the same concepts can be applied to develop a method for representing the diffraction of the field along tapered ribs. Similarly to the Spectral Index Method, because of the large refractive-index step between the core and the cladding, the top tapered rib, region A in Figure 2, is replaced by an effective (tapered) rib surrounded outside by zero electric field. This introduces evanescent boundary conditions. These conditions uncouple the components of the vectorial field, and the scalar wave Equation (5) can be applied separately to the H_y and E_y components for TE_y and TM_y polarization, respectively. Moreover, in the case of small angles, θ (slowly varying taper), it is convenient to separate the slowly and the quickly varying parts of the field by adopting the expression introduced in Equation (8), and thus solving the paraxial wave Equation (11), instead. Henceforth, in this paper the analysis is directed toward tapers with small flaring angle θ (adiabatic), which satisfy the paraxial conditions of Equations (9) and (10).

Following the same procedure as for the Spectral Index Method, the analysis of the tapered waveguide is subdivided into two regions, namely, inside the rib (region A), and underneath the rib (region B) (Figure 2). The field in region B is Fourier transformed along the uniform x direction, while a particular ansatz is specified in region A. Since the ansatz determines and "drives" the spatial distribution of the field in the bottom region, B, the choice of the expression of the field inside the rib must be judicious.

As an initial field, an eigenmode of the input rib waveguide is launched into the taper. Because the input waveguide is longitudinally uniform, it supports mode solutions, and it is reasonable to specifically analyze how each of these modes propagates along the tapered section (this type of initial condition is also known as a two-dimensional mode-excitation template).

4.1 Modal Expansion Inside the Rib

Inside the rib (region A, Figure 2), the slowly varying function, $F(x, y, z)$ in Equation (8), is expressed by using the same metal-like modes, Equation (14), as for the longitudinally uniform case, but including the variation of the rib width explicitly inside the functional form of such modes. Thus, assuming that the argument of the cosine functions varies along z according to the variation of the taper width, $w(z)$, the electric field inside region A for the symmetric case is expressed as

$$E_A(x, y, z) = F_A(x, y, z)\exp(-ipz)$$

$$= \sum_{k=1}^{\infty} A_k(y, z)\cos\left[\frac{(2k-1)}{w(z)}x\right]\exp(-ipz). \quad (23)$$

The set of basis functions

$$\cos\left[\frac{(2k-1)\pi}{w(z)}x\right], \quad k = 1, 2, \ldots, \quad (24)$$

is not complete. At the input of the taper, $z = 0$ and $w(z) = w_0$, the cosine terms of Equation (23) exactly match the eigenmodes of the uniform input waveguide. Because of the adiabatic conditions in Equation (10), it is expected that as the input field propagates away from $z = 0$, along the tapered section, its profile remains unchanged: thus the assumption of Equation (23) seems physically reasonable. The expression of Equation (23) constitutes an "educated" approximation of the field, which satisfies in approximate terms the wave equation for the given taper geometry.

The longitudinal, z, and lateral, x, directions are linked explicitly through the terms of Equation (24) to include the effect of the taper, but the longitudinal dependence is retained even in the coefficients $A_k(y, z)$, in order to satisfy energy conservation. As a first approximation, only one term of the expansion of Equation (23) is considered, similarly to what is assumed in the Spectral Index Method for a uniform waveguide, i.e.,

$$F_A(x,y,z) = A(y,z)\cos\left[\frac{\pi}{w(z)}x\right] \quad (25)$$

$$= a(z)\cos\left[\frac{\pi}{w(z)}x\right]G(y).$$

Since only one specific mode of the uniform input waveguide is launched into the taper, the choice of only one term in Equation (23), i.e., the term corresponding to such a mode, is sufficient to describe the field. In fact, the adiabatic property of the taper does not significantly alter the shape of the propagating field from that of the initial field.

It must be emphasized that the cosine term alone in Equation (25) is not sufficient to describe the entire nature of the propagation, because then the power transmitted across the cross section at any z would not be the same as that transmitted across any other cross section at a different value of z. Thus, he z-dependence must be retained into the coefficient $A(y,z)$ to account for longitudinal energy conservation. Moreover, since the taper varies only in the horizontal (x,z) plane, the y variable can be separated from the x and z directions. By inserting the expression of Equation (25) into the paraxial wave Equation (11), it is possible to determine a functional form for the slowly varying term $a(z)$ as

$$a(z) = \frac{1}{\sqrt{w(z)}}\exp\left(-i\frac{q}{p}z\right), \quad q = q_R - iq_I, \quad (26)$$

with p being the fast propagating term and q being a complex constant. The entire derivation of Equation (26) is given in Appendix Section 6.3.

An initial arbitrary value for the fast propagating term, p, is chosen, and, consequently, the slowly varying term, $a(z)$, is determined. The term q_R describes the phase correction to the arbitrarily chosen fast propagation p, so that the total phase variation satisfies the taper geometry.

The amplitude term of $a(z)$,

$$|a(z)| = \frac{\exp\left(-\frac{q_I}{p}z\right)}{\sqrt{w(z)}} = \frac{\exp\left(-\frac{q_I}{p}z\right)}{\sqrt{w_0 + 2z\tan\theta}}, \quad (27)$$

accounts for the field amplitude decrease as it propagates longitudinally. This specific behavior complies with the principle of energy conservation at any transverse section z.

The value of the fast propagating term, p, must be chosen much larger than the phase correction, i.e., $p \gg q_R/p$, so that $a(z)$ satisfies the slowly varying conditions of Equation (9). In order to assign a mode of the uniform input rib waveguide as the initial field, it is necessary to chose p as the value of the propagation constant β of such a mode. In fact, at $z=0$, if $p=\beta$, the expression of the field inside the rib region, Equation (25), is equivalent to that of the uniform waveguide, Equation (16).

4.2 Modal Expansion Underneath the Rib

Below the rib, region B in Figure 2, the structure of the waveguide is the same as that of the longitudinally uniform waveguide. A more-general expression for the field can be used, and it is not necessary to explicitly specify the dependence between the x and z directions, as was done for the rib region in Equation (25). Any effect due to the presence of the taper in the top region will be enforced by the functional form of Equation (25), and by satisfying the continuity conditions at the common interface, $y=0$. The term $a(z)$ is maintained for convenience, together with the fast propagating term, p, as follows:

$$E_B(x,y,z) = F_B(x,y,z)\exp(-ipz)$$

$$= a(z)L(x,y,z)\exp(-ipz). \quad (28)$$

Similarly to the analysis of a longitudinally uniform waveguide, here, too, the field is Fourier transformed along the x axis, and solved for in the spectral domain, s:

$$\mathsf{F}_B(s,y,z) = \int_{-\infty}^{+\infty} F_B(x,y,z)\exp(isx)\,dx = a(z)\mathsf{L}(s,y,z) \quad (29)$$

with $\mathsf{L}(s,y,z)$ being the Fourier Transform of $L(x,y,z)$ with respect to x.

Making use of Equation (28), the paraxial wave Equation (11) becomes

$$\frac{\partial^2 \mathsf{L}}{\partial y^2}a(z) + \left[k_0^2\eta^2 - s^2 - p^2\right]\mathsf{L}a(z)$$

$$= 2ip\frac{da(z)}{dz}\mathsf{L} + 2ip\frac{\partial \mathsf{L}}{\partial z}a(z). \quad (30)$$

The two terms on the right-hand side of Equation (30) account for the effects of the taper. Of these two terms, the second one is negligible, i.e.,

$$\frac{\partial \mathsf{L}(s,y,z)}{\partial z}=\frac{\partial L(x,y,z)}{\partial z}\approx 0\,. \qquad (31)$$

This assumption can be justified because both the amplitude and the (small) phase perturbation due to the taper are described by the term $a(z)$ in the top region, where the taper occurs, and there are no other nonuniform parts beneath the rib that could generate longitudinal field variations in excess of that produced by the taper rib. Any field variation occurring in the bottom part is due to and determined by the top part. A physical interpretation of Equation (30) can be given by regarding the left-hand-side terms as the equation for a longitudinally uniform waveguide, similar to Equation (7), while the right-hand side can be regarded as perturbation terms to the uniform propagation. Thus, with the assumption of Equation (31), the perturbation effects are enforced only by the presence of the taper in the top part (i.e., only by the first term in the right-hand side).

Making use of the expression of Equation (26) for $a(z)$, it is possible to determine an analytic form for the slowly varying term, $\mathsf{F}_B(s,y,z)$, as

$$\mathsf{F}_B(s,y,z)=a(z)\left[B_1(z)\sin(k_{2B}y)+B_2(z)\cos(k_{2B}y)\right]$$

$$-t<y<0\,, \qquad (32a)$$

$$\mathsf{F}_B(s,y,z)=a(z)\left[C_1(z)\exp(k_{3B}y)\right],\; y<-t\,, \qquad (32b)$$

with k_{2B} and k_{3B} given by

$$k_{2B}^2=k_0^2\eta_2^2-s^2-p^2+4ip\frac{\tan\theta}{w(z)}-q\,, \qquad (33a)$$

$$k_{3B}^2=p^2+s^2-k_0^2\eta_3^2-4ip\frac{\tan\theta}{w(z)}+q\,, \qquad (33b)$$

and B_1, B_2, C_1 are coefficients to be determined by applying the boundary conditions at the common interfaces, $y=-t$ and $y=0$ (Figure 2). The kind of solution in Equation (32) reflects the fact that the field is bound inside the core region, and it is decaying in the substrate region, $y<-t$.

4.3 Interface Conditions and Variational Analysis

Similarly to the Spectral Index Method, the continuities of the electric field and its derivative at the common core/substrate interface, $y=-t$, are enforced in the spectral domain, i.e.,

$$\mathsf{F}_B\left(s,-t^-,z\right)=b\mathsf{F}_B\left(s,-t^+,z\right), \qquad (34)$$

$$\frac{\partial \mathsf{F}_B\left(s,-t^-,z\right)}{\partial y}=\frac{\partial \mathsf{F}_B\left(s,-t^+,z\right)}{\partial y},$$

with $b=1$ for TE_y and $b=\eta_2/\eta_3$ for TM_y polarizations.

The continuity of the field at the bottom of the rib region, $y=0$ (Figure 2), is enforced in the spectral domain, too:

$$\int_{-\infty}^{+\infty} F_A(x,y=0,z)\exp(isx)\,dx=\mathsf{F}_B(s,y=0,z)\,. \qquad (35)$$

In contrast with the uniform-waveguide case, the conditions of Equations (34) and (35) are now *z* dependent, and yet must be satisfied at any value of *z*. This requirement is accomplished in exact terms, since it is automatically built into the method. In fact, in the same way as these conditions were satisfied for each value of the spectral variable, *s*, in the case of uniform waveguides, Equation (22), they are now satisfied for each value of the spectral variable, *s*, and for the longitudinal variable, *z*.

As final condition, the continuity of the field derivative is required at the bottom of the rib, $y=0$. Of course, because the field inside the rib has been approximated with an expression that does not exactly satisfy the wave equation, it will not be possible to fulfill such a condition in exact terms. However, this limitation is overcome by applying a variational technique. The fast propagation term, *p*, in Equation (23), is chosen so as to assign a mode of the input waveguide as an initial condition. Therefore, the only term undetermined in the field expression for $E_B(x,y,z)$ is the term $a(z)$. The variational technique is applied by adjusting the slowly varying term $a(z)$ with the intent of minimizing the mismatch of the field derivative. As derived in Appendix A2, the variational form for a tapered device is given by

$$\int_{-\infty}^{+\infty}\int_{z_0}^{+\infty}\left[F_A^*\frac{\partial F_A}{\partial y}\bigg|_{y=0^+}-F_A^*\frac{\partial F_A}{\partial y}\bigg|_{y=0^-}\right]dxdz$$

$$+\frac{\iiint_V 2ipF_{AB}^*\partial_z F_{A,B}\,dxdydz}{\iiint_V F_{AB}^*F_{A,B}\,dxdydz}=0\,. \qquad (36)$$

The first integral in Equation (36) is similar to the variational expression for the longitudinally uniform rib waveguide [5], and accounts for the field derivative mismatch at the base of the rib. The second integral is due to the presence of

$\lambda_0 = 1.55\ \mu\text{m}$
$a_0 = 3.52\ \mu\text{m}$
$t = 2.64\ \mu\text{m}$
$h = 1.63\ \mu\text{m}$
$\eta_1 = 1$ (air)
$\eta_2 = 3.4764$ (Si)
$\eta_3 = 1.447$ (SiO)

Table 1. The set of parameters for the analysis of the tapered-rib waveguide

the taper. The expression in Equation (25) chosen for the field is not sufficient to describe any other modes but the mode launched at the beginning of the taper. Therefore, the second integral is essential for representing (as a global effect) such other modes (guided and radiated) so that the total transmitted energy is conserved at the transverse cross section for any *z* [19].

5. Results: Optical Field Distribution

The model proposed in this paper is applied to deep-ridge adiabatic-taper waveguides with different flaring angles. The dimensions, with reference to Figure 1, and the refractive indices are summarized in Table 1.

The fundamental mode of the uniform-input rib waveguide is launched as an initial field inside the tapered device. The propagation constant of such a mode is obtained by applying the Spectral Index Method, and is given by $\beta = 3.468094\left(2\pi/\lambda_0\right)$. Figures 3b and 3c show how the

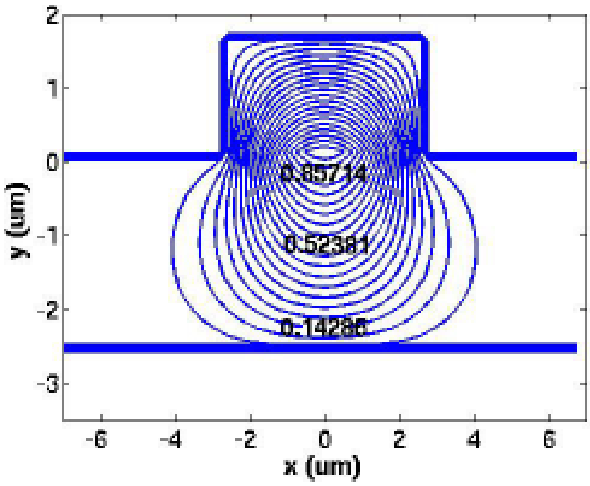

Figure 3b. A field profile contour plot, in arbitrary units, at the $z = 50\ \mu\text{m}$ transverse cross section of Figure 1. The angle $\theta = 2°$.

field, $E_0\left(x, y\right)$, launched at $z = 0$ (Figure 3a), spreads out as it propagates along the taper.

Further along *z*, as the waist of the taper becomes larger, the ridge tends more to confine the field in the lateral x direction. The increase of the ridge width in effect increases the horizontal confinement of the field (the same as in slab waveguides), provided that both the etch depth and the refractive indices are kept constant.

The field in the rib region A is always entirely confined inside the rib, as enforced by the assumption of external zero electric field. The total confinement of the field inside the rib region and the gradual broadening of the field in the region underneath can also be observed in the longitudinal contour plots, Figure 4.

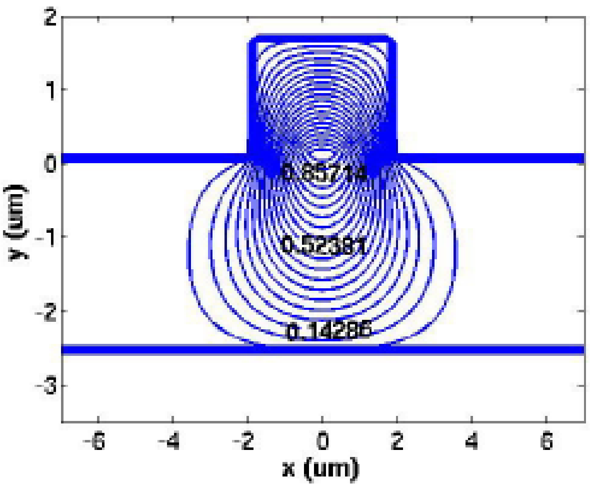

Figure 3a. A field profile contour plot, in arbitrary units, at the $z = 0$ transverse cross section of Figure 1: the initial field fed by the input rib waveguide. The angle $\theta = 2°$.

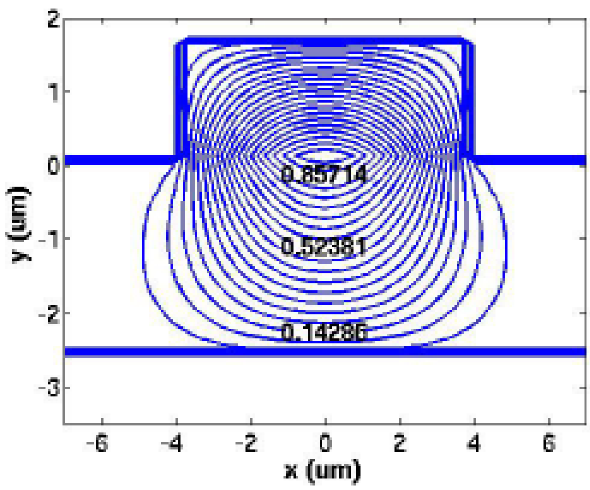

Figure 3c. A field profile contour plot, in arbitrary units, at the $z = 100\ \mu\text{m}$ transverse cross section of Figure 1. The angle $\theta = 2°$.

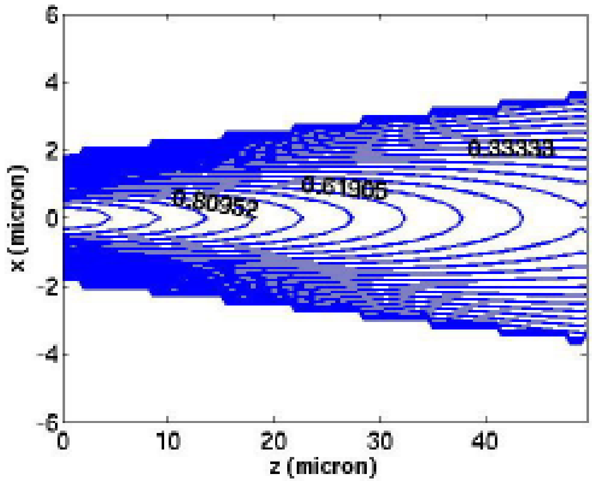

Figure 4a. A field profile contour plot, in arbitrary units, at the top rib region A longitudinal cross section of Figure 1, $y = 0.5\ \mu\text{m}$ *. The angle* $\theta = 2°$.

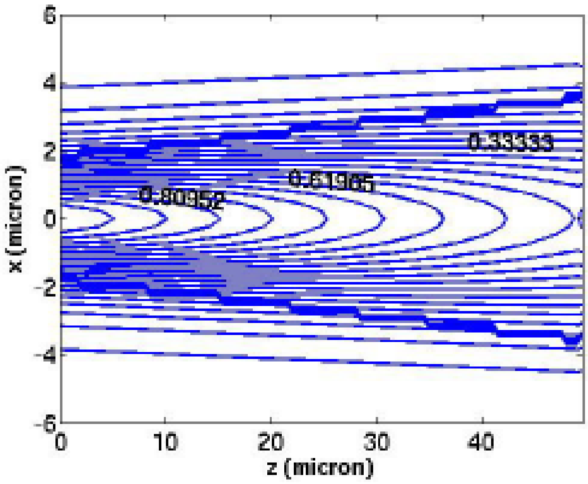

Figure 4b. A field profile contour plot, in arbitrary units, at the bottom rib region B longitudinal cross section of Figure 1, $y = -0.5\ \mu\text{m}$ *. The angle* $\theta = 2°$.

5.1 Comparison with Beam-Propagation Method and Local-Mode Expansion

In order to test the accuracy of the present model, the results were compared with those obtained by Yamauchi et al. [20] by applying a Finite-Difference BPM algorithm. The tapered structure analyzed had a flaring angle of $\theta = 0.5°$, and the field was propagated for a distance of 50 µm; the material's refractive indices were $\eta_2 = 3.44$, $\eta_3 = 3.40$. Because of the small refractive-index step between the core and the substrate, there was less field confinement in the vertical direction, and the field leaked more into the substrate layer. Figure 5 shows the similarities of the field profiles at the output of the tapered guide obtained by the two different methods. In both cases, the adiabatic taper retained the single peaked pear shape of the field, centered at the same location in the middle of the core region. The two profiles were normalized in amplitude so that the lateral spreading at the two sides of the rib could be compared.

