Broad-band Microwave Photonic Links for antenna applications[1]

Submitted to

Department of Electronics
New Delhi

NCRA • TIFR

National Centre for Radio Astrophysics
TATA INSTITUTE OF FUNDAMENTAL RESEARCH
Pune University Campus, Pune - 411007, INDIA

[1]Aj~SAK/DoEProj-rev

Department of Electronics

R&D Project proposal for Seeking Financial Support

SUMMARY SHEET

1	2		3
1.	Title of Project	:	Broad-band microwave photonic links for antenna applications
2.	Organisation		
	a) Name	:	National Center for Radio Astrophysics Tata Institute of Fundamental Research
	b) Address	:	Post Bag 3, Ganeshkhind, Pune University Campus, Pune 411007
	c) Legal status	:	Autonomus body
3.	Chief Investigator		
	a) Name	:	M.R. Sankararaman
	b) Designation	:	Scientific Officer–SF
	c) Department	:	NCRA–TIFR
	d) Address	:	NCRA–TIFR, Pune University Campus Post Bag 3, Ganeshkhind Pune 411 007 Tel:0212-357107, Fax:355149 E-mail:mrs@ncra.tifr.res.in
4.	Nature of Project	:	Application oriented Research & Development having production potential
5.	Objective of the Project	:	Development of technology for microwave photonic links upto 2 GHz signal bandwidth; extendable upto 5 GHz

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6.	Brief outline of the project with specific technology fallouts	:	The GMRT consists of 30 numbers of 45 metre diameter fully steerable parabolic dishes installed over an area of 625 sq.km approx. The antennas are located at various distances up to 15 Kms from a central electronics building (CEB). Signals received by the dishes in the frequency band of 38-1600 MHz (RF) are sent to the CEB after down converting them to IF frequency bands of 130 and 175 MHz corresponding to right and left circular polarizations. An optical fiber network is used for transmission of the astronomical signals, control & monitor data and voice between the CEB and the remote antennas. It consists of 30 independent pairs of single mode fibers and operates in the 1300nm band. Controlling and monitoring of dish movements and the receiver hardware at the antenna locations are done from the CEB. The IF signals received at the CEB from the antennas are converted to video band having a maximum bandwidth of a maximum of 32 MHz, sampled, delay corrected and correlated. The two way transmission between the CEB and antennas uses analog modulation technique. It has been planned to send the data and other signals to the academic centre of the GMRT at Pune through a *155 Mb/s optical fiber link between the telescope site (GMRT, Khodad) and academic centre (NCRA, Pune) and control the antennas and other systems from Pune by a similar link. This proposal specifically deals with a scheme for bringing the RF signals directly from the prime focus of the antennas to the CEB by a microwave photonic link using WDM technique working in the 1310 nm/1550 nm windows and sending the processed data to NCRA, Pune for analysis. The advantages of this scheme are: • Utilisation of the full bandwidth of the broad band feeds. As an example, the corrugated horn used in GMRT is a wide band feed and has a bandwidth of 1000-1500 MHz. Presently, in order to avoid intermodulation products, EMI and dynamic range problems, observations are restricted to 32 MHz slots across the band at a given time. In the proposed photonic modulation, these restrictions are not there; it is possible to recover the entire 500 MHz at any time as video signal and make the GMRT operating as a wideband interferometric / phased array instrument.

* The data rate will be extended to 1 Gb/s at a later date.

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- It gives the flexibility of choosing the frequency band of interest anywhere in the entire 500 MHz band unlike the present arrrangement of using a narrow bandwidth filter at the front end to avoid interference related problems. This will make GMRT a unique instrument having a competitive edge over contemporary radio telescopes.

- System complexity and losses are less

  The proposed scheme needs only the hardware required to modulate the RF signals onto the optical carrier and the optical transmission medium. The RF/LO/IF hardware at the remote antenna locations for down converting the signals will not be required. Hence, there will be saving in signal loss budget and a reduction in complexity of electronics at remote antennas.

- Easy estimation of system delays by employing round trip calibration signals from the CEB.

  It is proposed to send calibration signals from the CEB to the antennas in the forward optical links which can be recovered at the prime focus of the each antenna. They can be combined with the signals from space and returned to CEB (Round trip). The system delays from the front end up to the correlator input can be estimated directly by a comparision of the sent and received calibration signals for correcting the phase differences between the antennas(interferometry). Presently the delays are estimated by observing radio stars.

- EMI problems get eliminated by adopting photonic links and reducing hardware for hetrodyning signals.

  The GMRT group has developed expertise in transmitting signals upto 300 MHz using direct modulation technique. In this proposal,the range is extended to 2 GHz and beyond. WDM technique will be employed in this project for simultanously transmitting various signals in both the directions of the transmission medium. Such wideband backbone links can be used for satellite onboard communications, integrated service of voice, data and other signals, Radars etc.

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7.	Expected outcome in physical terms		
	a) Specifications of subsystem / system	:	Details same as mentioned item 6 above.
	b) Nature of documents for technology transfer	:	Know how document.
	c) Manpower trained	:	
	i. Level of training		Communication engineers and technical assistants.
	ii. Numbers		8 (Eight) Nos.
8.	Agency with which link up is established / proposed	:	As one of the users of the system developed under the project,it is proposed to replicate them in the other GMRT antennas.
9.	Duration of Project	:	Two years.
10	Year-wise break-up of physical achievements with specific intermediate milestones (in terms of aims and objectives)	:	

FIRST YEAR

a.	Preliminary Design (PD) of the microwave photonic link for 2 GHz extendable to 5 GHz.	2 months
b.	Identification of components and detailed design (DD)	3 months
c.	i) Procurement of components and equipments ii) Final design review (FDR) iii) Testing and commissioning the 155Mbps optical fiber link between GMRT,Khodad and NCRA, Pune	7 months

SECOND YEAR

d.	Development & Prototype testing of the 2GHz link in lab	6 months
e.	Testing the prototype in the field	3 months
f.	Integration and Commissioning	3 months

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		Notes on intermediate milestones:

- Preliminary design documents will be prepared with detailed specifications and drawings at the end of 2 months.
- Design will be reviewed after knowing the availability of components in the market at the end of 5 months.
- Final Design review at the end of 8 months.
- Since the knowhow is available for the backend data link, it will be completed as soon as components are procured and tested on bench. Expected date of completion is the end of first year.
- Prototype development and testing of the 2 GHz link at the end of 18 months.
- A spare system also will be developed. These two systems will be installed in two of the GMRT antennas which will be operated as an interferometer pair and the performance will be evaluated and validated for replication.

11. Likely End-user(s) : GMRT and ISRO

12. Name of other organisations jointly participating in the project (including organisations abroad) : nil

13. Total budget outlay

(Rs. lakhs)†

Head	1st Year	2nd Year	TIFR	DOE	Total
Capital Equpt.	34 (34)	–	4	30 -20 =10	34 ← 20 lakhs cut finally
Consumable stores	18 (17)	6 (5)	–	24	24
Duty on import, if any	–	–	–	–	–
Manpower	15	15	20	10	30
Travel & training	3 (1.5)	3 (1.5)		6	6
Contigencies	2(1)	3(1)		5	5
Overheads, if any	6	2		8	8
Grand total (FEcomp)	78 (53.5)	29 (7.5)	24	83 -20 =63	107 -20 = 87

FE Components are indicated inside brackets.

† These are indicative figures only. Conversion factor of Rs.40 = $1 has been taken for calculation.

14. a) Contribution of Project Implementing / & other Organisation (TIFR) in total budget outlay : Rs.24.00 Lakhs

b) DOE Contribution : Rs.83.00 Lakhs

Signature of Chief Investigator
Name M.R. Sankararaman
Designation Scientific Officer (SF)
Date

Signature of Head of the Institution
Name Prof. V.K. Kapahi
Designation Director, NCRA
Date

Note: A brochure narrating the activities of the GMRT project is enclosed herewith.

Details of the Project Proposal
PART 1: BACKGROUND INFORMATION

1	2		3
1.	Title of Project	:	Broad-band Microwave Photonic Link for Antenna Applications
2.	i. Chief Investigator	:	M.R. Sankararaman
	ii. Co-Investigator	:	R.Balasubramanian, A.Praveen Kumar, M.Srinivas, S.Sureshkumar
3.	Other investigators of the Project with their designations	:	—
4.	Brief Biodata Chief Investigator & other investigators	:	(Biodata of the investigators enclosed — Annexures (a, b, c, d, e)
5.	Competence of Investigator in Project Area	:	Chief Investigator 1. Senior member of the electronics group of the GMRT project having 29 years of experience in the field of Radio Astronomy instrumentation. 2. Has developed VHF antennas, system for signal reception, transmission. 3. Has extensive experience in system engineering. 4. Has experience in development and management of analog optical fibre links for GMRT.
6.	Other Committments of the Chief Investigator and Co-Investigators.	:	Management, development and up keep of the systems of the GMRT project.
7.	Details on each of the ongoing/completed projects with the Chief Investigator/Co-Investigator/R&D Team	:	1. Completion and upgradation the analog fiber optic links for the GMRT in the range of 10 to 300 MHz. 2. Completion and upgradation of the asynchronus and synchronus communication systems of the GMRT for voice and data transmission. 3. Prototype development of a 256 kbps long haul photonic link for data transmission.