The results were also compared with those obtained by using the Local-Mode Expansion (LME) technique [9]. Figure 6 compares the longitudinal contour plot of the field in the bottom region. Both methods predicted the increasing lateral confinement of the field as it propagated along the longitudinal *z* direction.

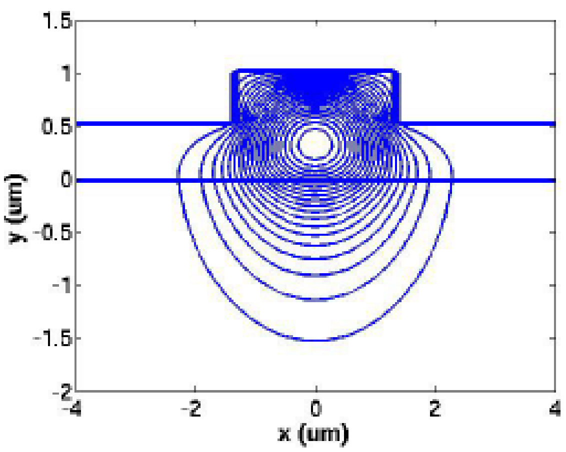

Figure 5a. A comparison of results from the current model with the Finite-Difference Beam Propagation Method (FD-BPM): A field profile contour plot, in arbitrary units, at the transverse output section of the taper using the present model. The angle $\theta = 0.5°$.

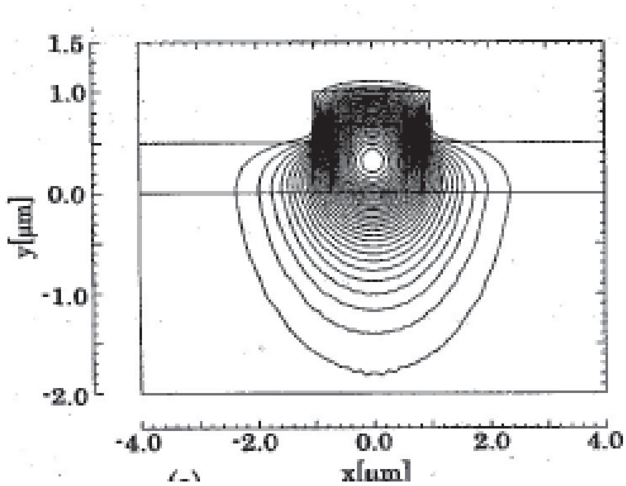

Figure 5b. A comparison of results from the current model with the Finite-Difference Beam Propagation Method (FD-BPM): A field profile contour plot, in arbitrary units, at the transverse output section of the taper using the FD-BPM. The angle $\theta = 0.5°$.

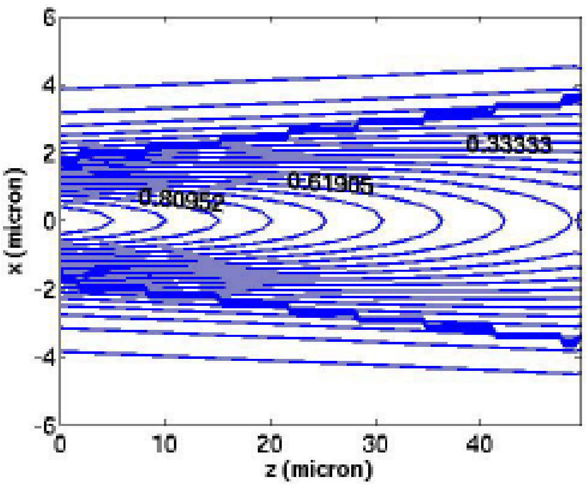

Figure 6a. A comparison of results from the current model with the LME method: A field profile contour plot, in arbitrary units, at the longitudinal cross section underneath the rib, $y = -0.5$ µm in Figure 1, using the present model. The angle $\theta = 2°$.

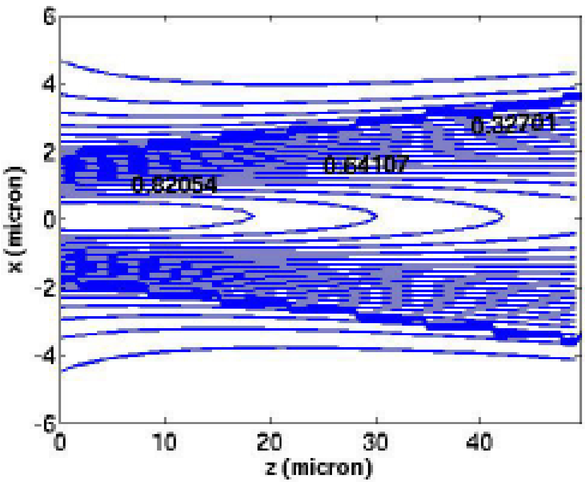

Figure 6b. A comparison of results from the current model with the LME method: A field profile contour plot, in arbitrary units, at the longitudinal cross section underneath the rib, $y = -0.5$ µm in Figure 1, using the Local Mode Expansion Method. The angle $\theta = 2°$.

The observation of the computational runtimes shows that the present method was faster than both the FD-BPM and LME methods. More specifically, in the case of FD-BPM and LME, the structure is divided longitudinally into N sections (usually, the larger the number N, the more accurate the results), and the field is computed for each section. In the case of the present method, the field is computed over all of the entire device once, in a single computer cycle. Therefore, the FD-BPM and LME methods require a computational time of the order at least N times longer than the present method.

5.2 Effect of the Taper Angle on the Field Propagation

The optical propagation for different taper angles is solved in order to examine how the same field launched at the beginning of the taper propagates in different flared structures. Three taper angles were chosen for comparison: $\theta = 0.5°$, $\theta = 2°$, $\theta = 5°$, each small enough to ensure that the paraxial approximation was valid.

In the case of small angles, i.e., $\theta = 0.5°$ (Figure 7a), the field resembled the kind of propagation in a uniform waveguide. Conversely, in the case of a large angle, $\theta = 5°$, the effects of the taper were more evident: on the one hand, the waist of the field increased as the waist of the rib was increased, but on the other hand, the taper enforced more lateral confinement underneath the rib (Figure 7c).

The effect of the taper angle on the field propagation can be quantified by observing the values obtained for the parameter, q, of the slowly varying term $a(z)$ in Equation (26). Table 2 illustrates how larger angles required higher correction terms to the chosen fast propagation term $p = \beta$. The values of q act on both the amplitude and phase

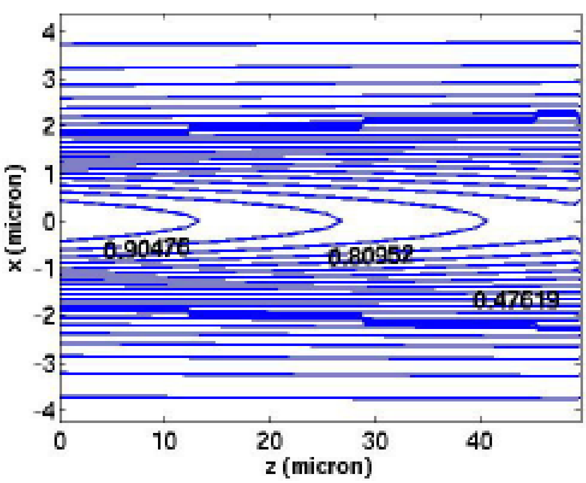

Figure 7a. Field propagation for different taper angles: A field profile contour plot, in arbitrary units, at the longitudinal cross-section $y = -0.5$ µm, for $\theta = 0.1°$.

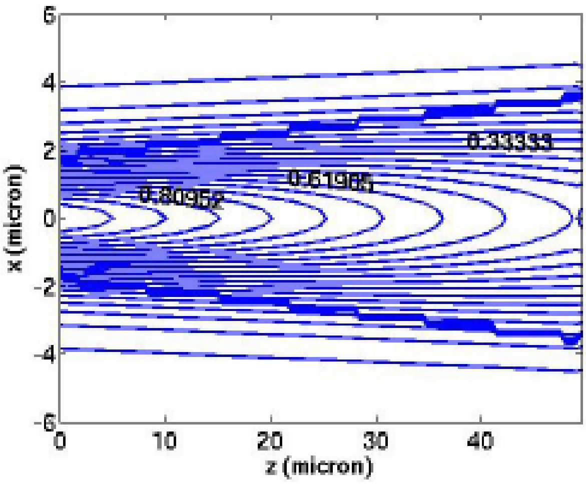

Figure 7b. Field propagation for different taper angles: A field profile contour plot, in arbitrary units, at the longitudinal cross-section $y = -0.5$ µm, for $\theta = 2°$.

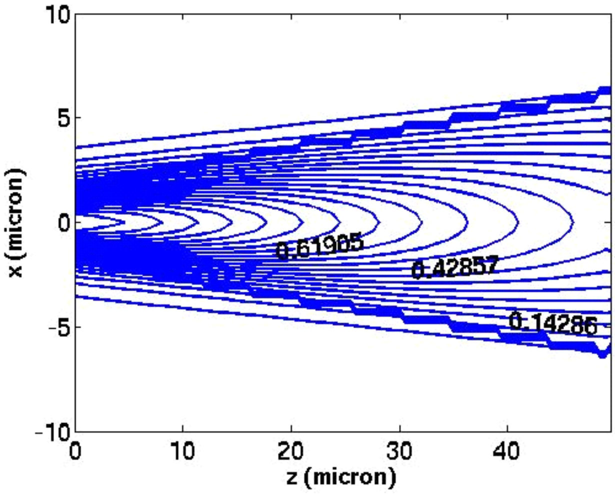

Figure 7c. Field propagation for different taper angles: A field profile contour plot, in arbitrary units, at the longitudinal cross-section $y = -0.5$ µm, for $\theta = 5°$.

of $a(z)$. However, the effect on the phase is small, so that the slowly varying approximation is always verified: in fact, examining the values of q_R in Table 2, it was always true that $q_R / p << p$. Regarding the amplitude, $a(z)$ in Equation (27), the decay is larger in tapers with large angles, i.e., the value of q_I increases with the angle. Since in a large-angled taper the field waist broadens faster, the amplitude must decay faster in order to ensure the conservation of the transmitted energy at any transverse cross-section (z = constant).

5.3 Total Longitudinal Phase Variation

An indirect test of the validity of the model can be obtained by examining the total longitudinal phase variation along the *z* direction. According to the expression utilized for the field inside the rib region, Equations (23-26), the longitudinal phase variation is formed by the contribution of two terms: (a) the fast propagating term, p, and (b) the phase part of the slowly varying term, $a(z)$, i.e., q_R/p.

Angle	q_R	q_I
0.5°	0.257	0.054
2°	0.298	0.149
5°	0.308	0.221

Table 2. The values obtained for $q = q_R + iq_I$ as the taper angle was varied ($p = 14.5197$).

Therefore, the total longitudinal phase variation is

$$\phi_{tot} = p + q_R / p \cdot \tag{37}$$

In the limiting case of a uniform waveguide, Figure 8a (flaring angle $\theta = 0°$), the longitudinal phase variation must be equivalent to the propagation constant of the uniform waveguide, $\phi_{tot} = \beta$. The opposite limiting case, with flare angle $\theta = 90°$, Figure 8b, must be equivalent to the propagation of the initial field into the half-space region $z > 0$, made from the vertical layer stack cladding-core-substrate. This sequence forms a longitudinally uniform slab waveguide and, hence, the total phase, ϕ_{tot}, cannot exceed the effective propagation constant of such a slab waveguide. The total phase variation in Equation (37) for all other intermediate angles must lie between these two limiting cases (Figure 9).

6. Conclusions

The electromagnetic optical propagation inside nonuniform semiconductor waveguides has been investigated. A quasi-analytical model, capable of analyzing tapered-waveguide structures, the solution for which would otherwise be known only in terms of purely numerical techniques, has been suggested. The method introduced thus constitutes a convenient tool for designing and analyzing the feasibility of novel structures.

The electromagnetic analysis focused mainly on the field propagation inside deep-ridge waveguides. The

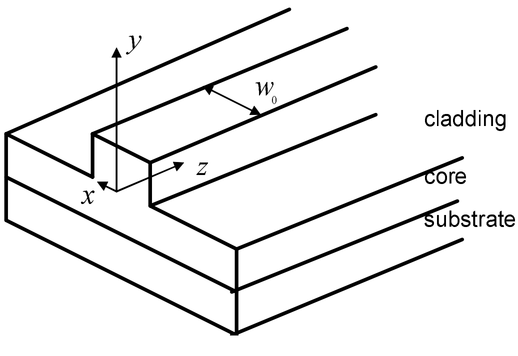

Figure 8a. The $\theta = 0°$ limiting angle for the flared geometry.

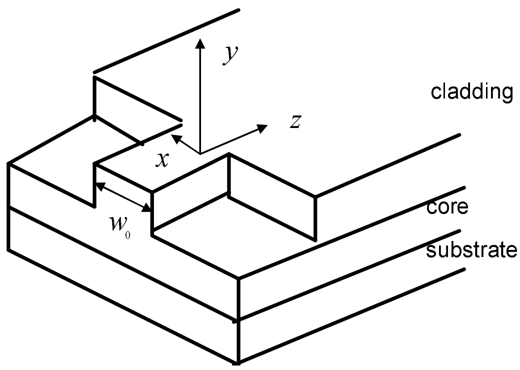

Figure 8b. The $\theta = 90°$ limiting angle for the flared geometry.

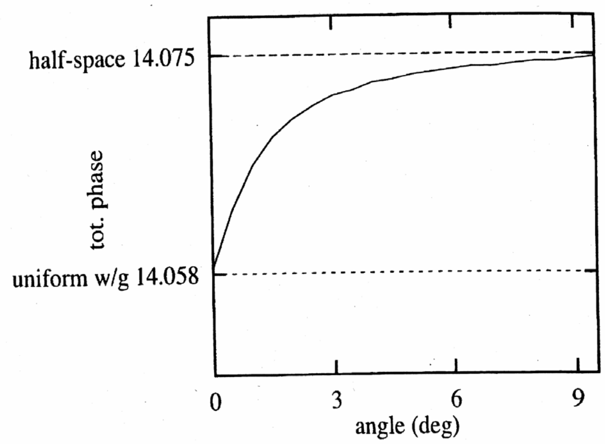

Figure 9. The total phase, ϕ_{tot}, of the propagating field for different flare angles. The total phase varies between the propagation constant of the uniform waveguide and the half-space phase propagation constant (asymptotically).

established Spectral Index Method has been extended and adapted to the analysis of longitudinally nonuniform (adiabatic) waveguides, such as small-angle tapers. Results have been compared against other numerical methods, showing satisfactory agreement. The stronger influence of larger flaring angles on the field propagation has also been investigated and illustrated.

6. Appendix

6.1 Variational Analysis for Uniform Waveguides

In the case of a longitudinally uniform rib waveguide, the exact field solution satisfies Helmholtz's Equation (7). This can be rewritten in the variational form for the propagation constant, β [5, 10, 21], as

$$\beta^2 = \frac{\iint_{A,B}\left[k_0^2\eta^2|E|^2 - \left|\frac{\partial E}{\partial x}\right|^2 - \left|\frac{\partial E}{\partial y}\right|^2\right]dxdy}{\iint_{A,B}|E|^2\,dxdy}. \tag{38}$$

The surface integrals are over the entire transverse section, i.e., the union of the two regions A (top) and B (bottom) in Figure 2.

If the field is not an exact solution, the variational form that makes β stationary can be rewritten in a different form. By multiplying Helmholtz's Equation (7) by $E^*(x,y)$ (complex conjugate) and integrating over each region A and B, the new variational form becomes

$$\beta^2 = \frac{\iint_A\left[E_A^*\frac{\partial^2 E_A}{\partial x^2} + E_A^*\frac{\partial^2 E_A}{\partial y^2} + k_0^2\eta_2^2 E_A E_A^*\right]dxdy}{\iint_A E_A E_A^* dxdy} \tag{39}$$

in region A, and

$$\beta^2 = \frac{\iint_B\left[E_B^*\frac{\partial^2 E_B}{\partial x^2} + E_B^*\frac{\partial^2 E_B}{\partial y^2} + k_0^2\eta_2^2 E_B E_B^*\right]dxdy}{\iint_B E_B E_B^* dxdy} \tag{40}$$

in region B. Integrating Equation (39) by parts, and using the divergence theorem yields, after some algebra,

$$\beta^2 = \frac{\iint_A\left[k_0^2\eta^2|E_A|^2 - \left|\frac{\partial E_A}{\partial x}\right|^2 - \left|\frac{\partial E_A}{\partial y}\right|^2\right]dxdy}{\iint_A E_A E_A^* dxdy}$$

$$-\frac{-\oint_{C_A} E_A^*\frac{\partial E_A}{\partial x}dl - \oint_{C_A} E_A^*\frac{\partial E_A}{\partial y}dl}{\iint_A E_A E_A^* dxdy}. \tag{41}$$

The second and third line integrals in the numerator of Equation (41) are calculated around the boundary of region A, as indicated by the closed curve *CA* (dotted) in Figure 10. Because the field is zero, $E = 0$ along the rib, these two line integrals reduce to the integration along the x axis (the only part of the curve *CA* where the field is nonzero). A similar form of Equation (41) is obtained by solving the integral in Equation (40) in region B. In that case, since the field vanishes at $x = -\infty$, the line integrals around *CB* (the dashed line in Figure 10) reduce to the integration only along the x axis.

Adding Equations (39) and (40), and making use of Equation (38), the variational form, Equation (41), reduces to

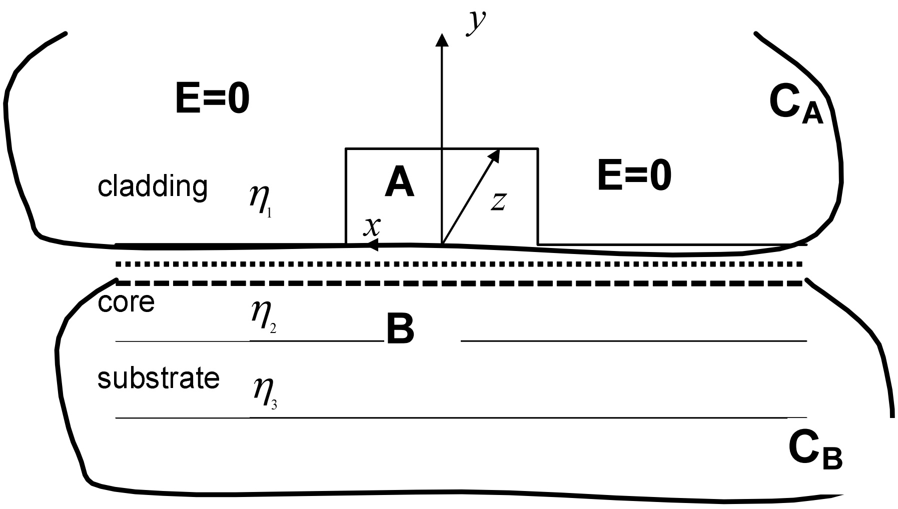

Figure 10. The regions of integration. CA (dotted line) is the boundary of region A; CB (dashed line) is the boundary of region B.

$$\int_{-\infty}^{+\infty}\left[E_A^*\frac{\partial E_A\left(x,y=0^+\right)}{\partial y}-E_B^*\frac{\partial E_B\left(x,y=0^-\right)}{\partial y}\right]dx=0 . \tag{42}$$

If the field expression $E(x,y)$ is an exact solution, i.e., the continuity of the field derivative at the base of the rib can be ensured, then Equation (42) is an identity, and Equations (39) and (40) reduce to the exact form, Equation (38).

6.2 Variational Analysis for Nonuniform Waveguides

The slowly varying term of the field profile, $F(x,y,z)$ in Equation (23), satisfies the paraxial wave Equation (11). Multiplying Equation (11) by F^* (complex conjugate) and integrating yields

$$p^2=\frac{\iiint_V\left[F^*\frac{\partial^2 F}{\partial x^2}+F^*\frac{\partial^2 F}{\partial y^2}+k_0^2\eta_2^2 FF^*\right]dxdydz}{\iiint_V FF^* dxdy}$$

$$-\frac{\iiint_V\left[2ipF^*\frac{\partial F}{\partial z}\right]dxdydz}{\iiint_V FF^* dxdy} . \tag{43}$$

The integrals are over the entire volume space, V, occupied by the tapered-rib waveguide. The first term on the right-hand side of Equation (43) can be treated equivalently to Equations (39) and (40) for the uniform case. Integrating by parts and after some algebra, the variational expression for a tapered geometry is given by

$$\int_{-\infty}^{+\infty}\int_{z_0}^{+\infty}\left[F^*\left.\frac{\partial F}{\partial y}\right|_{y=0^+}-F^*\left.\frac{\partial F}{\partial y}\right|_{y=0^-}\right]dxdz$$

$$+\frac{\iiint_V\left(2ipF^*\partial_z F\right)dxdydz}{\iiint_V\left(F^*F\right)dxdydz}=0 . \tag{44}$$

6.3 Slowly Varying Term for Tapered Waveguides

The field profile inside the tapered rib, region A in Figure 2, has been represented as given in Equation (25). Inserting Equation (25) into the paraxial wave Equation (11), multiplying by $\cos(\pi x/w)$, and integrating over x yields

$$\frac{d^2G(y)}{dy^2}a(z)+\left(k_0^2\eta^2-s_A^2-p^2\right)G(y)a(z)$$

$$=2ip\left[\frac{da(z)}{dz}+\frac{\tan\theta}{w(z)}a(z)\right]G(y) \tag{45}$$

with $s_A=\pi/w_0$.

In Equation (45), it is possible to separate the two variables y and z, and obtain two interdependent expressions for $G(y)$ and $a(z)$, linked through the common complex parameter $q=q_R-iq_I$:

$$\frac{d^2G(y)}{dy^2} + \left(k_0^2\eta^2 - s_A^2 - p^2\right)G(y) = qG(y) \quad (46a)$$

$$\frac{da(z)}{dz} + \frac{\tan\theta}{w(z)}a(z) = -i\frac{q}{p}a(z). \quad (46b)$$

The first equation, Equation (46a) is similar to the slab waveguide Equation (17). The second equation, Equation (46b) provides an analytic form for the slowly varying coefficient $a(z)$, i.e.,

$$a(z) = \frac{1}{\sqrt{w(z)}}\exp\left(-i\frac{q}{p}z\right). \quad (47)$$

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Electromagnetic Spectrum: A Friend of Humanity

A.P.J. Abdul Kalam

I am delighted to participate in the inauguration of the General Assembly of the International Union of Radio Science (URSI). My greetings to the organizers, scientists, educationists, technologists, and distinguished participants, especially delegates coming from various parts of the planet. I particularly greet Dr. A. P. Mitra for his pioneering contribution to radio science. The domain of URSI extends throughout the solar system and out among the galaxies. I am sure that when man reaches the outermost limit of the observable universe, he will be assisted by means of radio for communicating with Earth from the space platform for navigation and control using electromagnetic waves envisaged by Maxwell, J. C. Bose, and Marconi about a century ago. In the eight decades of the existence of URSI, this is the first time the General Assembly is being held in New Delhi, and offers an excellent opportunity to the radio scientists, particularly young scientists, to interact with international experts on state-of-the-art subjects. I have selected the topic "Electromagnetic Spectrum: A Friend of Humanity."

Study of Upper Atmospheric Electrojet

When I see you friends, scientists, and technologists of different disciplines connected with the electromagnetic spectrum, belonging to India and different countries assembled here, I am reminded of an event that took place on November 21, 1963, when I was a rocket engineer at Thumba. This was a very important day in the history of India's space program. On that day, the first sounding rocket from India was launched from Thumba with international cooperation. The rocket and payload were integrated in the Thumba Equatorial Rocket Launching Station (TERLS).

The rocket carried the sodium-vapor payload to study the upper atmospheric winds, and a Longmuir wave probe to study the upper atmospheric electrojet. This first experiment paved the way for many sounding rocket experiments, and TERLS was dedicated to the international scientific community for the unique experiments in the electromagnetic jet, as India was uniquely placed near the electromagnetic equator to study electrojet and related phenomena in the ionosphere. The 1963 rocket launch from Thumba was my first experience with radio propagation and related studies. The starting of the Thumba Equatorial Rocket Launching Station (TERLS) was the seeding of India's space program. Since Prof. Vikram Sarabhai was the founder for the Physical Research Laboratory at Ahmedabad, which was spearheading the space research, TERLS became the laboratory for space experiments.

Here, I would like to mention the contribution of Prof. Vikram Sarabhai, who worked on experimental cosmic rays; Dr. Homi Jegangir Bhabha, who carried out research relating to cosmic radiation; and Dr. Kothari, who is well known for his work on ionization of matter by pressure in cold compact objects, like planets. Apart from their contribution in their areas of specialization, Prof. Vikram Sarabhai sowed the seeds for ISRO; Dr. Homi Jegangir Bhabha, architect of nuclear science, created the Department of Atomic Energy; and Dr. Kothari was the architect of defense science in India. We are proud of the contribution made by these three physicists in building three great scientific and technological institutions to nurture and grow science and technology in our country. Today, the space program, through its sounding-rocket program and geosynchronous-satellite program, is contributing to India's communication covering the major electromagnetic spectrum.

Radio Communication: Lifeline of Projects

In the early days of the space program, for overseas communications we used to have a wireless communication link between Trivandrum and Mumbai for onward

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connectivity to the rest of the country and outside world. Similarly, in the early phase of the missile program, the communication link between Hyderabad and Chandipur, Balasore, was also through wireless sets. In fact, the entire operational communication system between Wheeler Island, mainland, Balasore, SHAR, downrange ships, and Car Nicobar was through HF wireless communication links. These communication facilities made me understand the value of robust noise-free radio communications, and the role of scientists and engineers in realizing these systems for real applications.

Child's Fantasy

Recently, I participated in the award ceremony of Shankar's International Children's Competition at New Delhi. There, I found the visualization of a 13-year-old girl, named Aardhra Krishna, on how the Earth's civilization will look like around 3000 AD. In her imagination, the citizens are forced to migrate to Mars and have made Mars the home to a flourishing civilization. This advanced civilization, which was manmade, comes suddenly under threat created by nature in the form of an asteroid of Jupiter. The asteroid from Jupiter's orbit was coming towards Mars, and Mars was in danger of extinction. The scientists on Mars come up with a very innovative plan of a barrage of nuclear cannons to attack the oncoming asteroid. The bombardment destroys the asteroid and the year 3000 sees a Martian civilization surviving from the fury of nature by an innovative scientific application. What a wonderful scientific and technological thinking of the young mind? Will it all be possible without the availability of radio science, which transmits large amounts of information encompassing the entire solar system? When I was admiring this imagination of the young student, a real-time space experiment took place that gave some meaning to the imagination of the youth.

Combating Asteroids

On July 4, 2005, one important event took place in space. That was the impact of the NASA spacecraft called Deep Impact smashing into the comet Tempel-I, with enough force to create a football-stadium-sized crater with a depth of a 14-story building. The spacecraft was navigated through a ground-control system by an Indian, Shyam Bhaskaran: the Deep Impact traveled 431 million kilometer in 172 days, escaping from the Earth orbit, and intercepted the comet at a straight distance from Earth at 134 million kilometers. The comet was orbiting around the sun every five and one-half years. This is a landmark in radio communications and space exploration.

This event is an important milestone to a develop standardized technique for combating asteroids, which may hit the Earth in the future. One such large asteroid (1950 AD) is predicted with certain probability to hit the earth on March 16, 2880 AD, and nearly one-third of the Earth would be damaged. Like the "Deep Impact," many spacecraft will be required to be sent with high-energy material particles to divert or break the asteroid, to move it out of the dangerous orbit. All this is possible only if we have a reliable robust radio-communication system.

Binary Millisecond Pulsar

One of the important areas of application of radio science in India is the discovery of a binary millisecond pulsar. A pulsar is the remnant of a star that exploded, leaving behind a sphere made up of neutrons just 20 km in size, but weighing more than the sun. The pulsar emits a beam of radiowaves that is seen from the Earth as a pulse every time it rotates. These waves are very weak when they reach the Earth. In order to detect the pulsar, one needs facilities like the Giant Meter Wave Radio Telescope (GMRT). The Tata Institute of Fundamental Research (TIFR) has built this largest radio telescope in the world in a rural area near the village of Khodad, 80 km from Pune. Because of the unique capabilities of our GMRT, scientists from all over the world, including the USA and Canada, visit the center to conduct collaborative experiments. Our scientists played a leading role in the recent discovery of a new "binary millisecond pulsar." Discoveries like the one that has been made by the scientists of the National Centre for Radio Astrophysics of TIFR are important contributions for our radio science. Particularly, I greet the team lead by Prof. Govind Swarup.

Earthquake Forecast and Electromagnetic Phenomena

In many places in our planet, we experience severe earthquakes, resulting in loss of life, loss of wealth, and, in some cases, it destroys the decades of progress made by the country and its valuable civilization's heritage. India has earthquake problems periodically in certain regions. Recently, in our states of Jammu and Kashmir and the neighboring country there was an earthquake. US, Japan, Turkey, Iran, and many other countries also suffer due to earthquakes.

An earthquake is a subterranean phenomenon, and predicting this from space observations would be a great challenge. An earthquake phenomenon in a broader sense starts to produce some precursors before the final rupture, although these precursors generating the pre-rupture stage are not usually regarded as part of an earthquake. The question is whether such precursors really exist or not. So-called pre-slip, envisaged in the dynamic models of the earthquake source, is also a good theoretical possibility, but its observation appears difficult. Precise geodetic measurement by GPS may succeed in the detection of the pre-slip. It seems that electromagnetic phenomena prior to final rupture may be promising.

According to new concepts, earthquakes occur when the crust reaches a critical state. Emission of electromagnetic signals before final rupture is theoretically plausible, notably in the ultra-low-frequency (ULF) range and very-low-frequency (VLF) range.

It is hoped that well-organized electromagnetic monitoring may provide unique observational information on the pre-slips. Atmospheric/ionospheric anomalies still remain unresolved. Post-earthquake disaster recovery, communication, and damage assessment are also areas where space science and communication technology can quickly make their impacts. I am sure radio scientists will definitely be keen to establish the correlation between the occurrence of earthquakes and the electromagnetic disturbances noticed in the specific region.

Disaster Warning System

It is important to mention and acknowledge the contributions made by the amateur radio operators, called hams, who started using radio-communication techniques, particularly the short waves, for long-distance communication through the ionosphere during the first decade of the 20th century. The experience of hams has been used for remote areas, disaster management, and emergency communication the world over during the last hundred years. NASA, ISRO, and other space agencies have honored the hams by launching an exclusive satellite for them, so that they can continue to contribute in the latest trends of satellite communication. During the recent tsunami, it was a coincidence that a Government-of-India-approved amateur-radio expedition was in Andaman and was operational during the disaster, and provided vital communications to the mainland and Indonesia for getting the latest updates on the movement of the tsunami waves and rescue operations. The contributions made by Indian hams in this tsunami have been acknowledged at national and international levels. Amateur radio and remote-area communication are synonymous with emergency communications. It is advisable to promote this hobby to set up amateur-radio stations in Panchayats offices, schools, and hospitals by voluntary agencies who will be able to locate and operate the hams throughout the day and night, on all days. Each Panchayat must encourage this hobby and can make it as a part of the village knowledge center. This will act as an early warning system for the village community in case of an unforeseen eventuality. At this hour, I would like to remember fondly the significant contribution of the late Dr. Shrikant Jichkar in promoting hams in India.

Commercial radio-communication systems operate with high power and frequency diversity with large antennas to improve the reliability of communication. Hams work with limited power under manmade and natural radio interference, and work in difficult circumstances. There is a lot of scope to improve narrowband communication techniques, multi-hop HF communication to remote areas such as Antarctica and Arctic, to improve the quality of ham communication. The members of the radio science community can definitely assist the ham operators through research in establishing low-cost narrowband communication techniques.

Space Industrial revolution

India is in the mission of transforming into a developed country. Many developed countries are racing towards the moon and Mars, which may lead to the next industrial revolution. We also have the opportunity of joining this exclusive club of nations to establish industry on the moon and Mars, with our core competence in space science and technology. The technological challenges are:

- Manufacturing and mining in reduced gravity
- Harnessing helium-3 in the moon for future energy, using oncoming fusion technologies
- Using dry-ice deposits in the moon and Mars as a source of fuel for rocket engines
- Extending the life of satellites in orbit through refueling and repairing
- Using the moon as a space transportation hub
- Building human habitats on the moon, Mars, and also in outer space
- Above all, it is essential to establish reliable space communication systems that will work during all ionospheric disturbances and sunspot activities.

Lunar Telecommunications Base

The characteristics of the moon have a vital implication for space science. As civilization spreads to Mars in five to eight decades, the moon will provide the main link between Earth and her scattered children. The Earth's ionosphere reflects all but the shortest radio waves back to Earth. Earth's dynamic atmosphere prevents the use of lasers for communication into space. On the near-airless moon, this would not be a problem, for the moon's sky is perennially clear to waves of all frequencies.

Thus, the moon will soon become a "telecommunications hub" for interplanetary communications, aiming its tightly focused laser beams to other planets and ships in space. With interplanetary communication systems located on the far side, the moon would also shield these communication stations from the continuous radio emissions from the Earth. The far side of the moon would be the quietest place within millions of kilometers from the Earth, in the sense of radio silence. The coming few decades will provide a great challenge to the radio scientists.

Conclusion: Suggestions for the Conference

Since a large number of radio-science specialists have assembled here, I would like to make the following seven suggestions to this scientific community, which will be useful to the entire mankind.

(1) There has been a revolution in communication science and technology all over the world. The result of this revolution has to reach the common man. This can be in the form of providing affordable high-bandwidth telecommunication to every villager, such as mobile phones with GPRS/CDMA, satellite and FM radio, and IP communication. Research is required to bring down the cost and make this revolution reach seamlessly to the six billion people of the world.

(2) The power of radio communication needs to be utilized for improving the educational standards of our rural masses. Recently, I was addressing the students of three universities in three different regions of the country from Rashtrapati Bhavan. While organizing this event, I found that the connectivity to various corners in the country is yet to become seamless. The radio and space communication specialists have to work together to make high-bandwidth seamless connectivity for the tele-education programs to reach our distant villages with ease through broadband communication.

(3) There are possibilities of correlation between the seismic activities and electromagnetic activity in the particular region. There is a need to have a comprehensive study on the subject. This study should also be linked with the study of other geophysical parameters relevant to an earthquake. This will be a great contribution of the radio science community to mankind towards disaster mitigation.

(4) India is in the process of establishing three science centers in different parts of the country to create a scientific research cadre. URSI can evolve a possible curriculum for study and research in the electromagnetic spectrum in these advanced centers.

(5) I understand that adaptive radio and software radio are among the thrust areas of wireless-communication technologies. In this connection, it is essential for the radio scientists to provide a solution for getting high-bandwidth communication in the wireless spectrum in a mobile environment for an optimal distance without the constraints of line of sight.

(6) Radio scientists and technologists should continue to strive for optimum and bandwidth-efficient communication techniques, even when higher-frequency bands, like millimeter waves, sub-millimeter waves, and quasi-optical waves have started becoming available; there is not much congestion at this stage in this frequency band, but the ever-increasing use of the radio frequency spectrum needs evolution of an allocation criteria.

(7) Solar power satellites may become a reality in a few decades. Because of its potential for transmitting large a volume of power in gigawatts, the possible electric power transmission is through microwave to the Earth. Research is essential to find out the relationship of transmitting frequency with atmospheric structure.

I find that radio science embraces all areas of human activity, such as provision of cost-effective communication to all the citizens, education, healthcare, development, disaster mitigation, earthquake forecasting, and a solution to the energy problem. In overall perspective, connectivity is the key for the growth of the humanity. Hence, radio scientists have a major role to play with their continuing research in promoting economic prosperity to the planet Earth through uninterrupted connectivity. My best wishes to all the participants of the General Assembly of International Union of Radio Science in their mission of making the electromagnetic spectrum a friend of humanity.

May God bless you.

Electronic Connectivity of a Billion People

A.P.J. Abdul Kalam

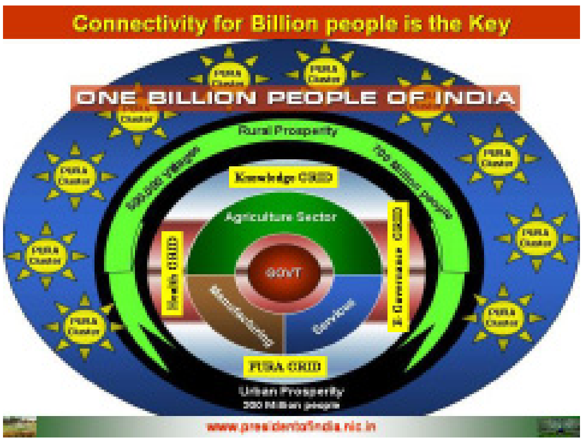
I am delighted to address the General Assembly of the International Union of Radio Science (URSI). My greetings to the organizers and all the members participating in the General Assembly. Today I would like to talk to you on the topic "Electronic Connectivity of a Billion People."

The total land area of India is around 3.3 million square kilometers, with 7000 kilometers of coast line. The altitude of the country varies from the sea level to 8,600 meters. The entire area is spread into deserts, hilltops, mountain tops, sea shores, islands, valleys, and plains. Out of the billion plus population in the country, 70% live in six hundred thousand villages. India is poised to become a knowledge society. Electronic and knowledge connectivity is the key to realize this goal. Connecting one billion people throws up multiple challenges. Now I would like to discuss the relationship between societal transformation and electronic connectivity. It also means the connectivities for a sixth of our planet's population. Perhaps these thoughts may serve as a model for your nation, if needed.

Connectivity Model

The core of this model for Electronic Connectivity for the prosperity of one billion people is the partnership between governmental and multiple institutions in the public and private domains. The strength of this partnership for collaborative growth and economic prosperity is facilitated by the free flow of knowledge and information in a seamless manner, cutting across levels and boundaries embracing all walks of life in the three sectors of the economy such as the agriculture, manufacturing, and services sectors.

In this model, the interconnectivity between these three sectors of the economy is brought about by four grids: namely, the Knowledge Grid, the Rural (Seven thousand PURA) Grid, the Health Grid, and the Governance Grid. Each grid is a system of multiple portals. The aim is to maximize gross domestic production and productivity of the land and people through maximizing the performance of each sector, synergized by the system of inter- and intra-sectoral electronic connectivity to serve one billion people. This will bring prosperity to 700 million people in the rural areas and 300 million plus people in the urban areas. In the process, it will ensure that the lives of 260 million people will be uplifted from below the poverty line.



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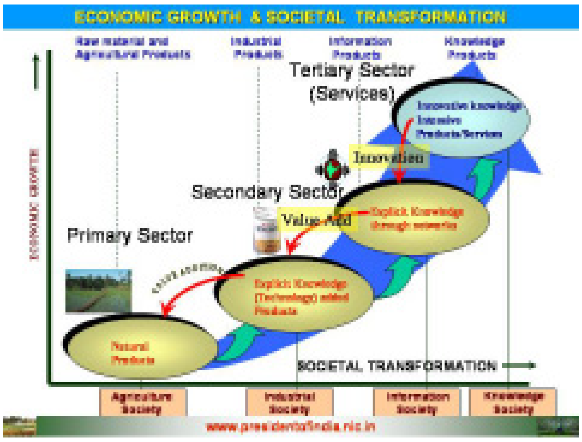
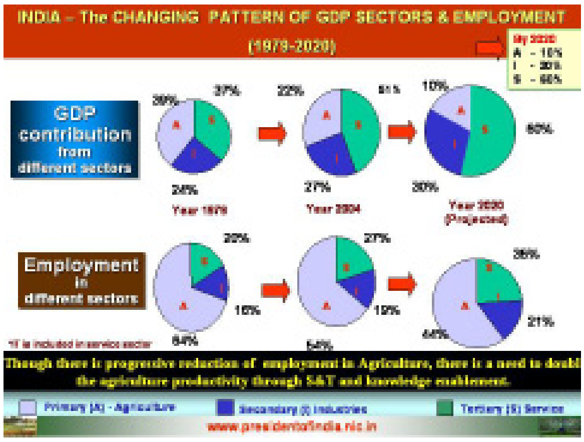
Societal Transformation

Societal transformation and economic growth are interlinked. Knowledge societies enrich information society through innovation. Information society enriches agriculture and manufacturing through value addition. The whole purpose of education in a country is to develop and enhance the potential of our human resources and to progressively transform it into a knowledge society. The knowledge society will be a society producing products and services that are rich in both explicit and tacit knowledge, thus creating value-added products. The real capital of this knowledge society will be its knowledge workers. The society will be highly networked to create a knowledge-intensive environment, along with enabling processes to efficiently create, share, use, and protect knowledge. Our educational system should realign itself at the earliest to meet the needs of the present-day challenges, and be fully geared to participate in the societal transformation.