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8.	Brief summary of other project proposals awaiting consideration of DOE and other funding agencies like DST, DRDO, DSIR, MHRD, ICICI, IDBI, etc.	:	Nil.
9.	Infrastructure and other facilities available at the institute of undertaking this project		
	a) List of major equipment alongwith model numbers, specifications, etc.	:	See list below
	b) Existing manpower and other personnel with names available for the project on full-time basis	:	M.R.Sankararaman, R.Balasubramanian, A. Praveen Kumar, M. Srinivas, S.Sureshkumar, S.Suresh Sabapathy. They will undertake responsibility in the project alongwith their work committment to GMRT jobs.
10.	Expensive Equipment / facilities available elsewhere which could be made use of for the project	:	NA
11.	Details of Collaborating agencies	:	NA
12.	Additional Information, if any	:	NA

List of major equipments

Name	Specifications	Model No.
1. Spectrum Analyzers	9 KHz - 1.8 GHz	HP8590/91
2. Signal Generator	10 KHz - 2.7 GHz	Marconi 2041
3. Signal Generator	0.26 - 2060 MHz	HP8644A
4. Vector Network Analyzer	3 kHz - 3 GHz	HP8753C
5. RF Powermeters		
6. DSO		
7. Arbitrary Waveform Generator		
8. OTDR	128 KMs range 35 dB DR	TEKRANGER TFS 031
9. OTDR	1300nm; 128 Kms	
9. Optical Attenuator		
10. Optical Power Source	- 7dBm o/p	TOP200
11. Optical Power Meter	+10 - -70 dBm	TOP140

PART II: TECHNICAL INFORMATION

2		3
2. Aim, Scope and Detailed description of the Project	:	The aim of the project is to develop a prototype of a 2 GHz microwave photonic link for the GMRT project for broadband signal reception and replicate it for use in all its antennas. The range of the link can be extended to 5 GHz.

The work involves –

- transporting the Signals received by the antennas of the GMRT in the range of 38 to 1600 MHz, from the prime focus to the central electronics building (CEB) 20 km away,by employing microwave modulation and WDM techniques.
- Transporting the processed data and other signals (video,voice, antenna control signals etc.) to the academic centre (NCRA) thro' a 90 Km long optical fiber link and
- Controlling the antennas and systems from the NCRA

The scheme is benificial to the GMRT users in a number of ways. The GMRT is a multi frequency instrument and operates in the range od 38 to 1600 MHz. It uses dual polarised feeds having large bandwidths. As an example,the feed for the L band is a corrugated horn whose bandwidth is 500 MHz. The receiver system uses filters at the front end to remove interference signals staturating the receiver chain and affecting the dynamic range of the GMRT.

By employing microwave photonic modulation, saturation problem and inter modulation products can be eliminated. The electronics at the remote antennas sites as well as CEB will become simpler. The schematic diagram† and the enclosed brochure‡ explain the topology of the GMRT network and the scope of the proposed project.

The antennas and the linear systems at Khodad can be controlled using the 90 km data link, from the academic centre at Pune and data can be obtained from the antennas for analysis at Pune. (Fig. 2)

† Figures 1(a) & 1(b).

‡ Annexure I

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3.	Need, forecast and urgency for the technology proposed to be developed with justification, such as importance of know-how, import substitution role, pay off w.r.t. purchase of know-how or development of technology competitiveness, technology exports, international alliances possibilities, etc.	:	For quite some time, researchers have been investigating photonic devices for use in mutiple disciplines such as antennas, phased arrays and sensors. Photonic antenna systems offer high immunity from EMI, provide extremely wide bandwidth and allow long cable runs with minimum loss. They also offer larger dynamic range. It is well known that receiver systems suffer from pass band slope effect of the cables which can be eliminated by using optical fiber links and modulator systems. The proposal offers the following advantages: • Utilisation of the full bandwidth of the broad band feeds As an example,the corrugated horn used in GMRT is a wide band feed and has a bandwidth of 1000-1500 MHz. Presently, in order to avoid intermodulation products, EMI and dynamic range problems, observations are restricted to 16 MHz slots across the band at a given time. In the proposed photonic modulation, these restrictions are not there; it is possible to recover the entire 500 MHz at any time as video signal and make the GMRT operating as a wideband interferometric/phased array instrument. It gives the flexibility of choosing the frequency band of interest anywhere in the entire 500 MHz band unlike the present arrrangement of using a narrow bandwidth filter at the front end which restricts the observable band. With increasing EMI pollution levels, it is essential that the maximum observational bandwidth is made available for judicious selection of RF passbands. This will make GMRT a unique instrument having a competitive edge over contemporary telescopes. • System complexity and losses are less The proposed scheme needs only the hardware required to modulate the RF signals onto the optical carrier and the optical transmission medium. The RF/LO/IF hardware at the remote antenna locations for down converting the signals will not be required. Hence, there will be saving in loss budget and a reduction in complexity of eletronics at remote antennas.

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			• easy estimation of system delays by employing round trip calibration signals from the CEB. The GMRT group has developed expertise in transmitting signals upto 300 MHz using direct modulation technique. In this proposal,the range is extended to 2 GHz and beyond. WDM technique will be employed in this project for simultanously transmitting various signals in both the directions of the transmission medium. Such wideband backbone links can be used for satellite onboard communications, integrated service of voice, data and other signals, Radars etc. This activity has been recommended by the technical panel on Microwave Photonics, set up by DOE, GOI.
4.	Specific manner in which know-how generated here is envisaged to be translated into production, details regarding a) the end product	:	The 2 GHz microwavephotonic link will be used in all the antennas of GMRT and will meet the specifications mentioned hereunder. SPECIFICATIONS Please see Annexure f for general targetted specifications.
	b) availability of pilot production facility in the organisation	:	Replication of the system will be done by the TIFR, Pune group.
5.	a) Name of production agencies willing to productionise / use and market surveys, if any, made by them regarding demand for the product b) Alternative production / user agencies	:	Not Applicable
6.	Period required for completing the project	:	2 years

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7.	Details of work already done by present investigators / R&D team in this or other areas		
	a) Successfully completed on schedule	:	1. GMRT fiber-optic link 2. RF Frontend Systems for all the GMRT frequency bands. 3. Telemetry links for GMRT for voice and data transmission. 4. Establishment of Fiber-optic communication link for Telemetry and IF transmission at MCF, Hassan.
	b) Currently in progress	:	Upgradation of telemetry links and optical fiber links of GMRT.
	c) Abandoned	:	NA
	d) Industry interaction / know-how transferred	:	NA
8.	Summary of similar work being done elsewhere in the country	:	To the best of our knowledge, no other agency is doing this type of work.
9.	Information regarding specific intermediate milestones	:	FIRST YEAR

a.		Preliminary Design (PD) of the microwave photonic link for 2 GHz extendable to 5 GHz.	2 months
b.		Identification of components and detailed design (DD)	3 months
c.	i.	Procurement of components & equipments	7 months
	ii.	Final design review (FDR)	
	iii.	Testing and commissioning the 155Mbps optical fiber link between GMRT, Khodad and NCRA, Pune	

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			SECOND YEAR
			d. Development & Prototype testing of the 2GHz link in lab — 6 months
			e. Testing the prototype in the field — 3 months
			f. Integration and Commissioning — 3 months
10.	a) Specific problems hold-ups and difficulties foreseen in the implementation of the project	:	Delays in importing components and equipments
	b If the answer is not Nil to 10(a), how does Chief Investigator propose to overcome them?	:	By proper follow up.
11.	Detailed PERT / BAR Chart	:	See Annexure g.
12.	Details of possible alternative arrangements if the Chief Investigator leaves institution or is unable for any other reason to continue on this project	:	Prof. S. Ananthakrishnan, Dean, NCRA Faculty
13.	Name of other organisations in India or Abroad jointly participating in this effort, extent of their involvement, specific division of responsibility, accountability, etc.	:	NA
14.	List of personnel already working in the organisation who would be transferred to work full time on this project	:	M.R.SANKARARAMAN, R.Balasubramanian, A.Praveen Kumar, M.Srinivas, S. Sureshkumar, Suresh Sabapathy. They will undertake the responsibilities in this project alongwith their work commitment to GMRT jobs.
15.	Name of the experts whom the Chief Investigator would invite to join the project team as full time / part time member	:	—

PART III — Financial Details

Table–I: Yearly Break-up

Budget requirements for the first year.