Changing Pattern of Society

When the world was moving from the industrial to information and knowledge era, we witnessed a changing pattern in the sectoral share of GDP and the number of people employed in each sector. The sectoral share of Gross Domestic Product (GDP) percentage has undergone a considerable change. The contribution of agriculture to India's GDP has reduced from 39% to 22% during the period from 1979 to 2005. During the same period, the contribution of the manufacturing sector has moved from 24% to 27%, whereas the contribution from the services sector has increased from 37% to 51%. There has been considerable change in the employment pattern, also. The percentage of people employed in agriculture has come down from 64% to 54%. Simultaneously, the percentage of people employed in manufacturing has gone up from 15% to 19%, and in the service sector from 20% to 27%. This trend has to continue, and by 2020, our employment pattern should aim at 44% in agriculture, 21% in manufacturing, and 35% in service sectors.



The displacement of 10% of the people from the agriculture sector has to be facilitated through skill-enabling for undertaking value-added tasks in the rural enterprises, so that migration to urban areas is reduced. Instead of persons from the rural areas going to urban towns in search of jobs in the manufacturing and services sectors, PURA (Providing Urban Amenities in Rural Areas) facilitates creation of employment in the rural areas itself. PURA achieves this by providing physical, electronic, and knowledge connectivities to a cluster of villages, thereby leading to their economic connectivity and prosperity. Knowledge creation and knowledge utilization is the key to the success of a PURA program. Now, I would like to talk about the characteristics of the knowledge economy.

Characteristics of the Knowledge Economy

I was studying different dimensions of the knowledge society: how will it be different from the industrial economy. In the knowledge economy, the objective of a society changes from fulfilling the basic needs of all-round development to empowerment. The education system, instead of going by textbook teaching, will be promoted by creative, interactive self-learning: formal and informal, with focus on values, merit, and quality. The workers, instead of being skilled or semi-skilled, will be knowledgeable, self-empowered, and flexibly skilled. The

Characteristics of Knowledge Economy

Characteristics	Industrial Economy	Knowledge Economy
Objective of Society	Basic needs for all through Development	Empowerment
Education	Text Book, Teaching & Formal	Creative, Interactive, Self-learning and Informal with focus on values, merit and quality
Workers	Skilled, Semi Skilled	Flexibly Skilled, knowledgeable, self-empowered
Type of work	Structured & hardware driven	Less Structured & Software driven
Management Style	Directing	Delegative
Quality of Personnel	Performance based	Knowledge based
Impact on Environment and Ecology	Heavy	Strikingly less
Economy	Industrial	Knowledge driven

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type of work, instead of being structured and hardware driven, will be less structured and software driven. The management style will be delegative rather than being directive. The impact on environment and ecology will be strikingly less compared to an industrial economy. Finally, the economy will be knowledge driven and not industry driven.

Connectivity for Universities and Institutions

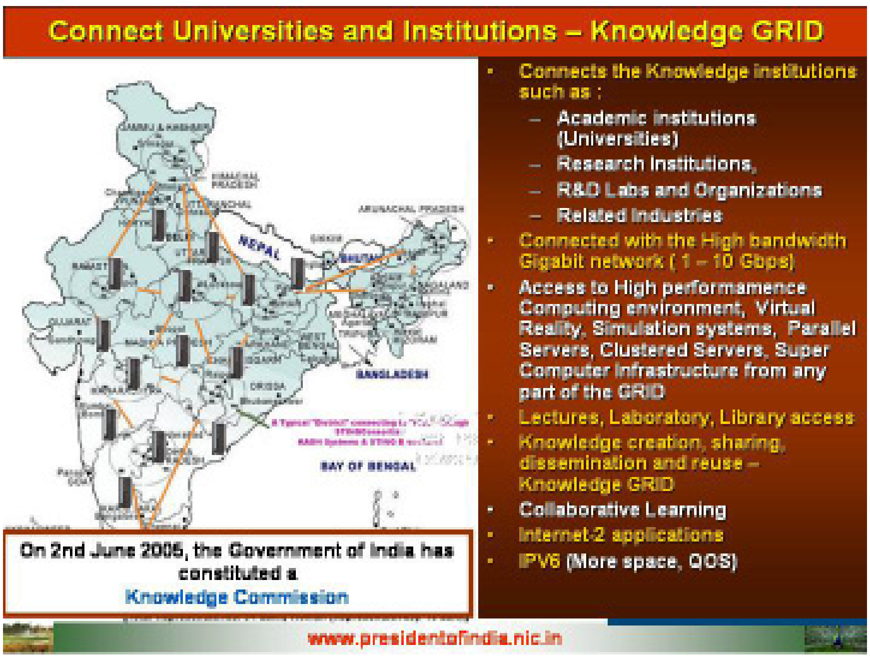
India is now in the process of creating virtual universities and institutions for knowledge sharing, knowledge dissemination, and knowledge reuse. While it is known that the virtual universities provide us with technologies of the future and the most economic way of scaling high-quality education in the country, they are no substitute for the campus-based education. The challenge before the virtual universities is to provide the best of breed of both the worlds. In this process, we could plan an optimum mix of direct-contact hours between the students and the teachers, and also amongst the students themselves. These interactions should also be used as a platform to excite the students to take to learning in the new paradigm.

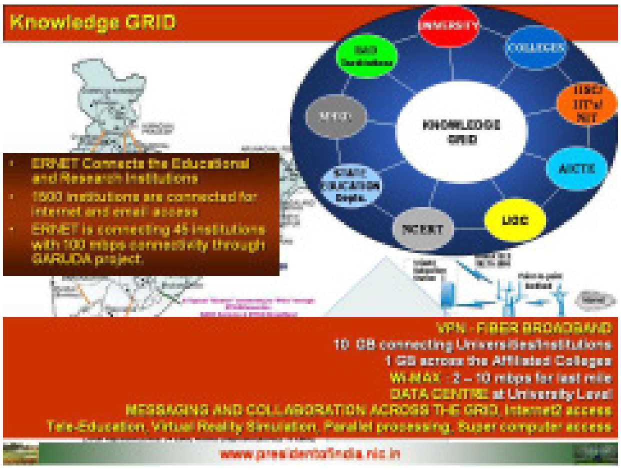
In the world of virtual universities, the equitable access to all its participants is the primary goal. Unlike in the real world – the equitable access is always the democratic average – in the virtual universities, the equitable access always means the equitable access to the best resources – be it the teachers, be it the library, be it the laboratory, available across the network. In effect, the network brings the best of its participants to every one of its participants. The three phases of learning are the lectures, library, and laboratories. They require increasing bandwidth, from a few 100s of kilobytes for the lectures to a few megabytes for the formal digital libraries and the informal world of knowledge from the Internet, to gigabits of connectivity for remote laboratories in the world of high-precision science and engineering. As the bandwidth becomes cheaper and available in abundance, universities should be able to run remote instruments and facilities as complex as NMR to wind tunnels. These are applications that can make a difference in how we engage in teaching, learning, and research in higher education.

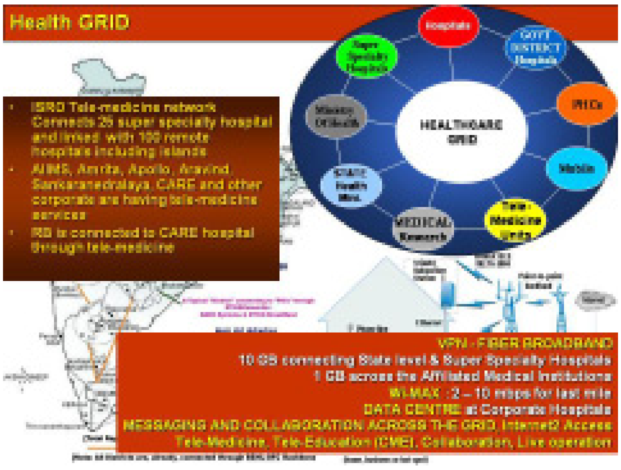
Internet2

The world is moving towards Internet2 applications. Internet2 applications require advanced networks. That is, these applications will not run across commercial Internet connections. Internet2 applications require enhanced networking functionality – such as high bandwidth, low latency (delay), or multicast – not available on our commercial Internet connections. Internet2 is about everything we do in higher education. Therefore, we encourage and support applications development in all disciplines, from the sciences through arts and humanities. Whether you're in the classroom, the laboratory, the library, or the dorm, you should be able to access Internet applications that provide benefit.

This will ultimately provide equitable access to the entire education system, beyond just the lectures and the lecturers. Thus, the bandwidth is the demolisher of imbalances and a great leveler in the knowledge society. We have rich knowledge institutions, but what we have to add is connectivity. This connectivity today is technologically possible, but would need creation of high-bandwidth reliable network infrastructure, to the extent of minimum 10 Gigabits per second all through the country, to provide uniform access of knowledge in different regions, leading to the creation of a Knowledge GRID.







ERNET is the Educational and Research Network of India, connecting 1500 institutions for Internet and intra-connectivity for e-mail and other collaboration. Presently, ERNET is connecting around 45 institutions across the country in a high-bandwidth network, with 100 mbps connectivity under the GARUDA project. This will become the part of the proposed Knowledge GRID.

So far, I have discussed with you knowledge institutions. Now, I would like to discuss establishing the next network in the system of GRIDs across the country, namely, the Health Grid.

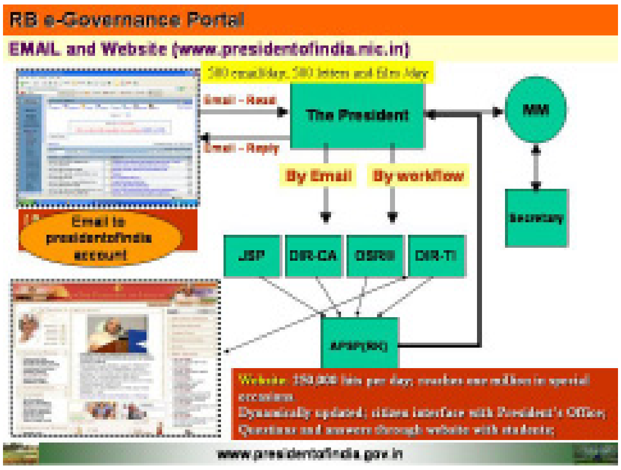
Health Grid

The Indian Space Research Organization, through their INSAT network, has connected 25 major hospitals in the mainland. From there, they are providing telemedicine connectivity to remote areas, including our islands. The Rashtrapati Bhavan Clinic is also connected to the CARE Hospitals Hyderabad through a telemedicine facility. Also, there are a number of public and private initiatives, such as AIIMS, Apollo, Narayana Hridayalaya, Sankara Nethralaya, and Aravind Hospitals. There are exclusive telemedicine, etc. The mission of telemedicine with multiple grids is gaining momentum, and it will spread to all the equipped Primary Health Centres in the country, medical colleges, and research institutions in due course.

We need to establish a Health GRID, connecting the various health-care institutions with regard to the super-specialty and general-medicine areas. Also, healthcare training institutes, such as nurses, para-medical staff and doctors, and the medical research institutions should be networked to Health GRID. This will enable unique case studies and experiences to be exchanged between the super specialists through this health grid. It will also be possible to conduct conferences of specialist doctors from multiple centers to discuss the critical disease patterns and provide treatment. In the Rashtrapati Bhavan Web site, we have a Virtual Vision applet, which will speech-enable any Web site for the benefit of visually challenged persons [http://www.presidentofindia.nic.in/?referrer=presidentofindia_com; link at bottom of "Recent Events"]. Thousands of people have already downloaded it and are using it.

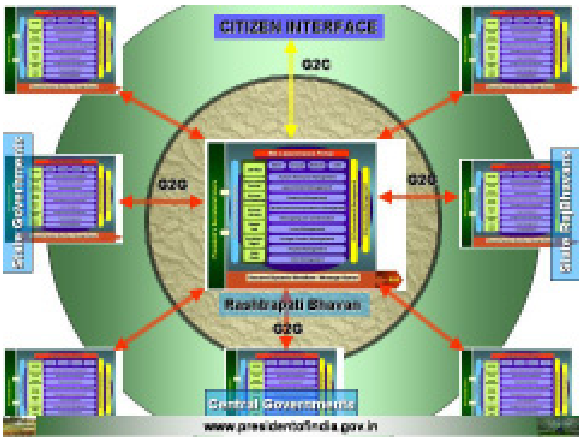
e-Governance Grid

As you are aware, with the arrival of space technology, there has been an explosive growth of many low-bandwidth networks for specific missions. There is a need to integrate the available networks and make them fast.



Let me first describe my personal experience in setting up and operating a typical e-Governance Portal, established at Rashtrapati Bhavan.

Rashtrapati Bhavan has introduced connectivity with our citizens, institutions, universities, government departments, and multi-lateral agencies during the last three years. For enabling such connectivity, all the important events in which the President participates are brought out in the Web site (www.presidentofindia.nic.in) as soon as the functions are over. Today, on an average, this Web site has a hit rate of over two hundred and fifty thousand per day. On certain special occasions, like Independence Day and



Republic Day, it touches nearly a million hits. In addition, I receive over 500 e-mails and 500 letters on an average from various people from all over the country and abroad. I also receive 100s of questions from the students and children every day. We have built in an e-Governance system to study all the correspondence on a day-to-day basis, analyze, prioritize, verify, and determine the action requirements to be taken by Rashtrapati Bhavan and other agencies of government and the relevant institutions, both public and private. We have now established a less-paper dynamic and secured workflow system for the file movements. As the part of the e-Governance portal inauguration, all the departments within Rashtrapati Bhavan were connected, and the school, clinic, and garage located in the President Estate were also connected. We have a fiber broadband POP (point of presence) that can connect up to 64 Mbps. We have established within Rashtrapati Bhavan facilities for G2G and G2C connectivity, and we are in the process of establishing the high-bandwidth broadband VPN connectivity with central and state governments and other relevant institutions for seamless flow of information within the existing systems and procedures of governmental functioning. This will soon become the part of the e-Governance GRID.

Connectivity and Collaboration at RB

Apart from this, we have had interactive collaborative conferences with a number of institutions in India and abroad. The typical among these are:

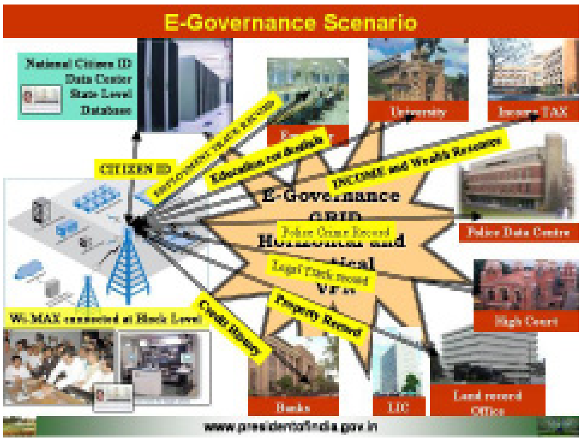
a. Interactive sessions with engineering students of Punjab colleges through VSAT and leased line.
b. IGNOU connectivity to 100 locations through EDUSAT. So far, we have connected 40 locations.
c. Inauguration of Virtual University of Madras, Calcutta, and Mumbai Universities with Anna University, Madurai Kamaraj Universities, and 40 learning centers of IGNOU. Where I took the inaugural class through EDUSAT, tele-education delivery system and the multimedia studio at Rashtrapati Bhavan using *PowerPoint* presentation for over 15,000 students and answered over 20 questions, referred my talk from the Web site, referred some pages from two books from RB digital library, drawn the GSLV and Payload in the smart board. A virtual classroom has been created during my one and a half hour interaction. The EDUSAT provided the necessary connectivity for the tasks.
d. Interaction with the Carnegie Mellon University, Pittsburg, USA, for digital library conference through the Internet, three inaugural addresses through video conference with US institutions.
e. Pan-African Network – a tele-education delivery system presentation to 28 African Union ambassadors through EDUSAT and Wi-MAX connectivity using the tele-education studio at RB.
f. 25 national and international conferences in India through VSAT, ISDN with interactive sessions with educationists, teachers, space scientists, doctors, business communities through NASSCOM, judiciary and science writers.
g. Interaction with Amrita Village Resources Centres and Kerala schools through EDUSAT, Loni Village connectivity through RF in Maharashtra.
h. Interaction with Periyar PURA and MSSRF Village knowledge centers.

During these interactive discussions and conferences, I have used all the available electronic connectivities through VSAT, EDUSAT, and leased lines, ISDN, Internet, and Wi-MAX. Presently, all these connectivities are fully established at Rashtrapati Bhavan and are highly effective. With the last three years of experience, I realize that for promoting effective, quality, and actionable communication we have to use multimedia comprehensively. This will be determined by the bandwidth availability.

No country has so far implemented an e-governance system for one billion people. It is a big challenge before us. Let us take an example to clarify the connectivity challenges of the country.

Connectivity for E-Governance

Good governance is being recognized as an important goal by many countries across the world. They have taken up specific initiatives for open government. Freedom of information is being redefined and supported by detailed guidelines. The Internet revolution has proven to be a powerful tool for good governance initiatives. An important dimension of the Internet potential is the possibility of providing services anytime, anywhere. Along with this, there is a conscious effort to put the citizen as the center of focus of the governance. Citizens are being perceived as customers and clients. E-governance has to be citizen friendly. Delivery of services to citizens is considered as a primary function of the government. Particularly in a democratic nation of a billion people like India, e-governance should enable seamless access to information and seamless flow of information across the state and central government in the federal setup.



also has an Internet data center with 80 terabytes of storage and more than 150 servers connected for the missions such as election data and event-oriented projects for the government organizations.

To establish a system such as what I have visualized, we need a high-bandwidth broadband connectivity across the many government departments such as state and district administration, election commission, universities, banks, home/police departments, insurance companies, etc. This scenario requires a vertical and horizontal grid established across various institutions. Hence, we can draw information and feed information from these GRIDs for seamless flow of data to achieve the goal of good governance.

Typical Scenario

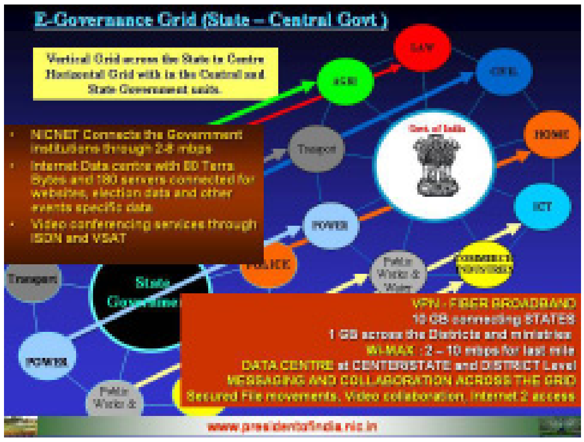
I visualize an election scenario where a candidate files his nomination from a particular constituency. Immediately, the election officer verifies his/her authenticity from the national citizen ID database through multifactor authentication, through a multipurpose citizen ID card. His education credentials come from the university records. His track record of employment comes from various employers with whom he had worked. His income and wealth resources come from the income-tax department, and other sources. His property record comes from the registration of land authority across the country. His credit history comes form various credit institutions like banks. His/her civic consciousness and citizenship behavior comes from the police crime record. His legal track records come from the judicial system.