(Rupees in Lakhs)

Sr. No.	Head	Local Expenses	Foreign Exchange (FE)	Duty	Total	Part of 6 to be borne BY TIFR	Amount payable by DOE
1	2	3	4	5	6	7	8
1.	Capital Eqpt.	-	34	-	34	4	30
2.	Consumable	1	17	-	18	-	18
3.	Manpower	15	-	-	15	10	5
4.	Travel/Training	1.5	1.5	-	3	-	3
5.	Contigencies/ Other Exp.	1	1	-	2	-	2
6.	Overhead, if any	6	-	-	6	-	6
	Total Rs.	24.5	53.5	-	78	14	64 -20 = 44 lakhs

Budget requirements for the second year.

(Rupees in Lakhs)

Sr. No.	Head	Local Expenses	Foreign Exchange (FE)	Duty	Total	Part of 6 to be borne BY TIFR	Amount payable by DOE
1	2	3	4	5	6	7	8
1.	Capital Eqpt.	-	-	-	-	-	-
2.	Consumable	1	5	-	6	-	6
3.	Manpower	15	-	-	15	10	5
4.	Travel/ Training	1.5	1.5	-	3	-	3
5.	Contigencies/ Other Exp.	2	1	-	3	-	3
6.	Overhead, if any,	2	-	-	2	-	2
	Total Rs.	21.5	7.5	-	29	10	19

Table-II: Sub-system wise break-up (Indicative list)

(Rs. in lakhs)

Sr.no		Item descrption	local	FE	Duty	freight	Total
1.	**Equipments:**						**34.00** - 20 lakhs finally not Sanctioned by DoT
	i.	Optical spectrum analyser		12.00			12.00
	ii.	Tunable Laser source with WDM test set		8.00			8.00
	iii.	Digital communication analyser with plug-in for 1000–1600 nm range		11.00			11.00
	iv.	Precision reflectometer		3.00			3.00
2.	**Components:**						**22.00**
	i.	Optical transmitter unit		10.0			10.0
	ii.	Optical receiver unit		2.0			2.0
	iii.	WDM unit		4.8			4.8
	iv.	Optical filter (@1300 nm & @1550 nm)		2.8			2.8
	v.	Other unit components like connectors, cables, etc.		2.4			2.4
3.	**Materials:**						
		PCBs, plug-in-units, chassis, etc.	2.0				**2.00**

Table III Manpower details

(Rupees in Lakhs)

Sr. No.	Manpower	Salary				Total Exp.
		1st Year		2nd Year		
		No. of posts	Total Exp.	No. of posts	Total Exp.	
1.	Regular Staff	7	10	7	10	20
2.	Project Staff	4	5	4	5	10
	Total:	11	15	11	15	30

PART IV

A. **Terms and Conditions Governing the Grant-in-Aid.**

i) the grant is for the specific project as approved by DOE and shall be subject to the following conditions:

(a) The grant amount shall be spent for the project within the specified time,

(b) Any portion of the grant which is not ultimately required for expenditure for the approved purposes shall be duly surrendered to DOE;

ii) The granteee institution shall maintain an audited record in the form of a register in the prescribed proforma for permanent, semi-permanent assets acquired solely or mainly out of DOE grant;

iii) The assets referred to in (ii) above will be property of DOE and should not, without prior sanction of DOE, be disposed of or encumbered or utilised for purposes other than those for which the grant has been sanctioned. An undertaking shall be given by the grantee institution that they agree to be governed by these conditions;

iv) At the conclusion of the project, DOE will be free to sell or otherwise dispose off the assets which are the property of DOE and grantee institution shall render to DOE the necessary facilities for facilitating the sale of these assets;

v) The grantee institution shall send to the Department of Electronics at the end of each financial year as well as at the time of seeking further instalments of the grant of a list of assets referred to in (ii) above;

vi) Should at any time grantee institution ceases to exist, such assets etc., shall revert to DOE;

vii) The grantee institution shall render progress-cum-achievement reports at interval of six months on the progress made on all aspects of the project including expenditure incured on various approved items during the period.

viii) The grantee institution shall render an audited statement of accounts to DOE;

ix) The audited statement of accounts relating to grants given during financial year together with the comments of the auditor regarding the observance of the conditions governing the grant should be forwarded to the Department of Electronics within six months following the end of the relevant financial year.

x) The utilisation of grant for the intended purposes will be looked into by the Auditor of grantee institution according to the directives issued by the Government of India at the instance of the Comptroller and Auditor General and the specific mention about it will be made in the audit report;

xi) DOE or its nominee will have the right of access to the books and accounts of the grantee institution for which a reasonable prior notice would be given;

xii) The grantee institution should maintain separate audited account for the project. If it is found expedient to keep a part or whole of the grant in a bank account earning interest, the interest, thus earned should be reported to this Department. The interest so earned will be treated as a credit to the grantee to be adjusted towards future instalment of the grant;

xiii) Sale proceeds of component, prototype, pilot project etc. fabricated as a result of the development of the project arising directly from funds granted by Department of Electronics shall be remitted to DOE.

xiv) The know-how generated by the project shall be property of DOE. Any receipt by way of sale of know-how, royalities etc., shall accrue to DOE. DOE may, in its discretion, allow or direct a portion of such receipts to be retained by the grantee organisation;

xv) DOE will have the right to call for drawing, specifications and other data necessary to enable the transfer of know-how to other parties and the grantee shall supply all the needed data at the request of DOE;

xvi) Application by grantee institution for any other financial assistance or receipt of grant/loan from any other Agency/Ministry/Department of this project should have the prior approval of Department of Electronics;

xvii) The Grantee institution is not allowed to entrust the implementation of this project for which grant-in-aid is received to another institution and to divert the grant-in-aid received from Department of Electronics as assistance to the latter institution.

Special Terms and Conditions for Co-financing

General terms and conditions as at S.No. xiii) ands xiv) would be changed to speical terms and conditions for co-financing for various scenarios.

B. **Special Terms and Conditions for Co-financing**

i) The funding by the Department of Electronics would be in the form of grant-in-aid. The general terms and conditions governing grant-in-aid are given in Annexure A.

ii) The co-financing industry would have the first right to commercialise the know-how on an exclusive basis for a fixed period after the completion of the project. The fixed period for different scenarios is indicated below.

a) In the case of direct R&D funding to industry where the industry is not only co-financing but also implementing the project, the industry would have to share atleast 50 per cent of the project cost at the industry. The fixed period for exclusive right on the know-how in this case would be three years.

b) In case of industry joining hands with DOE to fund an R&D activity at a third party, the fixed period for exclusive right to commercialise the know-how would vary in proportion to the extent of financial participation by the industry as follows.

3 years for 50% or more of the total project cost

2 years for 25% to 50% of the total project cost

1 year for 15% to 25% of the total project cost

Nil for 0% to 15% of the total project cost

c) In case of cooperative R&D where the industry is co-financing the R&D and the implementing agencies would include the co-financing industry as well as R&D laboratories and academic institutions, the industry would have to share atleast 50% of the project cost at the industry with the added proviso that the industry share of the total cooperative R&D project cost covering the projects at the industry, the R&D laboratories and academic institutions would be atleast 25%. As in the case of ii a) above, while the industry would have a three years fixed period of exclusive rights on the know-how generated at the industry, the period of exclusive right to the industry for the total know-how would vary in proportion to its share of the total project cost as follows:

3 years for 50% or more of the total project cost

2 years for 25% to 50% of the total project cost

1 year for 15% to 25% of the total project cost

Nil for 0% to 15% of the total project cost

d) In the case of R&D with user participation where the industry is merely executing the project co-financed by end users/DOE and other goverment departments, while it will have the rights to commercialise the know-how, the financiers will have full rights to transfer the know-how to any party of their choice immediately on completion of the project.

e) In case there are multiple co-financing industries as well as end-users/DOE and other government departments and multiple implementing agencies, the terms and conditions including, inter-alia, rights to commercialise and transfer of know-how will be settled prior to project implementation through mutual agreement of all concerned parties

iii) At the end of the fixed period for exclusive rights to the know-how in the above scenarios, in case the industry wants to have total ownership on the know-how, it will have to reimburse to the Department of Electronics and other co-financing users/government departments, the amounts provided by them as grant-in-aid alongwith the prevailing interest for the fixed period in a single instalment. Otherwise, DOE and other co-financing users/ government departments would have full rights to transfer the know-how to any other party at their discretion and the co-financing industry will not have any claim on the know-how fee.

iv) In case the co-financing industry indicates its disinterest to commercialise the know-how at the end of the project, Department of Electronics and other co-financing users/government departments may transfer the know-how to any other party at its discretion and the know-how fee charged by Department of Electronics would be shared with the co-financing industry in proportion to the sharing of the project cost.