All the details arrive at the computer terminal of the election officer within few seconds, automatically, by the act of e-governance software agents, which crawl across the various state and central government Web services directories through the network GRID, and collect the information automatically, and present the facts in real time with out any bias. Artificial intelligence software analyses his credentials and gives a rating on how successful he will be as a politician. Election officer sitting at the remote block of the country decides on the spot and the election process starts. All the voters vote from their home through virtual polling booths. Is it a dream? Is it possible? If possible, when shall we have it? Can we provide good governance to our one billion people? Can the governance speed up the delivery system? Can the governance differentiate between genuine transactions and spurious transactions? Can the governance ensure immediate action for the genuine cases that satisfies the check list for a particular service and suspend the action on spurious transactions? Can this be done by e-governance at a cost affordable by our nation? If we have this system implemented, then I can call this as a true e-governance system for the citizen.

NICNET, in India, is providing connectivity to government organizations using 2-8 mbps connectivity. It

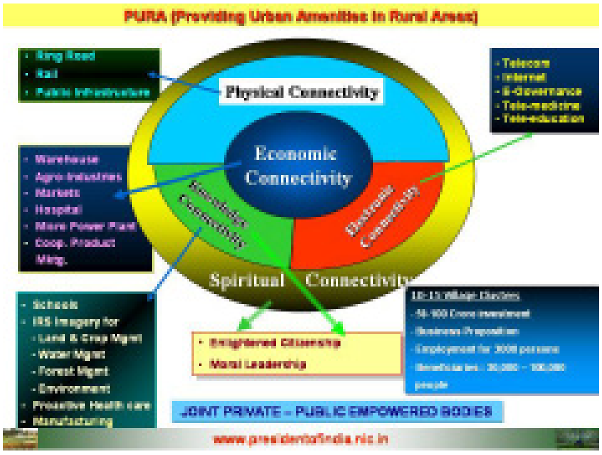
Characteristics of the Rural (Seven-Thousand PURA) Grid

For providing the knowledge connectivity to the PURA complexes, village knowledge centers will act as the frontline delivery system. I visualize establishment of a village knowledge center in the Village Panchayat to empower the villagers with the knowledge and to act as a local center for knowledge connectivity for the villagers within the overall framework of PURA.



Village Knowledge Center

The Village Knowledge Center should provide the essential data required for the targeted population, such as farmers, fishermen, craftsmen, traders, businessmen, entrepreneurs, unemployed youth, and the students. It has to be acquired by visiting the village, talking to the rural people, by understanding their requirements and core competence. Providing meteorological data for both farmers and fishermen has to be area specific, covering, say, 20 or 30 villages in the vicinity of the seacoast or in the farming area. Local relevance of information offered is essential. Users have simple needs of information, but often it is a tough problem for system integrators because of the need of updating of data. Trained manpower with experience has to



be deployed to generate information that can explain to the people in simple terms the meteorological data, weather data, marketing data on fish, agricultural, and other rural commodities. These data have to come from various connected institutions, which provide the service to the people on a timely basis, periodically. But the transformation of data into user-friendly information on a regular updated basis is the real challenge. The main focus of the village knowledge center should be to empower the youth to undertake development tasks of the villages and establish the rural enterprises that will provide large-scale employment to the youth of the village. So, it is essential to skill-enable and knowledge-enable through the academic institutions, industry, banking, and marketing institutions. The virtual knowledge center should act as a facilitator. Blended knowledge is a better knowledge.

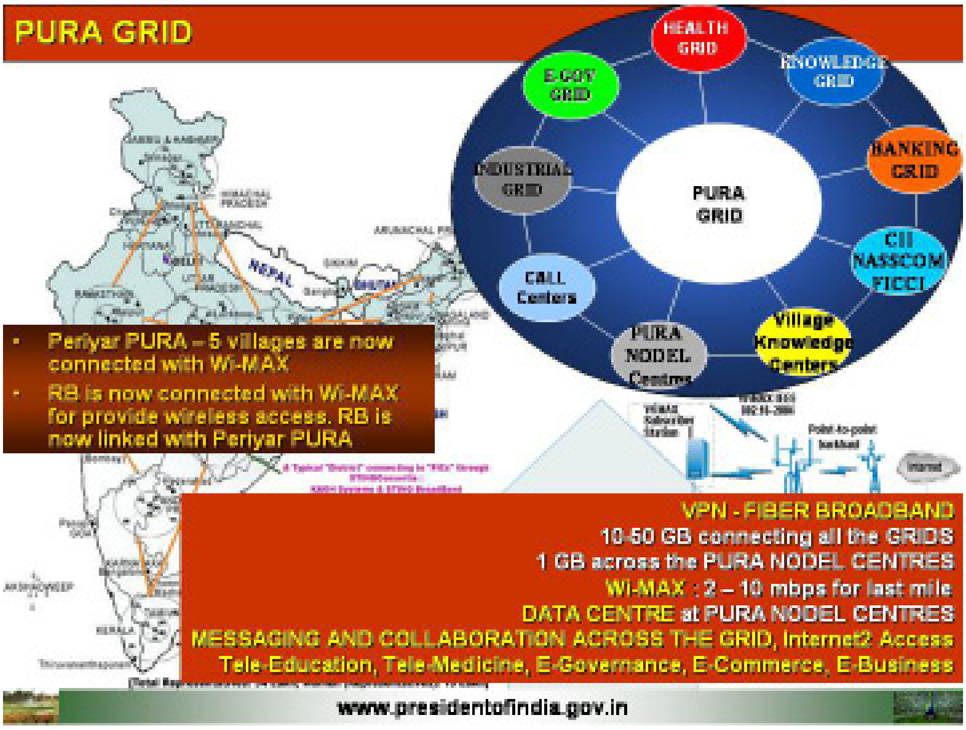
Infrastructure and Connectivity

A low-cost multi-task handheld computer with GPS and wireless mobility should be developed by the private industries and organizations, and should reach the fishermen and farmers in different parts of the country. They should add value to this tool for their benefit to increase their earning capacity. The village knowledge center should have a computer terminal, wireless (Wi-Max) connections or fiber broadband or satellite connectivity to connect to the Nodal Centers for acquisition of knowledge and dissemination of updated real-time data.

Nodal Data Center and Services

Each PURA should have "Nodal PURA Knowledge Data Centers," which should be the hub for all the activities creating the vibrancy in the PURA as a viable, sustainable business proposition. These "Nodal PURA Knowledge Data Centers" should be linked to the nominated domain service, providing organizations in agriculture, including fisheries, cottage, and small-scale industries and commerce, education and human-resource development and health-care sectors. These domain institutions will have a mechanism to create continuously updated information systems needed to service the village knowledge centers.

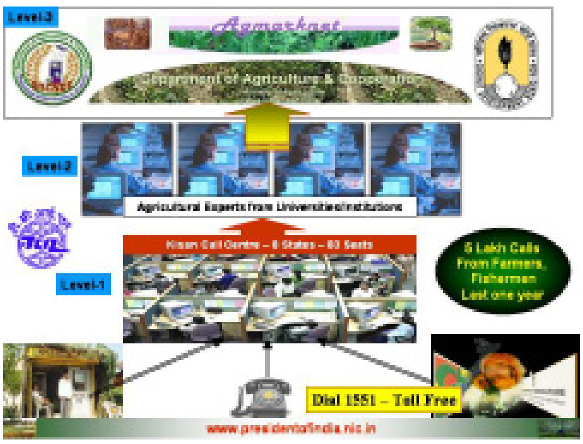
With this experience, we should make the village resource centers as the knowledge centers in the villages in a fully connected environment with a mission of skill and knowledge enabling people leading to sustainable economic development in the rural areas.



Domain Service Provider for PURA Complex

I have studied a system which is working and used by the farmers and fishermen in different parts of the country. This is called the Kisan Call Centre (KCC), established by the Ministry of Agriculture in partnership with TCIL (Telecommunication Consultant India Ltd.), a government enterprise under the Ministry of Communication and Information Technology.

The Kisan Call Centre offers three levels of interaction and support in the agriculture, fisheries, and animal husbandry domains through the nationally nominated experts and corresponding directorates at the central level. In the last one year of its operation, the call center has provided consultancy, information, assistance, and guidance to over half a million callers from the villages of eight states.



Anywhere in India, people can call 1551 as a toll-free number to get the services. The top users of the scheme are Maharastra and Tamil Nadu, followed by UP and Rajasthan.

PURA Nodal Knowledge Data Centre

As we have seen in the Kisan Call Centre setup, similar domain-service-provider call centers are required in the fields of commerce and industry, entrepreneurial skill development and employment generation, travel and tourism, banking and insurance, meteorological forecasting, disaster warning systems, education and human resource development, and health care.

These Call centers will act as a service provider to the PURA Nodal Knowledge Data Centers, located in the PURA complexes, which, in turn, will provide the area-specific and customized knowledge to the village knowledge centers in the villages in a holistic manner. This delivery will depend on the availability of robust connectivity to different parts of the country. This forms the PURA GRIDs, which draw information from the other GRIDS and will act as a catalyst for the societal transformation in the rural areas.

So far, I have discussed with you the necessity for establishing various GRIDs by citing examples of how connectivity is important, one in e-governance and the other with knowledge institutions. Now, I would like to discuss how to connect all the GRIDs across the country to fulfill the mission objective of entering into a knowledge society.

Inter-GRID Connectivities: Societal GRID

So far, we have discussed the connectivities within the various proposed grids, that is, intra-grid connectivities. However, to maximize the synergy between the grids, leading to maximization of GDP and productivity, there is a need for inter-grid connectivities, which may be called a Societal Grid. Knowledge sharing, knowledge utilization, and knowledge reuse are very vital to all constituents of the society for promoting nonlinear growth. The Societal Grid consists of:

1. **Knowledge Inter-connectivity GRID:** Interconnecting universities with socio-economic institutions, industries and R&D organizations.
2. **Health Care Interconnectivity GRID:** Interconnecting the health-care institutions of government, corporate and super specialty hospitals, research institutions, educational institutions, and, ultimately, pharmacy R&D institutions.
3. **e-Governance Inter-connectivity GRID:** Interconnecting the central government and state governments and district and block-level offices for G2G and G2C connectivity.
4. **PURA Knowledge GRID:** Connecting the PURA Nodal centers with the village knowledge centers and domain service providers. Since this is the backbone for rural development, all other GRIDs will infuse the knowledge into this GRID for sustainable development, healthcare, and good governance. For example, five of the Periyar PURA villages have now connected using Wi-MAX connectivity.
5. **Integrated village knowledge centers** will act as an interconnected delivery mechanism for tele-education, tele-medicine, and e-governance services apart from individual access by the people, within and between the village knowledge centers through the PURA Grid.

Importance of High Bandwidth

These connectivity GRIDs will connect the billion people using the available networks such as VSAT, fiber broadband, wireless, and through mobile phones. Many options exist for the last-mile connectivity in India. While wireless 802.11 and 802.16, the Wi-Fi and Wi-Max, are becoming very popular everywhere, we still feel that there are enough opportunities for the fiber-to-the-home users, as well. This is due to the fact that the cost of fiber has come down drastically, as also has the cost of laying the cables. This has the potential to give near-terabit connectivity or almost unlimited bandwidth to every rural and urban home.

In India, we already have more than 400 channels of TV being beamed to every home. The Direct-to-Home (DTH) TV has become a reality. Imagine the high-speed fiber to the home carrying all the entertainment, education, e-governance, e-commerce, health care, newspaper, telephone, and all other forms of text, voice, and video data, both synchronous and asynchronous data, being pumped in and out through the fiber to the house! This will create a world of unlimited bandwidth.

In order to make the country the most advanced knowledge society, we should aim at making the bandwidth available without hindrance and at no cost. Making the bandwidth available is like the government laying the roads. Movement of materials through these roads creates wealth in the industrial economy, and the government recovers more than the investment on the roads by way taxes and enhanced prosperity of its people. In the modern digital economy, driven by knowledge products, bits and bytes traverse the network and create wealth, and this will recover the cost of investments in the bandwidth.

Conclusion

The electronic connectivity for one billion people must transform into a network and provide a seamless access between

- the knowledge creator that is the universities, institutions, and government;
- The R&D institutions, public and private sector industries that convert knowledge into products and services;
- The knowledge consumer that is the citizens.

With the dawn of the twenty-first century, the world has entered an era of depleting energy and water resources. Endemic oil shortages are looming large, and the need for renewable energy substitutes, such as bio-diesel, have become mandatory. However, a massive program for production of bio-diesel calls for deep integration and system engineering between various sectors of the economy.

To illustrate India's response to the oil crisis, as it affects our transportation sector, let us take a large-scale mission in the Jetropha plantations for generation of bio-fuel, partially or totally substituting for diesel. The Jetropha plantation technology and methods are provided to the farmers by the agricultural university. The R&D institutions in the country work on converting Jetropha seeds into bio-fuel and byproducts, and also enhancing the combustion efficiency of internal combustion engines running on bio-fuel. Rural small-scale industries will establish enterprises for producing bio-fuel and marketing it. The rural development and Agricultural Ministry, in coordination with the Ministry of Petroleum and Natural Gas and the state governments, would need to provide the policy framework for pricing and use of bio-fuel. Also, there is a need for the university to work on the development of a variety of hybrid seeds for increasing the productivity of oil from the seeds. These complex interactions between various institutions have to take place as public-private partnerships through electronic connectivity. Such a model is being developed, and there are indications that the work already done in five states is accelerating unprecedented progress in this area over the last one year.

Thus, we can see that there is a closed cycle between the farmer, researcher, educational institutions, industry, government, and the user, requiring a variety of knowledge inputs at different stages, which can be made available effectively only if all these institutions are brought under a knowledge grid, and a common communication protocol with high-speed access is made available to them.

Connectivity is the key to the conversion of a billion people into members of a knowledge society. Connectivity for the billion people is the connectivity of the planet: it means we are connecting 600,000 villages in a single country. This experience will become the foundation for other continents. The major effort should be towards making the bandwidth free and unlimited and available on demand for a billion people. Bandwidth will determine the prosperity level of our country.

My best wishes to the members of the International Union of Radio Sciences in their mission of working towards a fully connected, prosperous, safe, and happy planet.

May God bless you.

XXVIIIth General Assembly

BUSINESS TRANSACTED BY COMMISSION D

Chair: Prof. Peter Russer
Vice Chair: Dr. Frédérique de Fornel

Commission D Business meetings were held by Prof. Peter Russer (Chair) on the following two days:
Meeting 1: Monday, October 24th, 18:00-19:30h
Meeting 2: Wednesday, October 26th, 18:00-19:00h

The following issues were discussed and decided upon.

I. Triennial Activity for 2002 – 2005

Pr. Peter Russer reported on:

1. The growing importance of wireless and optical communication technology has led to continued strong interest in the activities of Commission D, "Electronics and Photonics".
   Commission D has continued the successful policy of providing technical co-sponsorship to a number of meetings of interest to Commission D while focusing financial sponsorship on the established International Symposium on Signals Systems and Electronics, ISSSE, jointly sponsored with Commission C. For this triennium we also provided financial sponsorship to the 2004 Asia-Pacific Radio Science Conference (AP-RASC'04).
2. 2004 International Symposium on Signals, Systems and Electronics (ISSSE'04) in Linz, Austria
   The 6th International Symposium on Signals, Systems, and Electronics, ISSSE 2004, was held in Linz, Austria on August 10-13, 2004. ISSSE is an international symposium held once every three years. This symposium is organized and sponsored by the International Union of Radio Science (URSI), Commissions C and D.
   After the review of nearly 130 submissions, 89 were accepted for presentation. Authors came from more than 20 countries, thereof 63% from Europe, 29% from Asia, and 8% from North America. During the symposium two best papers have been awarded.
3. The following conferences were supported by Commission D:
   1. MMET'02, Int. Conf. on Mathematical Methods in Electromagnetic Theory, Kiev, Ukraine, 10-13 September 2002,
   2. Getting the Most out of the Radio Spectrum, London, U.K., 24-25 October 2002,
   3. ISMOT 2003 - 9th Int. Symp. On Microwave and Optical Technology, Ostrava, Czech Republic, 11-15 August 2003,
   4. 11th MICROCOLL, Budapest, Hungary, 10-11 September 2003,
   5. CAOL 2003, Int. Conference on Advanced Optoelectronic and Lasers, Alushta, Crimea, Ukraine, 16-20 September 2003,
   6. Telecom 2003 & JFMMA, Marrakech, Morocco, 15-17 October 2003,
   7. MSMW'04, Fifth Int. Kharkov Symposium on Physics and Eng of Microwaves, Millimeter- and Submillimeter-Waves, Kharkov, Ukraine, 21-26 June 2004,
   8. ISSSE'04, International Symposium on Signals, Systems and Electronics, Linz, Austria, 10-13 August 2004
   9. AP-RASC 04: 2004 Asia-Pacific Radio Science Conference, Beijing, China, 20-23 August 2004,
   10. ISMOT 2005 - 10th International Symposium on Microwave and Optical Technology, Fukuoka, Japan, 22-25 August 2005,
   11. CAOL 2005, Int. Conference on Advanced Optpelectronic and Lasers, Yalta, Crimea, Ukraine, 12-17 September 2005,

II. New Chair and Vice-Chair for 2005-2008

Two candidates were presented:

- Franz Kaertner, Full Professor , Department of Electrical Engineering and Computer Science, M.I.T., Cambridge, MA, U.S.A.
- Hiroyo Ogawa, Director of Yokosuka Radio Communication Research Center, National Institute of Information and Communications Technology

The voting was held for the incoming Commission D Vice-Chair 2005 – 2008. The successful candidate was Franz Kaertner.

III. Appointment of Commission D Editor for Review of Radio Science

The Commission D Editor for RRB will be Prof. F. Kaertner (incoming Vice-Chair).

IV . Appointment of Commission D Associate Editor for Radio Science Bulletin

The Editor for the Radio Science Bulletin 2005-2008 will be Professor S. Tedjini.

V. Terms of Reference

The Terms of Reference were reviewed and discussed.

Considering:

1. That nanoscale devices and quantum devices are of growing interest in research;
2. That this development has to be considered in the terms of reference of the Commission D.
3. That the complete spectrum of frequencies from low frequencies up to the optical region has to be considered.

Resolve

1. That the terms of reference have to be modified on item (c) after "electronic and photonic devices" in adding: *down to nanoscale including quantum devices* has been added; and
2. That the expression *covering all frequencies, including those in the microwave and optical domains* has been replaced by *from the low frequencies to the optical domain*.

The new terms of reference shall be (changes marked in italic):
The Commission promotes research and reviews new development in:
(a) Electronic devices, circuits, systems and applications;
(b) Photonic devices, systems and applications;
(c) Physics, materials, CAD, technology and reliability of electronic and photonic devices *down to nanoscale including quantum devices*, with particular reference to radio science and telecommunications.

The Commission deals with devices for generation, detection, storage and processing of electromagnetic signals together with their applications *from the low frequencies to the optical domain*.

Termes de référence de la Commission D
Les nouveaux termes de référence devraient être : (changements indiqués en italique):
La Commission tend à promouvoir les recherches et à faire le point des nouveaux développements dans les domaines suivants :
(a) Dispositifs électroniques, circuits, systèmes et applications;
(b) Dispositifs photoniques, systèmes et applications;
(c) Physique, matériaux, CAO, technologie et fiabilité des dispositifs électroniques et photoniques *jusqu'à l'échelle nanométrique incluant les dispositifs quantiques* présentant un intérêt particulier pour la radioélectricité scientifique et les télécommunications.

La Commission étudie les dispositifs pour la production, la détection, le stockage et le traitement des signaux électromagnétiques, ainsi que leurs applications *des basses fréquences au domaine optique.*

VI. Scientific Program of the next General Assembly

For the next General Assembly in 2008, the paper submission was discussed and agreed upon, that a centralized electronic submission and review system be used. It was also agreed on that a one time submission of a paper (up to four pages), plus an abstract in the specified format, be used in the program.

A few scientific sessions were proposed for the next General Assembly:

- Nanoelectronics and Nanophotnics.
- Nanovacuum technology
- Joint commission on SPS
- Terahertz technology
- Metamaterials
- Joint session D-A-B(?)-C(?) simulation and characterization of mixed signals
- Microwave Photonics
- Reconfigurable surfaces
- RFIDs Radio Frequency Identifier
- Organic Devices
- UWB Components

VII. White Paper on Solar Power Satellites

The commission D studied the report on the Solar Power Satellites. The problems of this technology open many fields of study for electronics and the photonic one.

It gives an opinion favorable for the deepening of this technology and the publication of this White Paper.