PART V

Endorsement by the Head of the Institution

1. I have read the terms and conditions (including special terms and conditions for co-financing) governing the grant-in-aid and I agree to abide by them.
2. I certify that I have no objection to the submission of this research proposal for consideration by the Department of Electronics.
3. In case the project is approved, I undertake to make available facilities to carry it out, to arrange for the submission of periodic progress reports and other information that may be required by the Department of Electronics and in general to ensure that the conditions attached to the award of such grant are fulfilled by my institution/organsiation.
4. I certify that in case present chief investigator is not available for any reason to continue work on this project, the following persons will be available to carry it through to completion:

   Name Designation

   1. PROF. S. ANANTHAKRISHNAN, DEAN, NCRA

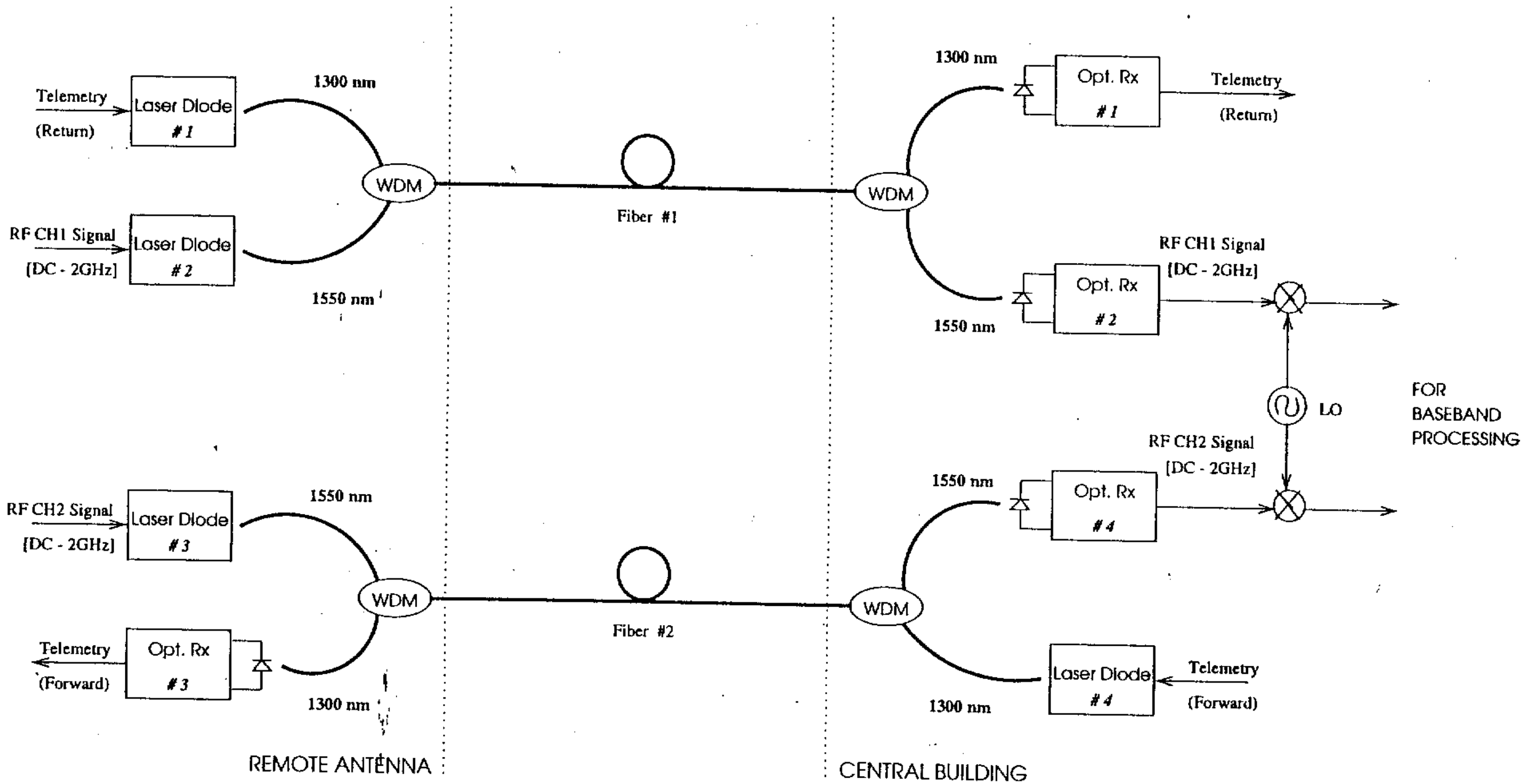
   2.
5. I certify that the facilities mentioned in the body of this report are available at my institution.
6. I certify that I shall ensure that accounts will be kept of the funds received and spent and made available on demand, as specified and required by the Department of Electronics.
7. I certify that I am the competent authority, by virtue of the administrative and financial powers vested in me by . . . . to undertake the above stated commitments on behalf of my institution.

VKKapahi

Signature of the
Head of the Institution
Designation

Date:

Scheme 1



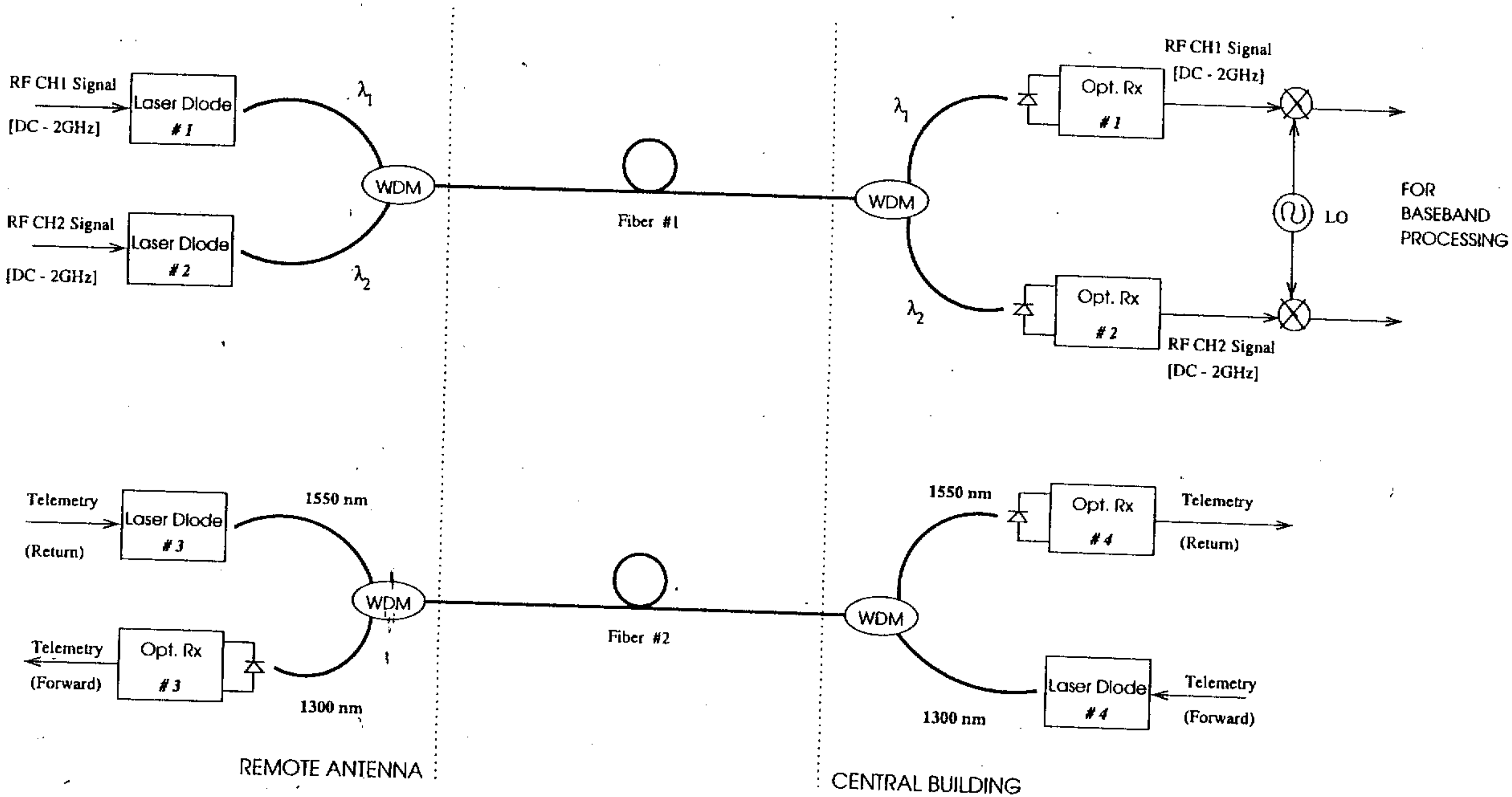
NOTES

#1 The Telemetry link will be 255 Kbps digital link operating at 1300 nm.

#2 The dual polarized astronomical signals (CH1 & CH2) is carried via analog link operating at 1550 nm.

FIGURE 1a.