BUSINESS TRANSACTED BY COMMISSION E

Chair: Prof. Flavio Canavero (Italy)
Vice-Chair: Prof. Christos Christopoulos (UK)

I. Terms of reference

After some discussion, Commission E voted the following amended version of ToR.
Commission E - *ELECTROMAGNETIC NOISE AND INTERFERENCE.*
The Commission promotes research and development in:
(a) Terrestrial and planetary noise of natural origin, seismic associated electromagnetic fields;
(b) Man-made noise;
(c) The composite noise environment;
(d) The effects of noise on system performance;
(e) The lasting effects of natural and intentional emissions on equipment performance;
(f) The scientific basis of noise and interference control, electromagnetic compatibility;
(g) Spectrum management.

Also, during the discussion, the issue of changing the title of the commission was brought up. The Chair was charged to make a proposal for the next GA. During the business meetings in Chicago, this proposal will be discussed and voted, and finally ratified by the Board.

II. Working Groups

The Commission E activities are based on the work conducted by the working groups (WG). After some discussion, Commission E voted the following amended list of WG.

II.1 Working Groups 2005-2008

E.1. Terrestrial and Planetary Electromagnetic Noise Environment
Co-Chairs : M. Hayakawa (Japan), A.P. Nickolaenko (Ukraine) and C. Price (Israel), K. Hattori (Japan);
E.2. Intentional Electromagnetic Interference
Co-Chairs : W. Radasky (USA) and M. Bäckström (Sweden);
E.3. High Power Electromagnetics
Co-Chairs : C.E. Baum (USA) and R.L. Gardner (USA);
E.4. Lightning Discharges and Related Phenomena
Chair : Z. Kawasaki (Japan);
E.5. Interaction with, and Protection of, Complex Electronic Systems
Co-Chairs : J. Nitsch (Germany) and J-P. Parmentier (France);
E.6. Spectrum Management
Chair : T. Tjelta (Norway);
E.7. Geo-Electromagnetic Disturbances and Their Effects on Technological Systems
Chair : A. Viljanen (Finland);
E.8. Electromagnetic Compatibility in Wire and Wireless Communication Systems
Co-Chairs : J. Gavan (Israel) and A. Zeddam (France);

Also, Commission E designated its representatives to WG jointly operated with other Commissions. A list follows:

II.2 Joint Working Groups

Inter-commission working group on Solar Power Satellites
Co-Chair for Commission E: Zen Kawasaki (Japan)
EGH. Seismo Electromagnetics (Lithosphere-Atmosphere-Ionosphere Coupling)
Co-Chair for Commission E : M. Hayakawa (Japan)

III. Sponsorship of Conferences

The following meetings have been supported in the past triennium either in mode A (without financing) or in mode B(with financing):

- EMF and Cardiac Pacemakers and Defibrillators, Paris, France, 25 October 2002, mode A
- EMC Zurich 2003, Zurich, Switzerland, 18-20 February 2003, mode B
- 2003 IEEE Int. Symp. On Electromagnetic Compatibility, Istanbul, Turkey, 11-16 May 2003, mode B
- Telecom 2003 & JFMMA, Marrakech, Morocco, 15-17 October 2003, mode A
- WARS04 (Workshop on Applications of Radio Science) conference 2004, Hobart, Tasmania, Australia, 18-20 February 2004, mode A
- EMC'04 Sendai - 2004 International Symposium on Electromagnetic Compatibility, Sendai, Japan, 1-4 June 2004, mode A
- EMC Wroclaw 2004, Wroclaw, Poland, 29 June - 1 July 2004, mode B
- AP-RASC 04: 2004 Asia-Pacific Radio Science Conference, Beijing, China, 20-23 August 2004, mode A
- Radar 2004, Toulouse, France, 19 - 21 October 2004, mode A
- EMC Zurich 2005, Zurich, Switzerland, 15-17 February 2005, mode B
- Telecom 2005 & JFMMA, Rabat Morocco, 23-25 March 2005, mode A
- VIth International Symposium on Electromagnetic Compatibility and Electromagnetic Ecology, St. Petersburg, Russia, 21-24 June 2005, mode B

- ICEAA'05, International Conference on Electromagnetics in Advanced Applications, Torino, Italy, 12-16 September 2005, mode A
- Microwave, Radar and Remote Sensing, Kiev, Ukraine, 19-21 September 2005, mode A

The chair is charged to collect as much as possible of the requests for support from National Representatives, in order to be able to plan a budget for future years.

IV. Vice Chair Election

Professor Christos Christopoulos (University of Nottingham, UK) was elected as Vice-Chair. He will also serve as the Commission E Editor of the Radio Science Bulletin.

BUSINESS TRANSACTED BY COMMISSION H

Chair: Prof. Umran Inan (USA)
Vice-Chair: Dr. Richard Horne (UK)

I. Business Meeting 1: Monday, 24 October 2005

I.1 Election of Commission H Vice-Chair for 2005-2008

The chair, Umran Inan, announced that two candidates stood for electron, Yoshiharu Omura and Ondrej Santolik. After counting voting slips returned by the Commission H national delegates, and those cast at the GA, Yoshiharu Omura was elected as Vice-chair, subject to confirmation at the URSI Council meeting.

I.2 Discussion on GA 2005 Organisation and Programme

The chair, Umran Inan, thanked the local organisers and noted that they had a difficult time organising this assembly. He also thanked the incoming chair, Richard Horne, for his help is organising the sessions, and the session convenors.

The submission of abstracts was discussed, as it was at previous GAs. It was felt that the current system of submitting a 1 page abstract, followed by a 4 page extended abstract and a 100 word summary was excessive. Commission H (along with Commission G) has always regarded the 4 page extended abstract as optional. The general feeling was to continue with a 1 page abstract and 100 word summaries and keep the extended abstract as optional.

The issue of internet access was raised, and requested that wireless access be made available at the next GA.

I.3 Terms of Reference

The terms of reference were reviewed and it was decided to simplify the wording. It was also decided to include a reference to space weather to reflect the important role that wave-particle interactions play in controlling the flux of energetic particles in the radiation belts which cause satellite damage. The terms of reference are now:

(a) To study waves in plasmas in the broadest sense, and in particular :
  (i) the generation (i.e. plasma instabilities) and propagation of waves in plasmas,
  (ii) the interaction between these waves, and wave-particle interactions,
  (iii) plasma turbulence and chaos,
  (iv) spacecraft-plasma interaction ;
(b) To encourage the application of these studies, particularly to solar/planetary plasma interactions, space weather, and the exploitation of space as a research laboratory.

I.4 Meeting Support

Over the last 3 years Commission H has provided support for 6 meetings in mode A (moral support, no funding), and 7 in mode B where funds up to Eu 1,500 have been provided for individual meetings. In total Eu 7,750 has been provided and there is a balance of Eu 2,130. The chair proposed that this money is carried forward and added to new funds in the next triennium as there will probably be additional meetings related to the International Polar Year.

I.5 Publications

The Chair, Prof U Inan, thanked the incoming chair, Richard Horne, for acting as editor for Reviews of Radio Science. During the last 3 years Commission H has been the most productive with 6 review papers published or in press. Richard Horne thanked the authors for their hard work.

Title	Author	Status
Remote sensing of the plasmasphere	Carpenter, D.	Published March 2004.
Solar power satellites	Matsumoto, H.	Special issue Sept 2004
Kinetic and nonlinear processes in space plasmas	Lembege et al.	Published Sept. 2005
Use of RF waves in space propulsion systems	Bering et al.	Published Sept. 2004.
The CLUSTER fleet explores waves in the magnetosphere: chosen illustrations	Decreau et al.	Published Dec. 2005
Space weather effects on communications satellites	Koons and Fennel	Published March 2005

The incoming vice chair, Yoshi Omura, agreed to act as the new editor for Commission H for Reviews of Radio Science and Radio Science Bulletin.

I.6 URSI White Papers

URSI has adopted the idea of issuing white papers on important topics relevant to URSI science where it can provide sound scientific information and an open forum for discussion. The first white paper will be on solar power satellites (SPS), led by Professor Matsumoto (former URSI president and Comm H). This white paper was supported by Commission H. So far, other suggestions for a white paper include the effects of mobile phones on human health.

I.7 Commission H Resolutions

There were no Commission H resolutions.

I.8 Proposals for H-led Sessions in 2008

A call for H led sessions for GA 2008 was made, for discussion at BM3 (see below).

I.9 Other business

Three venues had been proposed for GA 2008, Chicago (USA), Istanbul (Turkey) and Goteborg (Sweden). The final decision will be made by a vote at the URSI Council meeting later in the week.

II. Business Meeting 2: Wednesday 26 October 2005

This was a joint meeting between Commissions H and G.

II.1 Joint Working Groups 2002-2005

Activities during the past triennium and recommendations for future activities were reviewed and presented for the joint Commissions G and H working groups and activities.

- GH1: Active experiments in Space Plasmas: Co-Chair for Commission G: Sa. Basu (USA), Co-Chair for Commission H: B. Thide (Sweden). Recommend continuing with Commission G representative (and Co-chair) as Dr Keith Groves (USA), and Commission H representative as Dr. Ruzhin (Russia). The meeting expressed its thanks to Santimay Basu for the long and dedicated service that he has given leading this WG.
- GHC Wave and Turbulence Analysis: Co-Chair for Commission G: D. Hysell (USA), Co-Chair for Commission H: T. Dudok de Wit (France), Co-Chair for Commission C: G Kubin (Austria) Recommend discontinuing as the work of the working group is completed.
- EGH: Seismo-Electromagnetics. Co-chair for Commission G: S. Pulinets (Russia), Co-chairs for Commission H: M. Parrot (France) and O. A. Molchanov (Russia). Recommend continuing with the same officers.
- HGEJ: Supercomputing in Space Radio Science. Co-chair for Commission G: A. Barakat, USA, Co-chair for Commission H: Y Omura (Japan). Recommend continuing with the same Commission H representative, but Commission G will withdraw.
- ABDFGHJK: An inter-commission working Groups on Solar Power Satellites: Co-chair for Commission G: M Rietveld (Germany), Co-chair for Commission H: N. Shinohara (Japan). Recommend continuing with the same officers.

Commissions G and H also coordinate the reports from certain other Groups which fall under the aegis of both URSI and another union. Further, Commissions G and H make recommendations to the URSI Board in respect to the URSI representation to these Union.

- URSI-COSPAR on International reference Ionosphere (IRI). Chair: B.W. Reinisch (USA), Vice Chair for COSPAR: Martin Friedrich (Austria), Vice Chair for URSI: Lida Triskova (Czech Republic); Secretary: D. Bilitza (USA). Recommend continuing with same officers.
- URSI/IAGA VLF/ELF remote Sensing of the Ionosphere and Magnetosphere (VERSIM), URSI Rep: M. Parrot (France). Recommend continuing with J. Lichtenberger (Hungary) as representative for Commissions G and H.

II.2 Commission G and H Resolutions

There were none.

II.3 Proposed URSI Representatives to Organisations

Commissions G and H recommended the following external representatives from within their own ranks:

- CAWES (Climate and Weather of the Sun-Earth system): Sunanda Basu.
- COSPAR (Committee on Space Research): Dr Z. Klos for a second term.
- FAGS (Federation of Astronomical and Geophysical Data Analysis Services): Phil Wilkinson
- ICSU Panel on World Data Centres (Geophysical and Solar): Dr. D. Bilitza (USA)
- ISES (International Space Environment Service): Dr. S. Pulinets (Russia)
- SCAR (Scientific Committee on Antarctic Research): Dr. M Clilverd (UK)
- SCOSTEP (Scientific Committee on Solar-Terrestrial Physics): Christian Hanuise (France)

Commissions G and H assumed that the following members from Commissions G and H would continue in the following roles:

- ICSU (International Council for Science): Prof. K. Schlegel (Germany)
- IUGG / IAGA (International Union of Geodesy and Geophysics/International Association of Geomagnetism and Aeronomy): Prof. G. Lakhina (India).

II.4 Joint Programme for 2005-2008

There was no discussion.

II.5 Other Business

There was no other business.

III. Business meeting 3: Friday 28 October 2005

III.1 Opening Remarks

The outgoing chair, Umran Inan, thanked the commission for their support, and thanked the incoming chair for his help over the last triennium, and especially over the organisation of the sessions for the GA. The incoming chair, Richard Horne, thanked the outgoing chair for the work that he had done, and for his advice and help – he had been a good teacher. He also welcomed Yoshi Omura as new vice chair, which had been confirmed at the URSI Council meeting. Richard Horne then took over chairing the meeting.

III.2 Proposed Sessions for GA 2008

URSI Council decided that the next GA will be in Chicago 2008. The chair pointed out that at this GA there were 11 half day H led sessions plus a 1.5 day poster session and that for planning purposes we should assume that GA 2008 will have a similar number of sessions. As a guide, the session titles and number of papers at GA 2005 are given in the table below.

Session at GA 2005	papers
H1. Microscopic processes in boundary layers	7 oral + 9 poster
H2. Radiation belts and the Plasmasphere	10 oral + 11 p
H3. Waves and coherent structures in space plasmas	7 oral + 15 p
H4. Multi-point measurements	10 oral + 0 p
H5. Open session & latest results	7 oral + 11 p
HG1. Radio-frequency observations in space	10 oral + 15 p
HG2. Ionospheric modification by high-power radio waves	10 oral + 10 p
HG3. Dusty plasmas and laboratory plasmas	7 oral + 6 p
HGCJ. Diagnostics of media fluctuations with radio methods	7 oral + 12 p
HGE. Ionospheric effects of lightning	7 oral + 3 p
HADFBJK. Solar Power Satellites	7 oral + 2 p

Several new sessions were proposed for GA 2008 including (with suggested convenors):

- H1: Boundary layers: kinetic mechanisms (B. Lembege, G. Lakhina)
- H2: Wave effects on the radiation belts (J. Albert, R. Horne). Including radiation belt remediation.
- H3: Waves and coherent structures in space plasmas (J. Pickett, Y. Omura)
- H4: Multi-point measurements of space plasmas (O. Santolik, M. Andre)
- H5: Waves and Dynamics of the Plasmasphere (B. Fraser, H. Laakso)
- H6: Acceleration and Heating by Plasma Waves (R. Bingham , T. Chang)Including tokamaks and lab plasmas
- H7: Open session & latest results (R. Horne, Y. Omura)

Several joint sessions were also discussed:

- HG: Active Radio Frequency Space Experiments (B. Reinisch, G. James, Ruzhin)
- HG: Dusty Plasmas and Laboratory Plasmas (G. Ganguly, Havnes, Mareev)
- HX (inter-union): Solar Power Satellites (H. Hashimoto)

- GH: Ionospheric Modification By High-Power Radio Waves (Groves from Commission G, suggest T. Leyser and S. Basu, B. Thide for Comm H)
- HGE: Effects of Lightning on the Ionosphere and Magnetosphere, (Suggest M. Blanc, Price, V. Pasco)
- HGE: Seismo Electromagnetics (M. Parrot, O. Molchanov)

It was suggested that the open session should be on the first day to encourage full attendance. In this GA there were 11 H led sessions which meant they had to be restricted to half day sessions. There was a feeling that fewer but longer sessions might be more appropriate at the next GA.

III.3 Suggestions for H Tutorial Lecture for GA 2008

Three people were suggested including Don Gurnett, Umran Inan and Gordon James.

III.4 Requests for URSI Meeting Sponsorship

Several meetings have requested Commission H support during the next triennium, including:

- Radio Science Symposium for A Sustainable Humanosphere, March 20-21, 2006, Kyoto, Japan (Mode A)
- ISROSES: International Symposium on Recent Observations and Simulations of the Sun-Earth System, September 18-22, 2006, Bulgaria, (Mode B)
- IRI Workshop, October 16-20, 2006, Buenos Aires, Argentina (Mode B)
- COSPAR Meeting July. 17-23, 2006, Beijin, China (Mode B)
- VLF Workshop, Sodankyla, Sept 2006.
- The 8th International School/Symposium for Space Simulations (ISSS-8): 2008, USA (Mode B)

URSI Council had approved the carry forward of unused funds to the next triennium as proposed by the outgoing chair.

III.5 Publications

In accordance with tradition, the new vice chair, Yoshi Omura, agreed to take over as editor for Commission H of Radio Science Bulletin, incorporating Reviews of Radio Science. There are 4 review papers being written, but additional reviews papers would be sought. Additional suggestions include J. Holweg on coronal heating, M. Reiner and J. L. Bougeret on solar radio emissions, and R. Benson on IMAGE results and A. Cairns on wave heating in tokamaks.

III.6 Review of GA 2005

It was felt that the GA had been a good meeting. Although the number of US attendees was less than in previous years, the number of papers submitted had increased over GA 2002. There had only been 2 oral talks where the authors could not attend, but these were filled with other talks. Attendance varied between 40-90 people but some sessions had over 100 including members from other commissions. The Commission H tutorial was very well attended. The room size was more than adequate, and the coffee facilities by each room were excellent. It was expected that the next GA in Chicago would have a much higher US attendance.

BUSINESS TRANSACTED BY COMMISSION K

Chair: Dr. B. Veyret (France)
Vice-Chair: Dr. F. Prato (Canada)

This report is based on the conclusions from the two business meetings of Commission K that were held in New Delhi.

I. New Delhi General Assembly in New Delhi

I.1 Scientific Sessions

Ten scientific sessions were organised, including three sessions shared with Commissions A, B, and E:

Session	convenors	topic
K1	D'Inzeo	mechanisms
K2	Behari/Korenstein	biological effects
K3	Lin/Chiang	mobile telephony
K4a	Ueno/Prato	medical diagnosis
K4b	Ueno/Prato	medical applications
K6	Karpowicz/Hietanen	occupational medicine
KT	Vecchia	public health
KAE	Neubauer/Faraone	dosimetry
KB	Wiart/Taki	modelling
KE	Morrissey/Calcagnini	EMC

During the sessions, 80 talks were given and 47 posters, which are good numbers in view of the difficulty in organising trhe sessions and in travelling to New Delhi.

I.2 YS Program

Six young scientists took part in the work of Commission K.

I.3 Election Vice-Chair

There were four candidates to the position of vice president of the commission:
- Jitendra Behari, New Delhi, Indai
- Guglielmo D'Inzeo, Rome, Italy
- Rafi Korenstein, Tel-Aviv, Israel
- Niels Kuster, Zurich, Switzerland

Professor Guglielmo D'Inzeo was elected. He will become the next chair of commission K at the next General Assembly in Chicago.

II. Publications

Several papers have been published in the « Bulletin of Radio Science ». They were edited by the vice-chair Frank Prato :
- N Shupak et al. *Therapeutic Uses of Pulsed Magnetic-Field Exposure: A Review.* **Dec 2003**. 9-32
- S Engström. *Physical Mechanisms of Non-Thermal Extremely Low Frequency Magnetic-Field Effects*. **Dec 2004**. 95-106
- A Ahlbom, M Feychting, S Lönn. *Mobile phones and tumor risk: Interpretation of recent results (Sep 2005)*.
- J Lin. *Review on BBB permeability and xposure to ELF and RF (in press)*.

III. Other activities

- The links between Commission K and the SCT have been strong. Most of the contacts were established with WHO (International EMF Project)
- Several meetings of the national representative of Commission K were organised at various international scientific meetings.
- A major scientific meeting was organised jointly by the commission K, WHO, and ICNIRP[1] in Seville, Spain, in May 2004. More than 250 participants attended the meeting and commission K organised two sessions on medical applications, and MRI and TMS[2].
- The following scientific meetings have been sponsored by Commission K:
  1. *EMF and Cardiac Pacemakers and Defibrillators*, Paris, France, 25 October 2002.
  2. *JINA 2002*, Nice, France, 12-14 November 2002.
  3. *APMC'02*: Asia-Pacific Microwave Conference, Kyoto, Japan, 19-22 November 2002.
  4. *EMC Zurich 2003*, Zurich, Switzerland, 18-20 February 2003.
  5. *ISMOT 2003* - 9th Int. Symp. On Microwave and Optical Technology, Ostrava, Czech Republic, 11-15 August 2003.
  6. *International NIR Workshop and Symposium*, ICNIRP/URSI(K)/WHO, Seville, Spain, 20-24 May 2004.
  7. *MSMW'04*, Fifth Int. Kharkov Symposium on Physics and Eng of Microwaves, mm and Submm Waves, Kharkov, Ukraine, 21-26 June 2004.
  8. *EMC Wroclaw 2004*, Wroclaw, Poland, 29 June - 1 July 2004
  9. *AP-RASC 04: 2004 Asia-Pacific Radio Science Conference*, Beijing, China, 20-23 August 2004.
  10. *Radar 2004*, Toulouse, France, 19 - 21 October 2004.
  11. *JINA-04*, Nice, France, 8-10 November 2004.
  12. *EMC Zurich 2005*, Zurich, Switzerland, 15-17 February 2005.
  13. *CEFBIOS 2005* - Coherence and electromagnetic fields in biological systems, Prague, Czech Republic, 1-4 July 2005.
  14. *ISMOT 2005* - 10th International Symposium on Microwave and Optical Technology, Fukuoka, Japan, 22-25 August 2005.
  15. *International Workshop on Electromagnetic Fields at the Workplaces*, Warsaw, Poland, 5-7 September 2005.