Scheme 2

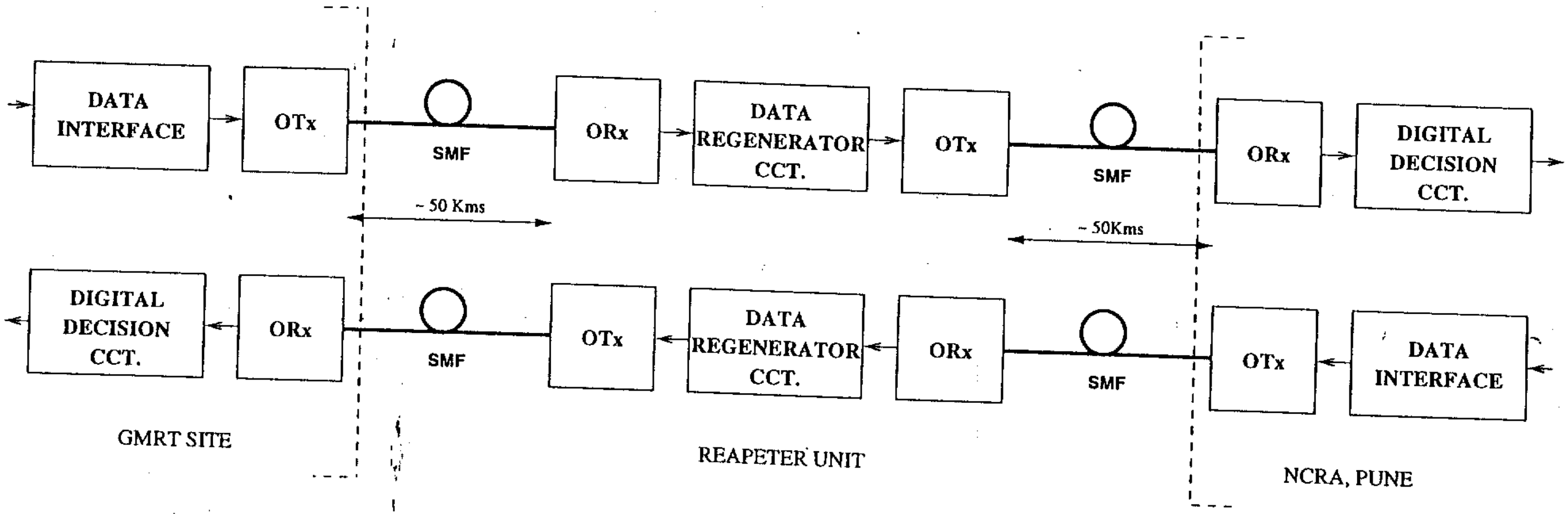


NOTES

#1 The dual polarized astronomical signals will be sent on boradband analog links. The operating wavelengths will be either in the 1300 nm band or in the 1550 nm band.

#2 The telemetry link will be a bi-directional 256 Kbps digital link operating at 1300 / 1550 nm bands.

FIGURE 1b.



NOTES

The following specifications are indicative only.]

#1 Data rate < 1 Gbps

#2 Optical Loss = 30 dB @ 1300nm for 50Kms range
20 db @ 1550nm for 50Kms

#3 Electrical Input : ECL / PECL

#4 BER < 10E-09

SCHEMATIC OF THE DIGITAL LINK BETWEEN GMRT SITE AND NCRA,PUNE

Fig 2

Annexure: a

BRIEF BIO-DATA OF M.R.SANKARARAMAN

Name : M.R.Sankararaman

Mailing address : NCRA-TIFR,
Pune university campus,Ganeshkhind,Pune- 411 007.

Date of birth : 25-08-1945.

Qualifications : M.Sc (Physics)
DMIT(Electronics and communication engineering).

Experience : 29 years
Joined TIFR in the year 1969.
Experience in

a. VHF/UHF antenna engineering designs,and development.
b. Receiver systems for Radio Astronomy.
c. telemetry systems.
d. optical fiber communcation systems.
e. General system engineering.

Publications : Four papers.

a. A VLF time signal receiver,Time &freq.symposium held at NPL,New Delhi,Year 1976.
b. Control and monitor system for Ooty Synthesis Radio Telescope,IETE,VOL 28,No.5,1982.
c. Metre-wavelength VLBI experiment at Ooty.IJRS,vol 14, 1985.
d. Microsecond time synchronisation between GMRT,Pune and NPL,NEW DELHI using INSAT standard time and Frequency broadcast in differential mode IETE tech.review,vol 13, nos.45,july -oct 1996.

Awards : Dr.K.S.Krishnan award for the best paper in IETE magazine for the year 1982,shared with other authors.

Distinction : Fellow of IETE.

Annexure-1.

BRIEF BIO-DATA OF R.BALASUBRAMANIAM

Name	:	R.BALASUBRAMANIAM
Mailing Address	:	National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, P.B. No.3, Pune University campus, GaneshKhind, Pune, 411 007.
Date of Birth	:	10th June, 1952
Qualifications	:	B.Sc(Physics) : 1973 Grad.IETE(AMIETE) : 1980 Corporate Member of IETE.
Specialization	:	Data Communication systems and Networking.
Experience (TIFR)	:	Jan.1974 - To date. 24 years Exp. Presently working as Scientific Officer, SE. The major projects designed and developed includes 'Control and Monitor system for the GMRT,'Declination Control and Monitor system for the New Feed of Ooty Radio Telescope, 'Control and Monitor system for the Ooty Synthesis Radio Telescope etc.
Present Activities	:	Design and development of "Control and Monitor system " for the 30 antennas of GMRT.All the systems have been developed and commissioned in the respective antennas.
Publications	:	1)Co-author of 'Control and Monitor system for the OSRT'. Journal of the IETE,28(5), 1982,pp 216-225.This paper was selected as the best paper in system-oriented studies in 1982 and was awarded K.S.Krishnan memorial award by IETE. 2)Author of 'Control and Monitor system for GMRT,Technical poster in Asia-Pacific Conference,1993. 3)Author of 'Declination Control and Monitor system for the New feed of ORT'. (Under preparation).

Annexure: C

BRIEF BIO-DATA OF A.PRAVEEN KUMAR

Name	:	Alexander Praveen Kumar
Mailing Address	:	National Centre for Radio Astrophysics (NCRA), Tata Institute of Fundamental Research (TIFR), Post Bag No.3, Pune University Campus, Ganeshkhind, PUNE - 411007, Maharashtra.
Date of birth	:	2nd June, 1952
Qualifications	:	B.Sc. (Physics) - 1972 Chartered Engineer (C.Eng)-1981 [CEI-IERE, London,UK].
Specialisation	:	RF &.Microwave Electronics.
Experience (TIFR).	:	Jan 1974 - to date in the design and development of various Systems and Subsystems associated with the Radio Telescope Receivers. Present Grade - Scientific Officer (SE).
Present Activities	:	Design and Develpment of Low Noise Receiver Systems, Fiber-Optic Communication Systems.
Publications	:	(1) 'Asynchronous Modem Incorporating LSI Circuits', A.Praveen Kumar. Journal of 'Computer Science & Informatics' Vol.12, No.1, 1982, pp 15-20 (2) 'Sensitivity Boost to the Ooty Radio Telescope: A New Phased Array of 1056 Dipoles with 1056 Low Noise Amplifiers', A.J.Selvanayagam, A.Praveen Kumar, D.Nandagopal and T.Velusamy. 'IETE Technical Review', Vol.10, No.4, July-August 1993, pp 333-339

Annexure: d

BRIEF BIO-DATA of SRINIVAS M.

1.	Full Name	: Srinivas Meenakshi Sundaram
2.	Date of Birth	: January 10, 1971
3.	Mailing Address	: TIFR, GMRT Site, PB # 6, Narayangoan Pune Dist., Maharashtra INDIA - 410504
3.	Academic Qualificatios	: BE (Hons) Instrumentation [BITS]; 1992
4.	Specialization	: RF Frontend Electronics; Fiber-Optic Links
5.	Experience	: Electronics Engineer SC; 1992 - To date Worked on Design & Development of GMRT RF Electronics; Realization of space qualified 327MHz LNA for a space radiotelescope; Upgradation of GMRT optical fiber links; GMRT receiver system analyses
6.	Present Activities	: System analyses of GMRT analog receiver Upgradation of the optical fiber link of GMRT

Annexure: e

A brief Bio-data of S.SureshKumar

Name	:	S.SureshKumar
Mailing Address	:	NCRA-TIFR, Poona University campus, Ganeshkhind road, P.box. no: 3, Pune -411 007.
e-mail Address	:	skumar@ncra.tifr.res.in / skumar@gmrt.ernet.in
Date of Birth	:	18 th Nov. 1967
Qualifications	:	B.Sc (Physics) - 1989. B.Tech. (Electronics) - 1992. M.E. (Microwave) - will be completing by 1998 March.
Specialisation	:	Fiber Optic Communication Systems
Experience	:	As Electronics Engineer - SC : 1992 - To date, in NCRA-TIFR, Pune.
Work experience	:	1. Antenna design and development 2. Fiber optic communication systems design and development 3. Fiber optic sensors
Present Activities	:	Design and development of long distance digital / analog fiber optic systems for GMRT applications.
Publications	:	Technical reports - 4 nos.

Technical Reports:

i. S.SureshKumar " **Rayleigh Backscattering and Fresnel reflection induced noises in GMRT** ", Nov., 1996 - Internal Tech. report no : R00134.

ii. S.SureshKumar " **Methods to reduce backscattering and reflection induced noises in GMRT fiber optic system**", Jan., 1997 - Internal Tech. report no : R00135.

iii. S.SureshKumar, " **A Project proposal for Pune - Narayangaon fiber optic link**", Sep., 1997.

iv. S.SureshKumar, " **Phase Stability of the GMRT Fiber Optic System**", Oct., 1997.

Annexure: F

GENERAL TARGETTED SPECIFICATIONS FOR MICROWAVE PHOTONICS LINK

# 1. ELECTRICAL BANDWIDTH	:	2 GHz (10 MHz to 2 GHz)
# 2. AMPLITUDE FLATNESS	:	=/- 2 dB.
# 3. FIBER TYPE	:	SINGLE MODE SMF 28 TYPE.
# 4. WORKING RANGE	:	UP TO 25 KMS.
# 5. SNR(16 MHz)	:	> 30 dB.
# 6. INPUT/OUTPUT VSWR	:	BETTER THAN 1.5:1
# 7. INPUT /OUTPUT IMPEDANCE	:	50 OHMS.
# 8. ONE dB COMPRESSION POINT	:	MIN + 13 dBm.
# 9. THIRD ORDER INTERMODULATION INTERCEPT POINT	:	MIN + 30 dBm
#10. OPERATING WAVELENGTH	:	FOR SCHEME 1. 1550 nm FOR MICROWAVE PHOTONIC LINK AND 1300 nm FOR TELEMETRY AND OTHER EXISTING SERVICES OF THE GMRT. FOR SCHEME 2. THE WAVELENGTHS (λ_1, λ_2) WILL BE CHOSEN WITHIN 1540 AND 1565 nm RANGE.

Annexure G

PERT CHART

Sr. No.	Work to be undertaken	I year						II Year					
		months						months					
		2	4	6	8	10	12	2	4	6	8	10	12
1	Preliminary design of the 2GHz MW Photonic link.	2											
2	Identification of components : Detailed Design Review		3										
3	Procurement of components : Final Design Review : Testing & commissioning of the digital fiber-optic link between GMRT site and NCRA, Pune.					7							
4	Development & prototype testing of the 2GHz link in Lab.								6				
5	Testing the prototype in field										3		
6	Integration & Commissioning												3

Annexure H

SHORT WRITE UP OF THE PROPOSAL: Broad-Band Microwave Photonic Links for Antenna Applications

ABSTRACT

Transmission of RF signals using optical carriers offer distinct advantages over conventional techniques. Photonic links allow extremely wide working bandwidth,high immunity from EMI besides savings on system losses. Recent advances in laser technology allow photonic links to have very low noise figure and large dynamic range. The paper discusses a proposal for bringing the RF signals of the Giant Metrewave Radio Telescope(GMRT) in the range of 38-1600 MHz from the front end to a central receiver facility(CEB)over a distance of some 20 Km by modulating a carrier in the 1500 nm band.

INTRODUCTION

THE GMRT consists of 30 antennas in a Y array configuration. The signals from the radio suorces are received by antenna feeds located at the prime focus of the 45 meter diameter dishes of the GMRT as described in the enclosed brochure. The signals are amplified and brought to the antenna shells located below the dishes for down conversion to IF bands and onword transmission to the CEB. Unlike other communication systems,the sensitivity of the GMRT is very high(Typically,it can detect changes in the radio emissions corresponding to noise temperatures of the order of 0.01 degree kelvin). The operation of such sensitive instruments can be affected by spurious transmissions as well by powerful out of band emissions. In order to avoid interference of out of band transmissions,the signals are passed thro' band pass filters(BPF) of ±10% of the center frequency of each band. However harmonic products due to strong out of band emissions which fall with in the bands of the GMRT can saturate the front end systems and cause inter modulation products and affect the linearity and dynamic range of the reciever. The GMRT uses different types of wide bandwidth feeds for the GMRT such as a wideband(500 MHz) horn for the range 1000-1600 MHz. The bandwidth is restricted by the amplitude and phase responses of the RF cables and BPF.

A more challenging application of photonics is the actual transport of RF signals to and and from the antennas via optical fibers by

- Preserving the broad band characteristics of the antenna feeds.
- significant reduction of RF/LO hardware used for down conversion in RF transmission techniques.
- Immunity from EMI
- providing high linearity and dynamic range for the receiver system
- physical parameters of systems such as size,weight get reduced.

DESCRIPTION OF THE EXISTING SYSTEM

THe GMRT electronics system is shown in the figure 2,annexure H.. The antennas have dual polarized feeds at all its six frequencies. The front end consisting of RF,LO, and IF electronics has been designed for low system temperature and good phase stability. The linear polarized signals are first converted to RHP and LHP signals, amplified using low noise amplifiers and are brought to antenna base by low loss cables. They are converted to IF bands using phase coherent LO signals regenerated at each antenna and sent to the CEB thro' optical fiber where they are further converted down to video bands of 16 MHz each. After sampling at 32 MHz rate,the signals from the different antennas are correlated, stored and used for offline analysis. In due course the data will be sent to the academic center of GMRT at Pune (NCRA)for processing.

A two way optical fiber system is employed for transmitting reference LO and telemetry signals from the CEB to the antennas and receiving the IF and other signals at the CEB. The optical transmitters contain laser diodes and isolators @ 1310 nm band and the receivers have photo diodes. The type of modulation is analog and the range of RF signals used for modulating the intensity of the laser is 10 MHz to 300 MHz. The link has been optimised for a bandwidth of 1.1 GHz with loss variation of = ± 1.5 dB.

DESCRIPTION OF THE CURRENTLY AVAILABLE PHOTONIC TECHNOLOGY AND THE PROPOSED SYSTEM FOR THE GMRT

With the advent of integrated optics, reliability,size,processing time have improved enormously that the benifits of moving towards optical domain seems logical. From the systemware point of view,as demand for bandwidth for services like broadband ISDN(B-ISDN), interactive multimedia and video conferencing increases,concepts in networking such as hierarchial transmission and asynchronous switching which are highly electronic device dependent are getting replaced by photonics transport and switching technologies.Optical domain proceesing will emerge and reduce protocol and other overheads. However for the present, photonic and electronic technologies will continue to co- exist either separately or as microwave photonic components.optical MMIC(OMMIC) chips can be successfully used in demodulating data directly from the microwave bands therby reduce the system overloads like compensating for the high attenuation suffered by RF signals,generating and transporting local oscillator signals,down converting the RF signals to intermediate frequency bands and so on.Further,EMI and EMC problems are less and weight and volume come down drastically.Recent advances in analog optical links have made it possible to use electro optic devices with proper impedence matching arrangements and improve noise figure and dynamic range performance(Charles Cox etal,IEEE tran.MTT,vol 45,no.8,Aug '97,Pages 1335-36).P-i-n photodetectors with high responsivity(0.9 A/W) over large 3 dB bandwidths have been reported.Also nearly ideal,high bias voltage photo diodes with reduced non linearities have been reported for operations in the range of few GHz.Semi conductor Fabry-Parot laser devices with very low RIN(-165dB/HZ) are available at all microwave frequencies which are better than commercially available DFB laser devices(RIN -150 dB/HZ) in 5-15 GHZ range.They have reduced low frequency niose compared to Nd:YAG laser divices and cause less problems of AM-noise sidebands. bands.Such lasers can be used for direct modulation in analog links(Gary E.Betts etal,IEEE tran.MTT,vol 45,No.8,Aug '97,pages 1280-87). Reflections assosiated with semiconductor lasers due to their large linewidths can be suppressed by anti reflection coatings and by using isolators. However for some crtical applications,tapered optical amplifiers(typical gain 35 dB in the 1320 nm band) can be used. It is also reported that detection sensitivity can be improved by using carrier suppression techniques.