IV. Resolutions

No new **resolution** was proposed by Commission K.

V. White paper

Commission K has worked on the draft of the SPS white paper and has improved the document mainly as far as the health chapter was concerned. It did not give an opinion on the technology and the legitimacy of the project itself.

A new white paper entitled "wireless communications and health" was proposed to be written under the leadership of Commission K.

VI. Terms of reference

In order to clarify the existing text a new formulation of the items was given:

(a) physical interaction of *electromagnetic fields** with biological systems;
(b) biological effects;
(c) mechanisms underlying the biological effects;
(d) experimental exposure systems;
(e) assessment of human exposure;
(f) medical applications.
* *(frequency range from static to terahertz)*

(a) interaction des champs électromagnétiques* avec les systèmes biologiques au niveau de la physique ;
(b) effets biologiques ;
(c) mécanismes à la base des effets biologiques ;
(d) systèmes expérimentaux d'exposition ;
(e) évaluation de l'exposition des personnes ;
(f) applications médicales.
* (domaine de fréquence du statique aux terahertz)

[1] International Commission on Non Ionizing Radiation Protection

[2] stimulation magnétique transcrânienne

Evaluation of the URSI General Assembly 2005

General

The XXVIIIth General Assembly of URSI was held October 23-29, 2005, in New Delhi, India. It provided the forum for exchange of views, scientific debates, and planning for future activities among radio scientists from all over the world that makes this triennial gathering such a unique and enjoyable event. In the following, an evaluation is presented from my position as Coordinator of the program. Annex 1 shows the schedule of sessions. Annex 2 presents the timetable of the sessions.

Participation

Total registration for the General Assembly was 1131, of which 757 (i.e., two-thirds) were foreign registrations, and 374 (i.e., one-third) were Indian registrations. These included a total of 142 Young Scientist Awards: 30 to Indian Young Scientists and 112 to foreign Young Scientists. For comparison, the total attendance at the previous General Assembly (Maastricht, 2002) was 1352, including 97 Young Scientists. The increased support of the Young Scientists Program was a particularly positive characteristic of this GA.

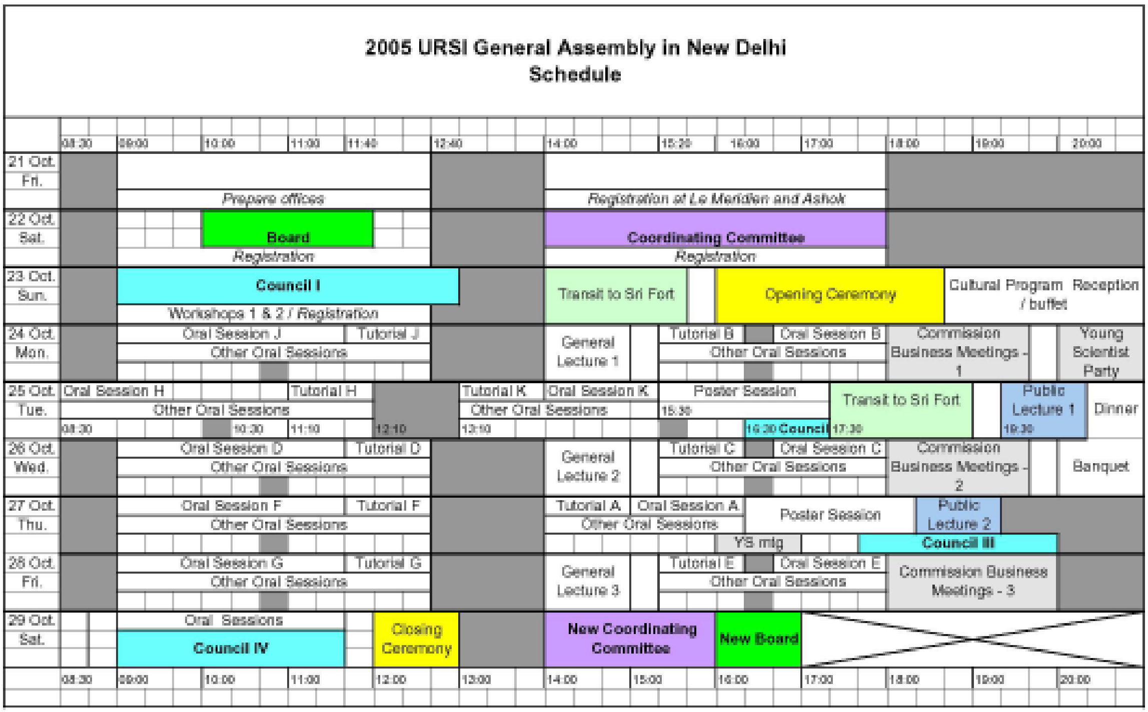
The registrations per country of more than 10 participants, per continent, and per Commission are given in Annex 3. Annex 4 shows the distribution of authors for the countries having more than 10 authors.

Statistics of the Sessions

The total number of sessions was 121, including General Lectures, Tutorials, and two large poster sessions. The total number of oral papers in the program was 815. The total number of posters in the program was 716.

The number of papers actually presented was given was different, for several reasons:

- there was a substantial number of no-shows
- gaps that resulted from no-shows in oral sessions were replaced by alternative presentations, mostly of poster papers



Annex 1: Schedule of Sessions

XXVIII[th] URSI GENERAL ASSEMBLY, NEW DELHI, INDIA, 2005

		Oral and Poster Sessions listed by Commission									
Commission		A	B	C	D	E	F	G	H	J	K
Room		Hall-D	Hall-R	Hall-4	Hall-3	Hall-B	Hall-C	Hall-5	Hall-6	Plenary	Hall-A
24 Oct. Mon.	am	A01	B01	C01	D06a	EB	F01	G04	H04	J03a / JT	K04a
	pm	General Lecture U1 (Plenary Hall)									
		A02	BT / B08	C04	DB2	E01	F03	GF1a	HG3	J03b	KE
25 Oct. Tues.	am	A03	BCD	C02	D03	E05	F02	GF1b	HGE / HT	J04	KAE
	pm	A06	B07	C05	D04	EC	F04	GHJ	HX	JB1	KT / --
		Posters (HNG)									
		Public Lecture L1 (Siri Fort)									
26 Oct. Wed.	am	A07	B03	C03	D02 / DT	E07	F08	G02a	HG2	J02	K02
	pm	General Lecture U2 (Plenary Hall)									
		A11	B05	CT / C08	D01/DB1	E02	F05	G02b	H01	JB2	K01
27 Oct. Thurs.	am	A10	B02	C09	D08 / DC	EA	FG / FT	G03	H02	J06	K03
	pm	AT / --	BCF	C06	D06b	E04	F09	G01a	H03	JE	KB
		Posters (HNG)									
		Public Lecture L2 (Plenary Hall)									
28 Oct. Fri.	am	--	B04	CBA	D07a	EGH	F10	G05a / GT	HG1	J01	K04b
	pm	General Lecture U3 (Plenary Hall)									
		--	BC	C07	D05	ET / E03	F07	G05b	HGCJ	J05	K06
29 Oct. Sat.	am	--	B06	CB	D07b	E06	F06	G01b	H05	J07	--
		Tutorials in Hall-E									

Annex 2: Scientific Session Timetable

- following its tradition, Commission J held two sessions of short presentations. These were not included individually in the program.

The exact numbers of papers presented cannot be given, since session reports were not received from all session conveners. Gaps in oral sessions due to no-shows that could not be filled by alternative presentations accounted for some 11% of the total. No-shows for poster-paper presentation totaled 30%.

At the previous General Assembly (Maastricht, 2002), the percentage of no-shows was 5%, both for posters and oral papers. The increased number of no-shows was the result of the decision that advance payment would not be a requirement for inclusion of the paper in the program.

The total number of oral papers actually presented was approximately 750. The total number of posters actually presented was approximately 500. In Maastricht, the total number of oral and poster presentations was 750 and 740, respectively.

Annex 5 (see on page 60) summarizes the main statistics per Commission. The assistance of Martin Hall in extracting some of these statistics from the program booklet is gratefully acknowledged.

Country	Nr	Continent	Nr.	Commission	Nr.
India	374	North America	169	A	56
United States	144	South America	12	B	134
Japan	124	Europe	351	C	123
France	69	Australia & New Zealand	23	D	61
Italy	43	Asia	558	E	68
Germany	38	Africa	18	F	106
United Kingdom	32			G	127
Netherlands	29			H	100
Canada	25			J	118
Russia	24			K	70
Australia	21			No indication	168
China (CIE)	20				
Finland	15				
Belgium	13				
Sweden	13				
Poland	12				
Israel	11				
Korea	11				
Czech Republic	10				
South Africa	10				
Other countries	93				

Annex 3: URSI GA 2005 Registration Statistics

Country	GA 2005	GA 2002
India	419	23
USA	228	321
Japan	146	196
France	76	123
Russia	72	121
UK	57	83
Germany	56	78
Italy	56	62
Canada	42	32
Netherlands	32	71
China (CIE)	22	27
Israel	21	23
Australia	19	29
Finland	17	29
Sweden	17	29
Brazil	16	12
Czech Republic	16	14
Poland	16	15
South Korea	15	9
Belgium	13	30
Malaysia	12	6
Greece	11	16
South Africa	11	6
Spain	11	14

Annex 4: URSI GA 2005 distribution of first authors

Attendance and Quality of the Sessions

Attendance at the sessions was generally lower than in Maastricht. Annex 1 shows that average attendance was 47, as compared to 66 in Maastricht. This reflects the lower total participation in New Delhi.

A number of session conveners had reported difficulties in filling the session with papers, as a result of negative responses to their invitations for papers. The quality of the presentations was, however, generally judged to be very good. Ironically, this was partly due to the increased number of no-shows. In many cases, a gap was taken up by allowing longer discussions, which apparently was very satisfying for the participants. Maybe there is a lesson to be learned here?

General Organization

The facilities provided by the Indian hosts were in general judged to be good. Some rooms did not have the usual theater arrangement, but the provision of multiple screens ensured adequate visibility of projections in some critical cases.

In a few cases, the usual problems occurred with incompatibilities of software, in particular affecting fonts. A more general problem in this area was incompatibility of the "beamer" projector with the computer screen, leading to poor representation of diagrams and failure of movies to run. Overall, the sessions appeared to have run well. Authors' instructions will require review and updating, in view of developments in software and equipment.

The only facility that was never fully operational was the Internet Café, despite a tremendous effort by the host organization. This requires attention, but will probably not be a critical item at the next GA. Since this will be held in a large hotel complex, which usually has its own facilities; no doubt in three years time these will be even further developed.

The organization of registration on the first days was poor. The sessions on Monday suffered from the delays incurred in registration. This is a critical area to be considered for future Assemblies. The registration peak just before the opening ceremony on Sunday requires adequate staffing, and on Monday the registration desk should be fully operational and well-staffed as early as half-past seven for a nine-o'clock start of the sessions.

The program booklets largely followed the format of the Maastricht General Assembly and were well prepared. The papers on the *Proceedings* CD-ROM are well readable, but the indexing is problematic. This will require extra attention in the future, since indexing is vital for the proceedings of a conference with some 1500 papers. The *Proceedings* can be accessed also via the URSI Web site.

The facilities for the poster sessions were excellent. The arrangement of poster boards was commented on very favorably by participants.

The hospitality provided during the entire week was exemplary. All participants enjoyed the multitude of examples of rich culture and kitchen of India.

In conclusion, we have seen a very successful and memorable General Assembly in 2005. Participants have enjoyed the unique combination of exciting scientific discussions, the meetings with the President of India, and the acquaintance with the culture of this impressive country.

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	Total Slots	Oral Papers	Poster Papers	Total	Percent no show Oral	Percent no show Poster	Average attendance	Peak attendance
Commission A								
Total 2005	**58**	**48**	**9**	**57**	**14.3%**	**0.0%**	**18**	**25**
Total 2002	88	78	31	109			46	
Total 1999	0	104	1	105				
Commission B								
Total 2005	**89**	**90**	**124**	**214**	**7.6%**	**35.2%**	**50**	**80**
Total 2002	80	77	175	252			44	
Total 1999	0	111	244	355				
Commission C								
Total 2005	**89**	**78**	**94**	**172**	**24.2%**	**40.4%**	**42**	**70**
Total 2002	82	72	47	119			66	
Total 1999	0	63	5	68				
Commssion D								
Total 2005	**89**	**88**	**6**	**94**	**13.6%**	**0.0%**	**28**	**60**
Total 2002	82	72	18	90			50	
Total 1999	0	73	12	85				
Commission E								
Total 2005	**89**	**80**	**38**	**118**	**11.5%**	**40.0%**	**24**	**30**
Total 2002	89	71	48	119			40	
Total 1999	0	96	56	152				
Commission F								
Total 2005	**89**	**89**	**52**	**141**	**17.6%**	**25.9%**	**42**	**75**
Total 2002	81	75	40	115			48	
Total 1999	0	93	102	195				
Commission G								
Total 2005	**89**	**89**	**134**	**223**	**6.7%**	**28.9%**	**77**	**100**
Total 2002	89	85	0	85			78	
Total 1999	106	0	131	131				
Commission H								
Total 2005	**89**	**89**	**120**	**209**	**7.9%**	**18.5%**	**58**	**80**
Total 2002	87	86	142	228			75	
Total 1999	0	107	104	211				
Commission J								
Total 2005	**89**	**99**	**84**	**183**	**2.2%**	**27.9%**	**79**	**110**
Total 2002	84	78	80	158			119	
Total 1999	0	114	65	179				
Commission K								
Total 2005	**78**	**74**	**55**	**129**	**12.5%**	**0.0%**	**32**	**32**
Total 2002	75	70	39	109			90	
Total 1999	0	77	57	134				
Tutorials								
Total 2005	**10**	**10**	**0**	**10**	**0.0%**	**0.0%**	**74**	**130**
Lectures								
Total 2005	**5**	**5**		**5**	**0.0%**	**0.0%**		
Grand Totals								
Total 2005	**863**	**839**	**716**	**1555**	**10.8%**	**30.2%**	**47**	
Total 2002	857	784	741	1525	4.8%		66	
Total 1999		851	777	1628				

Annex 5: URSI GA 2005 Statistics

Radio-Frequency Radiation Safety and Health

James C. Lin

The New IEEE Standard for Human Exposure to Radio-Frequency Radiation and the Current ICNIRP Guidelines

On October 3, 2005, the IEEE Standards Association formally approved a new IEEE C95.1 "Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz." Official publication of the standard by the IEEE was expected by late 2005, or soon thereafter. It is likely that by the time this column appears in print, the formal publication already may have taken place. In any event, the newly approved standard represents a complete revision of and replaces IEEE C95.1-1991. Note that there had been several amendments in the interim, notably in 1999.

The 1991 edition was developed by IEEE Standards Coordinating Committee 28 (SCC-28) under the sponsorship of the IEEE Standards Board, and was submitted to the American National Standards Institute (ANSI) for recognition as an American standard, in accordance with policies of the IEEE. In 2001, the name "International Committee on Electromagnetic Safety," ICES, was approved by the IEEE Standards Association Standards Board, in place of SCC-28.

With news of the approval, some observers and interested groups, including the Mobile Manufacturing Forum (MMF), have taken positions with respect to the International Commission on Nonionizing Radiation Protection (ICNIRP) guidelines [1] and their relationship to the new IEEE standard. For example, in a recent *View Point* article, entitled "New IEEE C95.1 Revision a Significant Step Towards Global Standards Harmonisation," MMF asserted that the new IEEE C95.1 standard and the ICNIRP exposure guidelines are harmonized in two ranges that encompass the frequencies used in mobile telecommunications and wireless devices and systems [2]. The two frequency ranges mentioned are 100 kHz to 3 GHz with respect to SAR limits, and 30 MHz to 100 GHz regarding external field-intensity and power-density limits for the general public.

Without actually saying it, the *View Point* article seemed to recognize that there may be potential differences. To put it simply, the new IEEE standard is not identical to the ICNIRP limits – in contrast to the MMF statement – even for frequencies used in mobile telecommunication systems. Moreover, the newly approved IEEE standard departs in major ways from the 1991 edition. This column will examine some of the more salient aspects applicable to mobile communication. I plan to cover the other differences at a future date.

In the frequency ranges of 100 kHz to 3 GHz, the new IEEE standard of 0.08 W/kg averaged over the whole body for the general public is based on restricting heating of the body during whole-body exposure. It is to be applied when an RF safety program is not available. The new basic restriction for localized exposure is 2 W/kg for most parts of the body. For the extremities (arms and legs distal from the elbows and knees, respectively, including the fingers, toes, hands, and feet) and for pinnae, the basic restriction expressed in terms of SAR is 4 W/kg. The value of SAR is obtained by averaging over some specified time periods (i.e., 6 to 30 min) and by averaging over any 10 g of tissue (defined as a tissue volume in the shape of a cube). The basic restrictions for localized exposure are enacted to prevent excessive temperature elevation that might result from localized or nonuniform exposure.

For frequencies between 3 GHz and 100 GHz, the basic restrictions are the same as the derived limits of maximum permissible exposures (MPE). The value of maximum permissible exposure is obtained by averaging over some specified time periods that vary from 2.5 to 30 min for different frequencies.

The frequency-dependent maximum permissible exposure is a convenient metric for exposure assessment, and can be used in determining whether an exposure complies

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Significant portions of this material appeared in J. C. Lin, "A New IEEE Standard for Safety Levels with Respect to Human Exposure to Radio-Frequency Radiation," IEEE Antennas and Propagation Magazine*, **48**, 1, February 2006, pp. 157-159, and is ©2006 by the IEEE, reprinted with permission.*

with the basic SAR restrictions. The basic SAR restrictions are referred to as *action levels* in the new IEEE standard. For incident power densities, they range from 1000 W/m^2 at 100 kHz, to 10 W/m^2 at 100 GHz, with the lowest value of 2 W/m^2 between 30 and 400 MHz. Again, these values were established to protect against tissue heating.

The new IEEE standard includes several major differences from the 1991 edition.

First and foremost, for the first time in its history, the new IEEE standard instituted an exclusion for the pinnae or the external ears by relaxation of the above-mentioned basic SAR restriction from 2 W/kg to 4 W/kg. This choice segregates tissues in the pinnae apart from all other tissues of the human head.

Of equal significance is the basic restriction for localized exposure at 2 W/kg in terms of SAR averaged over any 10 g of tissue. The SAR value has been increased from 1.6 W/kg averaged over any 1 g of tissue to 2 W/kg over any 10 g of tissue. Aside from the numerical difference between the SARs, the volume of tissue mass used to define the SARs in the new standard was increased from 1 g to 10 g. The increase in tissue mass can have a profound influence on the actual quantity of RF energy allowed to be deposited in tissue by the new exposure standard. It has been well established that the distribution of absorbed microwave energy is nonuniform, and it varies greatly from point to point inside a body. An averaging volume that is as large as 10 g would tend to artificially flatten out the SAR distribution, whether it is computed or measured. The smoothing also tends to substantially reduce the resulting SAR value. Thus, a 10-g SAR at 2 W/kg could be equivalent to 1-g SARs of 5 W/kg or higher. Simply put, the absorbed energy averaged over a defined tissue mass of 10 g is inherently low compared to a 1-g SAR.