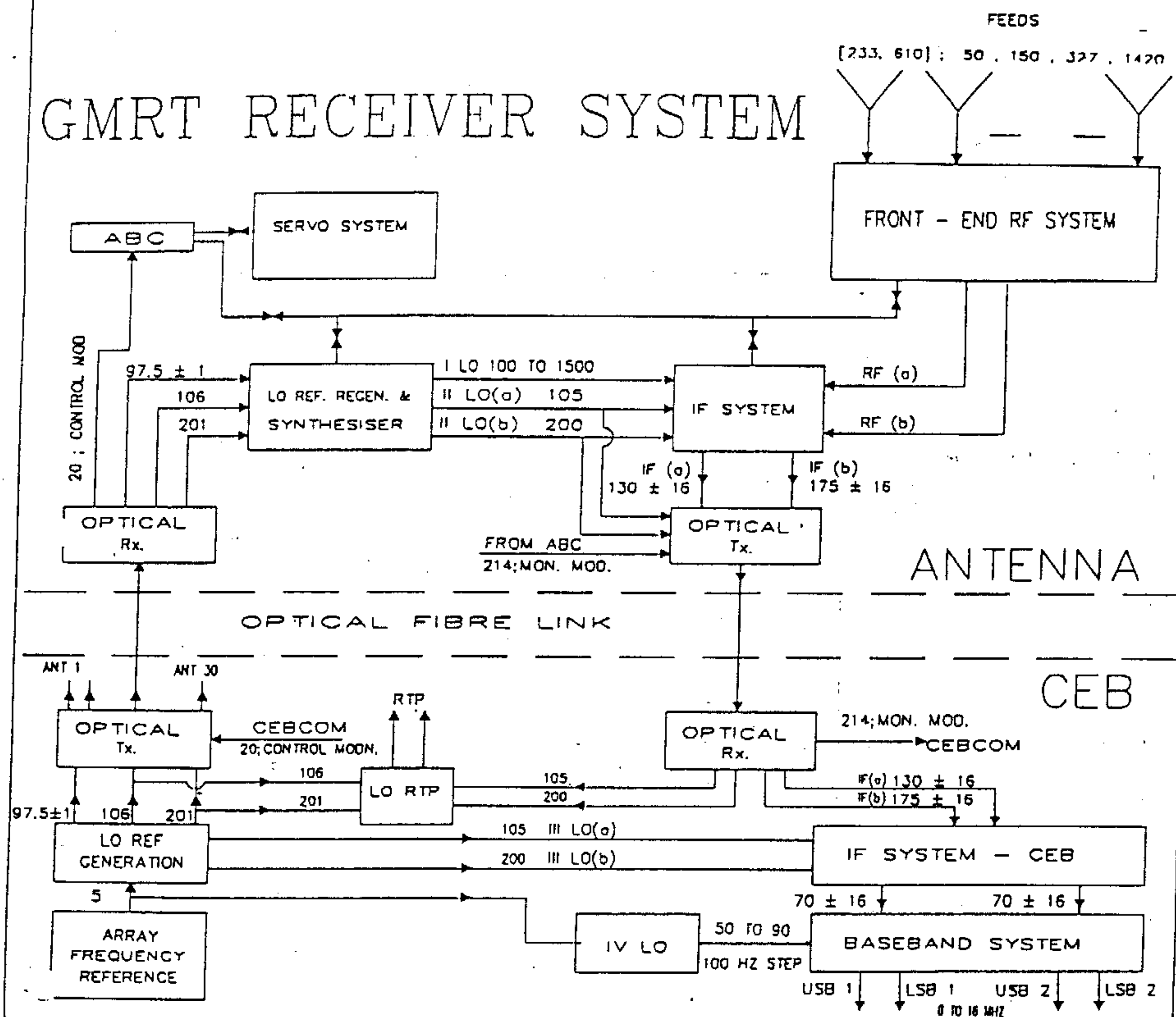
The GMRT group has been using anlaog modulation links for transporting signals in the VHF range and have plans to extend it to 2 GHz for directly bringing the signals from the feeds to the CEB. The benifits of this method over the exisitng hetrodyning technique have been discussed in the earlier section. In the following section,an analog link using microwave photonic technique to bring the signals and data from the GMRT antennas to the academic center of the TIFR(NCRA) at Pune is explained.

Figures 1a,1b and 2 describe two schemes which are under consideration for GMRT application. It consists of either directly modulated or an externally modulated DFB lasers . Generally direct modulation is preferred up to 2 GHz and for higher frquencies, indirect modulators like Mach Zender interferometer may be employed. In order to maintain the integrity of the existing signal transmission,WDM need to be deployed as shown in the figures. The chioce between narrow band WDM(1565 nm and 1540 nm) and wideband WDM (1310 and 1550 nm bands) is being explored . Reflections and back scattering problems in fiber links have been identified in the operation of the GMRT links and overcome by using isolators and low reflection connectors(¡72 dB return loss, E-2000 type APC). The photo diode sensitivity will be enhanced by using reactive matching. Such concepts will be used in the new links to improve S/N and dynamic range.

Higher Bandwidth analog links have been recognised as potential alternative transmission media for on-board satellite communication systems for transmission of signals in 5 GHz band with low loss and high immunity to interference. Microwave photonic links of this kind can be realised using a monolithically integrated DFB laser and an external modulator such as the electro-absorptive isolated laser; DFB laser module(EMILM) 266 type of Lusent technologies and microwave photodiode module available from Epitaxx Inc.-EPM820-FJ-S which is InGaAs Pin photodiode with internal 50 Ohms matching and working upto 8 GHz are under investigation for such purpose.

In continuation of the schemes described, the NCRA-TIFR group has been planning to transmit processed signals obtained from its 30 antennas to its centre at Pune via a dedicated optical fiber link and co-ordinate the data processing activities at both the places. The signals received from the dual polarized receivers of GMRT are sampled at 32 MHz, corrected for delay, multiplied and integrated in digital domain. The output data at 16 Mb/s can be stored at the observatory as well as transmitted from the observatory to the academic head quaters [NCRA, Pune] with a repeater station mid way between the two locationss. Besides the astronomical data, it has been planned to transmit video pictures of the processed data, audio,video and control and monitor signals for the antennas. It is envisaged that the transfer of these data can be met by a 155 Mb/s link between the two locations. It is proposed to build a Giga bit data link for future requirements.

Annexure - h



ALL NUMBERS ARE FREQUENCY IN MHz.

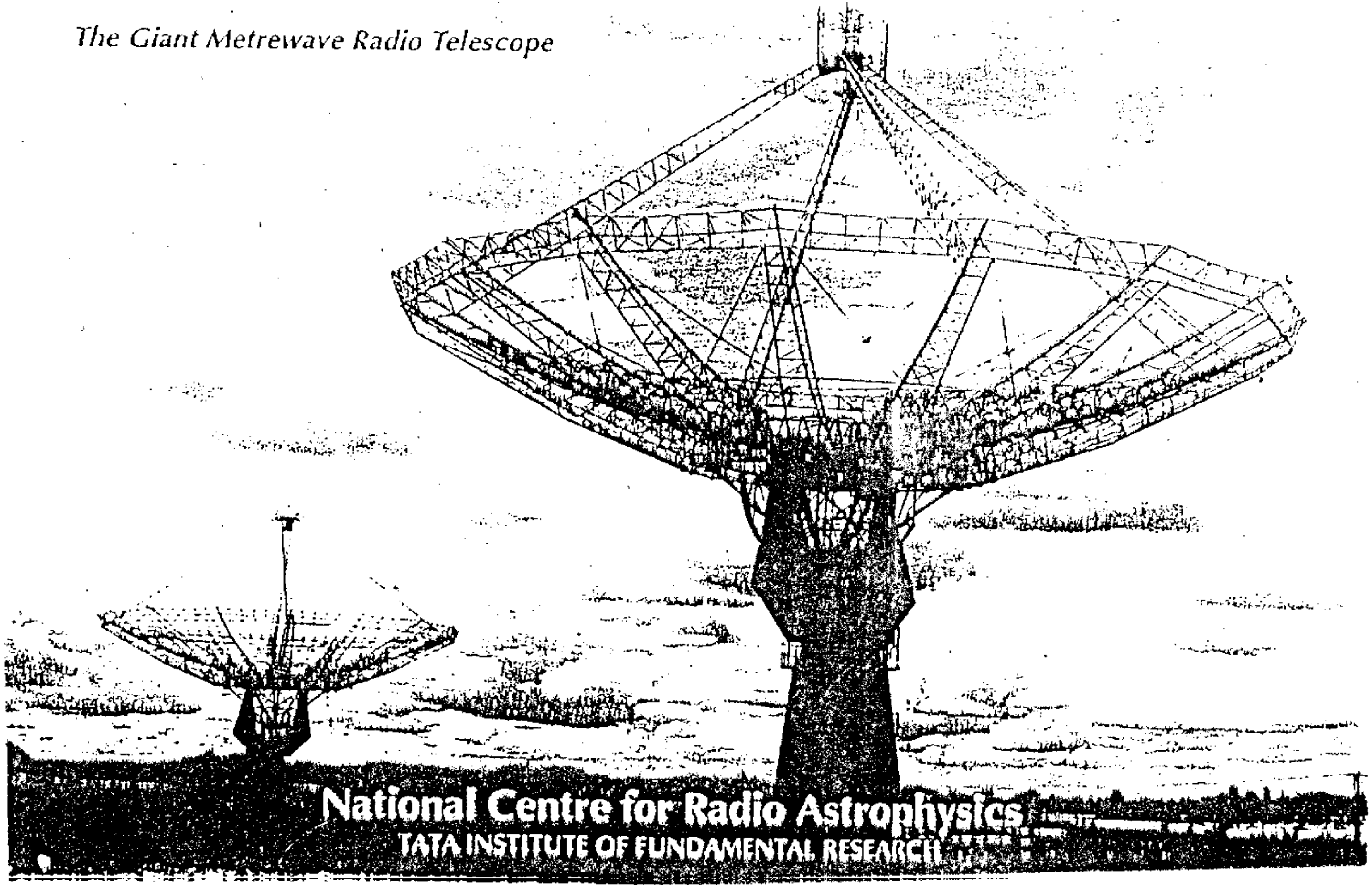
LO REFERENCE SIGNALS AT 106, 201, 105 AND 200 MHz ARE GENERATED FROM THE SYSTEM FREQUENCY REFERENCE OF 5 MHz AT THE CENTRAL ELECTRONICS BUILDING (CEB). THE PLL OFFSET SIGNAL AT 1 MHz AND THE ANTENNA CONTROL DATA FROM CEBCOM ARE MODULATED ON CARRIERS AT 97.5 AND 20 MHz; COMBINED WITH SIGNALS AT 106 AND 201 MHz AND BROADCAST TO ALL ANTENNAS USING THE OPTICAL TRANSMITTER.