The spherically-shaped human eye has a total mass of about 10 g. The use of an averaging volume as large as 10 g does not attribute any distinctions among tissues in the eye, and completely ignores the wide variation of SAR distribution throughout the eyeball. The choice of 2 W/kg over 10-g tissue volume in the shape of a cube could permit the deposition of RF or microwave energy in different parts of the eye that exceeds the basic SAR restriction by a large margin, while keeping the SAR for the entire eye below 2 W/kg.

At 2.5 GHz, the penetration depth in muscle tissue for a plane model is about 1.7 cm. A linear dimension of approximately 2.15 cm in the shape of a cube would correspond to 10 g of muscle tissue. Clearly, the exponentially attenuated SAR would be significantly greater close to the superficial layer of muscle tissue, which would be easily revealed by the 1-g SAR, but masked by a 10-g SAR

Moreover, the new IEEE standard stipulates that when averaging SAR over a 10-g volume of tissue in the extremities or pinnae, only SAR values for that tissue may be considered. In any cubic volume containing tissue from both the body and the extremities or pinnae, each must be considered separately. For example, when determining the SAR in a 10-g cube of tissue in the body, any lack of tissue contained in the cube from the extremities or pinnae is treated as air, with zero mass and zero SAR. This procedure appears rather ambiguous, and potentially could render a wide variety of SAR values in practice.

The 1-g SAR is scientifically a more precise representation of localized RF or microwave energy absorption, and a more biologically significant measure of SAR distribution inside the body or head. It should be noted that the sensitivity and resolution of present-day computational algorithms and resources, and experimental measurement schemes, can provide accurate SAR values with a spatial resolution on the order of 1 mm in dimension.

Another difference in the new standard from its 1991 edition pertains to the upper-frequency boundary over which whole-body-averaged SAR – serving as the controlling basic restriction – has been reduced from 6 GHz to 3 GHz in the new standard. Likewise, the upward ramp that starts for the relaxation of the power-density limits for localized exposure has also been changed from 6 GHz to 3 GHz.

There are other differences in the maximum permissible exposure (MPE) limits between the new standard and its 1991 edition for the general public, in the frequency range between 30 MHz and 100 GHz. The new maximum permissible exposure in terms of power density is 2 W/m^2 between 30 and 400 MHz. It ramps up from 2 to 10 W/m^2 between 400 and 2000 MHz. For frequencies greater than 2000 MHz, the maximum permissible exposure is 10 W/m^2. Also, the designated frequency bands and the associated maximum permissible exposures are different. Specifically, in the1991 edition, they were 10 W/m^2 between 30 and 300 MHz. The ramp up from 10 to 100 W/m^2 took place between 300 and 3000 MHz. For frequencies greater than 3000 MHz, the maximum permissible exposure was 100 W/m^2. In comparison, maximum permissible exposures in the new IEEE standard are in general more restrictive between 30 MHz and 100 GHz.

The new IEEE standard contains some of the characteristics of the current ICNIRP guidelines, but it also includes a number of differences. The following section highlights some of these similarities and differences for exposure of the general public.

The principal similarities are basic restrictions in terms of a 2 W/kg SAR averaged over 10 g of tissues in the head and trunk, and the reference levels or maximum permissible exposures of 2 to 10 W/m^2 for certain frequency ranges (i.e., 30 MHz to 100 GHz).

The major differences include the tissue mass and time period over which SAR values are to be averaged, and the applicable frequency bands for the maximum permissible exposures. Also, a most significant difference is the exclusion of pinnae from the head by IEEE, which made it possible to allow a higher local SAR value for the basic restriction at 4 W/kg. In the ICNIRP guidelines, pinnae are not excluded and are treated – as they should be – as integral parts of the human head.

The basic restrictions for whole-body average SAR and local SAR for frequencies between 100 kHz and 10 GHz are 0.08 and 2 W/kg, respectively. Moreover, localized SAR values in the ICNIRP guidelines are to be averaged over any 10-g mass of *contiguous tissue*. ICNIRP guidelines do not specify a cubic volume of tissue as the averaging mass. In addition, all SAR values are to be averaged over a 6-min period in the ICNIRP guidelines, in contrast to the 2.5 to 30 min stipulated in the new IEEE standard.

For whole-body exposures, the ICNIRP guidelines specify that the maximum spatial power densities, averaged over 1 cm^2, should not exceed 20 times the allowed spatial averaged values (10 W/m^2) over 20 cm^2 for frequencies between 10 and 300 GHz. Power densities are to be averaged over any $68/f^{1.05}$ -min period (where f is in GHz) to compensate for the progressively shorter penetration depth as the frequency increases. Thus, the spatial peak value of the power density should not exceed 200 W/m^2 over any 1 cm^2, for all practical purposes.

As mentioned above, the new IEEE maximum permissible exposures are 2 W/m^2 for frequencies between 30 and 400 MHz. It ramps up from 2 to 10 W/m^2 between 400 and 2000 MHz. For frequencies greater than 2000 MHz, the MPE is 10 W/m^2. Furthermore, it provides that the maximum spatial power density should not exceed 20 times the square of the allowed spatially averaged values at frequencies below 400 MHz, and should not exceed the 40 W/m^2 at frequencies between 300 MHz and 3 GHz, $18.56 f^{0.699}$ W/m^2 at frequencies between 3 and 30 GHz (f is in GHz), and 200 W/m^2 at frequencies above 30 GHz, within the specified averaging time period.

In summary, the new IEEE standard is not identical to the ICNIRP guidelines – in contrast to some claims – even for frequencies used in cellular mobile communications and wireless devices and systems. The new IEEE standard contains some features of the current ICNIRP guidelines, but it also includes a number of differences. Moreover, the newly approved IEEE standard departs in major ways from its 1991 edition (and its subsequent amendments). While the new IEEE standard and the current ICNIRP exposure guidelines possess some similarities, they are far from harmonized. Global harmonization of radio-frequency exposure standards for the general public would be a very desirable goal. However, it should not be approached on the basis of harmonization for harmonization's sake. The process must be aimed toward improvement beyond the current state of affairs through better precision in SAR specification, less uncertainty in exposure assessment, more accurate biological results, and greater reliability in health status data and end points. Advances in bioelectromagnetic research, and in electronic, computer, and wireless technology, have and will continue to facilitate this process. After all, a more scientifically based and commonly recognized exposure standard would bring palpable benefits to consumers, manufacturers, operators, and regulators alike.

References

1. ICNIRP, "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (UP TO 300 GHz)," *Health Physics*, **74**, 1998, pp. 494-522.
2. http://mmfai.info/public/docs/eng/Viewpoint%20C95%2E1%2004Oct05%2Epdf.

Conferences

CONFERENCE REPORTS

ClimDiff 2005 Symposium

cleveland, Ohio, USA 26 - 27 September 2005

General

ITU-R Study Group 3 is concerned with the study of radiowave propagation through the atmosphere. The Study Group prepares Recommendations that standardize the methods for the calculation of signal level, quality, and interference for of applications in all radio-frequency bands. These Recommendations provide the basis for system planning and standardization activities by operators as well as for other Study Groups of the ITU. The preparatory work is carried out by so-called Working Parties of radio scientists and engineers, appointed by Member States and organizations associated with the ITU-R. The work concentrates on global modeling of propagation factors in telecommunication system design. Over the last 10-15 years, the Working Parties dealing with tropospheric propagation (Working Parties 3J, 3K, and 3M) have developed the habit of organizing their meetings in parallel, allowing maximum interactions among the Working Parties. These annual meetings are held alternatively at the ITU Headquarters in Geneva and somewhere outside, at the invitation of the administration of a member state. Since 1990, the meetings outside Geneva are usually preceded by an open URSI Symposium, in which the latest results in two important areas of research of the Working Parties are presented. The areas addressed are:

1. The development of models that use climatic parameters to characterize radiowave propagation on a global scale, and
2. The development of models for propagation by diffraction.

For that reason, the symposium is named *ClimDiff*. The ClimDiff Symposia provide an excellent forum for interaction between the URSI propagation research community and the ITU. Input for the actual work of the Working Parties is provided by official documents submitted by the members of the ITU; in the ClimDiff Symposium, however, the latest information on the development of propagation models is exchanged with the scientific community not directly involved in the ITU-R work itself. The symposia are sponsored by URSI Commission F.

Symposium Results

ClimDiff 2005 was held in the Hilton Inn Downtown Hotel in Cleveland, Ohio, USA, September 26-27, 2005, preceding the Working Party meeting held there at the invitation of the US Administration. Both the Symposium and the ensuing Working Party meetings were hosted by NASA.

Total participation was 53 persons, and 40 papers were presented. As usual, the active participation of all participants in the lively discussions was one of the success parameters of the symposium. NASA generously provided the venue and logistics, allowing the event to be run without

Figure 1. ClimDiff '05 Coordinator Glenn Feldhake.

Figure 2. Symposium Chair Carol Wilson and Study Group Chair David Cole.

Figure 3. Some of the support staff.

Figure 4. Some ClimDiff '05 participants.

charging a registration fee. Mr. Glenn Feldhake of NASA was responsible for the coordination of local arrangements, a task he carried out to perfection.

In the course of two days, five "Clim" sessions on climatic parameters, two "Diff" sessions on diffraction, and two combined "ClimDiff" sessions were held. In view of the large number of interesting papers submitted, for the first time ClimDiff 2005 featured a poster session covering both areas.

The Symposium was very successful in "setting the scene" for the ITU-R Working Party members for their more-formal activities in the ensuing two weeks, but also in providing the URSI community an insight in the ITU-R requirements for information from the radio-science community. The reduction of radio-research activities by the privatized telecommunication operators has led to a reduction in scientific input from that side, which means that the ITU-R Study Group must rely more and more on information from the scientific community for its work

Symposium Organizing Committee

- Mrs. Carol Wilson, CSIRO ICT Centre, Australia, Symposium Chair
- Prof. Gert Brussaard, RADICOM Consultants, The Netherlands
- Dr. David Cole, IPS Radio & Space Services, Australia
- Mr. Glenn Feldhake, NASA, USA
- Mr. Rainer Großkopf, Institut für Rundfunktechnik GmbH, Germany
- Prof. Marlene Pontes, Wings Telecom, Brazil

Symposium Program

Monday, September 26, 2005

0900 – 0930 Welcome and Opening Remarks
0930 – 1030 Session ClimDiff 1: A variety of measurement programs
Chairman: Dr. David Cole (3 papers)
1100 – 1220 Session Clim 1: Measurement and modeling of clear-air parameters
Chairman: Dr. Terje Tjelta (4 papers
1400 – 1500 Session Clim 2: Measurement and modeling of rain parameters
Chairman: Dr. Emanoel Costa (3 papers)
1500 – 1630 Session ClimDiff 2: Poster session (9 papers)
1630 – 1730 Session Clim 3: Measurement and synthesis of rain parameters and effects
Chairman: Prof. Marlene Pontes (3 papers)

Tuesday, 27 September 2005

0900 – 1020 Session Diff 1: Diffraction effects due to buildings and structures
Chairman: Mr. Rainer Grosskopf (4 papers)
1050 – 1230 Session Diff 2: Diffraction effects due to terrain
Chairman: Dr. Hajime Suzuki (5 papers)
1400 – 1520 Session Clim 4: Measurement and modeling of clear-air effects
Chairman: Prof. Gert Brussaard (4 papers)
1550 – 1730 Session Clim 5: Measurement and modeling of precipitation effects
Chairman: Bertram Arbesser-Rastburg (5 papers)
Terje Tjelta, Lars Erling Bråten, David Bacon
1730 – 1800 Close

Gert Brussaard
E-mail: gert.brussaard@radicom.nl

Urban Remote Sensing Joint Event

Paris, France, 11-13 April 2007

The Urban Remote Sensing Joint Event will be held in Paris, France, 11-13 April 2007 and covers the Urban 2007 Workshop (4th IEEE GRSS/ISP RS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas) and the URS 2007 Symposium (6th International Symposium of Remote Sensing of Urban Areas)

The ponsors of this event are: The Institute of Electrical and Electronic Engineers/Geoscience and Remote Sensing Society, the American Society for Photogrammetry and Remote Sensing, CNES, ENST, the International Society for Photogrammetry and Remote Sensing , DLR, Università degli Studi di Pavia, Technical university Istanbul, URSI Commission F, EARSeL and the Ruhr - University of Bochum.

Objectives

The objectives of the Urban Remote Sensing joint event include:

· gathering people coming from industry, academia, local and national/international agencies together to discuss of topics related to remote sensing for urban monitoring;
· fostering the research and the applications of already available data sets over urban areas, with a special look to high resolution satellite data and data fusion;
· providing new ideas for developing sensors and/or systems able to analyze and monitor urban areas;
· improving the knowledge and the know-how by means of the interaction of researchers coming from different communities (town and regional planning, engineering, photogrammetry, geology, hydrology ...).

Committees

Joint Event Committee

Chair: Florence Tupin - ENST, France
Chair: Michel Roux - ENST, France
Co-Chair: Lucien Wald, Ecole des Mines de Paris, France

Technical Committee URBAN 2007

Chair: Paolo Gamba - University of Pavia, Italy

Technical Committee URS2007

Chairs

Carsten Juergens- University of Bochum, Germany
Derya Maktav - Tecn. University Istanbul, Turkey

Topics

Topics URBAN 2007

1. New data & sensors for urban area remote sensing
2. Structure detection and characterization in urban areas
3. Algorithms and techniques for remotely sensed data interpretation in urban areas
4. Algorithms and techniques for urban area applications

Topics URS 2007

5. Urban Climatology, Geology & Geohazards
6. RS Applications to Social Science
7. RS Applications to Urban Planning and Conservation
8. Urban Development and Growth tracking
9. Urban/Peri-Urban Ecology

Deadlines

First call and information:	1 April 06
Abstract submission:	30 September 06
Review process completed:	30 November 06
Final paper submission:	31 January 07
Meeting:	11-13 April 07

Contact

urban_2001@ele.unipv.it
http://tlc.unipv.it/urban-remote-sensing-2007

URSI CONFERENCE CALENDAR

July 2006

Workshop on Waves and Turbulence Phenomena in Space Plasmas
Kiten, Bulgaria, 1-9 July 2006
Contact : Prof. Ivan Zhelyazkov, Sofia University, Faculty of Physics, 5 James Bourchier Blvd, BG-1164 Sofia, Bulgaria, Fax +359 2-9625 276, E-mail : izh@phys.uni-sofia.bg

36th COSPAR Scientific Assembly
Beijing, China, 16-23 July 2006
cf. announcement in the Radio Science Bulletin of June 2005 p. 85
Contact : COSPAR Secretariat, 51, bd. de Montmorency, F-75016 Paris, France, Tel : +33-1-45250679, Fax : +33-1-40509827, E-mail : cospar@cosparhq.org Web : http://meetings.copernicus.org/cospar2006/

IRST2006 - Ionospheric Radio Systems and Techniques Conference
London, United Kingdom, 18-21 July 2006
cf. announcement in the Radio Science Bulletin of June 2005 p. 85
Contact : IRST 2006 ORGANISER, The IEE, Event Services, Michael Faraday House, Six Hills Way, Stevenage, Hertfordshire SG1 2AY, United Kingdom, Tel : +44 1438 765647, Fax : +44 1483 765659, E-mail: eventsa2@iee.org.uk, Web : http://conferences.iee.org/IRST2006/

September 2006

ISROSES - International Symposium on Recent Obsrvations and Simulations of the Sun-Earth System
Varna, Bulgaria, 17-22 September 2006
cf. announcement in the Radio Science Bulletin of March 2006 p. 53-54
Contact : E-mail : isroses2006@abv.bg, Web : http://www.isroses.org/

Vertical Coupling in the Atmospheric/Ionospheric System
Varna, Bulgaria, 18-22 September 2006
Contact : Dr. Dora Pancheva, Centre for Space, Atmospheric & Oceanic Science, Dept. of Electronic and Electrical Engineering, University of Bath, Bath BA2 7AY, United Kingdom, Fax : +44 1225-386305, E-mail : eesdvp@bath.ac.uk, Web : http://www.iaga.geophys.bas.bg/

IVth International Workshop on Electromagnetic Wave Scattering
Gebze, Kocaeli, Turkey, 18-22 September 2006
Contact : E-mail : ews2006@gyte.edu.tr, Web : http://www.gyte.edu.tr/gytenet/Dosya/102/ews/2006/index.html

International conference on Ultrawideband
Waltham, MA, USA, 24-27 September 2006
Contact : Dr. A. F. Molisch, Mitsubishi Electric Research Labs, 201 Broadway, Cambridge, MA 02139, USA, Fax : +1 617 621 7550, E-mail : Andreas.Molisch@ieee.org , http://www.icuwb2006.org/

October 2006

IRI Workshop 2006 - New Measurements for Improved IRI TEC Representation
Buenos Aires, Argentina, 16-20 October 2006
Contact : Marta Mosert, Av. Espana 1512 (sur), Capital, CP 5400, Ciudad de San Juan, Argentina, Fax +54 2644213653, mmosert@casleo.gov.ar , Web : http://www.casleo.gov.ar/WSIRI2006 (not yet operable)

November 2006

EuCAP 2006 - European Conference on Antennas and Propagation
Nice, France, 6-10 November 2006
Contact : EuCAP 2006 Secretariat, ESA Conference Bureau, Postbus 299, NL-2200 AG Noordwijk, The Netherlands, Tel. : +31 71 565 5005, Fax : +31 71 565 5658, E-mail : eucap2006@esa.int, Web : www.eucap2006.org and http://www.congrex.nl/06a08/

December 2006

International Workshop on Technical and Scientific Aspects of MST Radar
Gadanki/Tirupati, India, 11-15 December 2006
cf. announcement in the Radio Science Bulletin of March 2006 p. 54-55
Contact : Prof. D. Narayana Rao, Director, National Atmospheric Research Laboratory, Post Box 123, Tirupati-517 502, India, Fax : +91 8585 272018/272021, E-mail : mst11@narl.gov.in , Web : http://www.narl.gov.in/mst-11.html

APMC 2006 - 2006 Asia-Pacific Microwave Conference
Yokohama, Japan, 12-15 December 2006
cf. announcement in the Radio Science Bulletin of September 2005 p. 44
Contact : Dr. Takashi Ohira, 2-2-2 Hikaridai, Keihanna Science City, Kyoto 619-0288, Japan, Fax : +81 774-95 1508, E-mail : ohira@atr.jp , Web : http://www.apmc2006.org

April 2007

URBAN 2007 - Urban Remote Sensing Joint Event 2007
Paris, France, 11-13 April 2007
Contact : Paolo Gamba, Dipartimento di Elettronica, Università di Pavia, Via Ferrata 1, 27100 Pavia, Italy, Fax +390 382-422583, e-mail : paolo.gamba@unipv.it , Web : http://tlc.unipv.it/urban-remote-sensing-2007/index.html

August 2007

ISAP 2007 - International Symposium on Antennas and Propagation
Niigata, Japan, 20-24 August 2007
Contact : Yoshihiko Konishi (Publicity Chair), Mitsubishi Electric Corporation, 5-1-1 Ofuna, Kamakura, 247-8501 Japan, E-mail : isap-2007@mail.ieice.org, Web : http://www.isap07.org

AP-RASC 2007 - Asia-Pacific Radio Science Conference
Perth, Western Australia, August or September 2007 (exact date not fixed yet)
Contact : Dr. Phil Wilkinson, Deputy Director IPS Radio and Space Services, Department of Industry, Tourism and Resources, P O Box 1386, Haymarket, NSW 1240, AUSTRALIA, Tel : +61 2 9213 8003, Fax : +61 2 9213 8060, E-mail: phil@ips.gov.au, Web : http://www.ap-rasc07.org/

October 2007

Metamaterials 2007 - The First International Congress on Advanced Electromagnetic Materials for Microwaves and Optics
Rome, Italy, 22-26 October 2007
Contact : Dr. Said Zouhdi, Electrical Engineering, University Pierre et Marie Curie, Paris, France + Laboratoire de Genie Electrique de Paris LGEP-Supelec, Fax : + 33 1 69 41 83 18, E-mail : sz@ccr.jussieu.fr

August 2008

URSI GA08 - XXIXth URSI General Assembly
Chicago, IL, USA, 9-16 August 2008
Contact : URSI Secretariat, c/o INTEC, Ghent University, Sint-Pietersnieuwstraat 41, B-9000 Ghent, Belgium, Tel. : +32 9 264 3320, Fax : +32 9 264 4288, E-mail : info@ursi.org

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Information for authors

Content

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