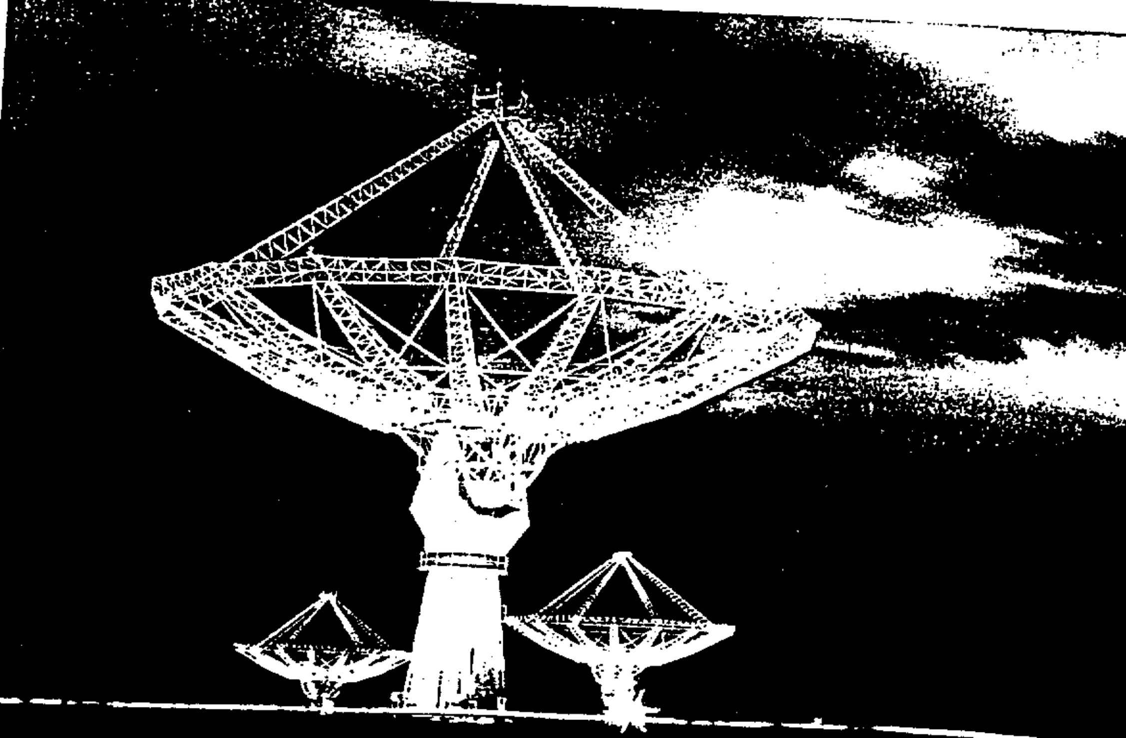
AT THE ANTENNA, THE LO REF REGENERATOR AND THE SYNTHESISER USE THE RECEIVED SIGNALS TO PRODUCE PHASE COHERENT I LO, II LO(a) AND II LO(b). THE ANTENNA BASE CONTROLLER (ABC) USES THE CONTROL INFORMATION FOR SETTING VARIOUS PARAMETERS. THE IF SYSTEM USES THE LO SIGNALS TO TRANSLATE THE SELECTED OUTPUT OF FEED AND FRONT-END RF SYSTEM, RF(a) AND RF(b) TO IF BANDS IF(a) AND IF(b). THE IF SIGNALS TOGETHER WITH THE MONITOR INFORMATION FROM ABC AND LO REFERENCE RETURN ARE BROUGHT BACK TO CEB THROUGH THE OPTICAL FIBRE LINK.

AT THE CEB, THE RECEIVED IF SIGNALS ARE PROCESSED USING THE III LO AND IV LO TO PRODUCE BASE-BAND OUTPUTS COMPATIBLE TO THE CORRELATOR. THE MONITOR INFORMATION IS PROCESSED IN THE CEBCOM.

ANY PHASE VARIATION IN THE LO IS ESTIMATED BY MEASURING THE ROUND TRIP PHASE (RTP) OF THE LO RETURN SIGNAL.

The Giant Metrewave Radio Telescope





A Word About NCRA

The National Centre for Radio Astrophysics (NCRA) is a part of the Tata Institute of Fundamental Research (TIFR) - India's premier institution for research in the basic sciences.
2 TIFR was founded by the late Dr.Homi Bhabha in 1945, with support from the Sir Dorabji Tata Trust and the then Government of Bombay. The main buildings and most of the research activities of TIFR are located in Colaba, Bombay. The institute is now funded by the Government of India, through the Department of Atomic Energy.

Research in Radio Astronomy has been pursued at TIFR since the formation of a group in this area in 1963. For over two decades the group operated from Ootacamund in the state of Tamil Nadu, where a large parabolic cylindrical radio telescope has been in operation since 1970, or from the TIFR Centre in Bangalore (from 1978 to 1989). The group is now involved in setting up the Giant Metrewave Radio Telescope (GMRT) about 80 km north of Pune. Designed to study many challenging astrophysical problems, GMRT will be the world's most powerful facility for radio astronomical research at metre wavelengths. Considering the magnitude of the project, most of the academic as well as research and development activities of the Group were relocated in 1989 to the Poona University campus on a site kindly made available by the University. These premises are now known as the National Centre for Radio Astrophysics (NCRA).

In the three decades since its formation, the radio astronomy group of TIFR has made many pioneering contributions at the frontiers of knowledge and is today regarded as being among the world's leading centres of excellence in this field.

Radio Astronomy and the Cosmos

Radio Astronomy is the study of the Universe through naturally produced radio waves reaching us from a variety of celestial objects. This new science was born in 1932 when Karl Jansky at the Bell Labs in USA discovered radio noise coming from our Milky Way Galaxy. Like light waves, radio waves are also electromagnetic waves but with much longer wavelengths. Celestial objects usually radiate in different regions of the electromagnetic spectrum - such as X-rays, ultra-violet, optical light, infra-red or radio waves - depending upon their physical conditions such as temperature, magnetic field, etc.

Sources of cosmic radio waves : With the use of the powerful radio telescopes, astronomers have discovered a series of remarkable objects and phenomena, such as radio galaxies, quasars, supernova remnants, pulsars, interstellar molecules etc. The strongest radio waves generally arise from highly energetic relativistic electrons in the presence of magnetic fields created in the aftermath of violent and catastrophic events occurring in stellar explosions and in the ultra-strong gravitational fields of the central regions of galaxies. The nuclei of some galaxies are believed to contain massive 'black holes' of millions of solar masses concentrated in a volume not much larger than that of our

Foreword

Radio Astronomy is the exploration of the Universe through naturally produced radio waves received by us from its many constituents. Although it is a relatively young science, it has given rise to many great discoveries of remarkable objects and phenomena that include radio galaxies, quasars, pulsars, cosmic masers, the 3 K microwave background radiation and a large number of molecules in the interestellar space such as water vapour, ammonia, alcohol, etc. Many of these and other phenomena are being actively studied in India by radio astronomers of the National Centre for Radio Astrophysics (NCRA) of the Tata Institute of Fundamental Research.

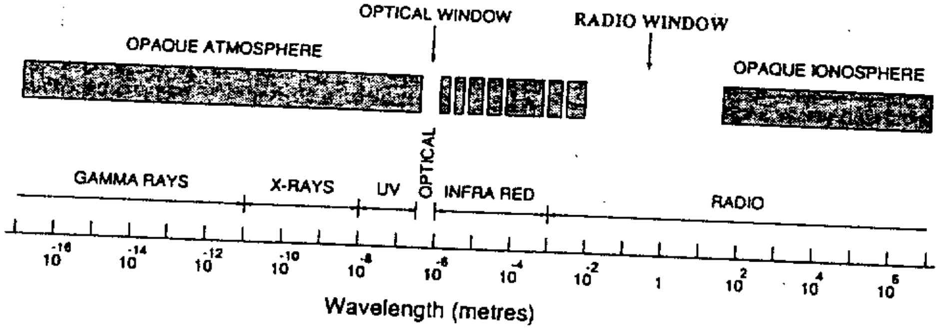
NCRA is currently setting up the Giant Metrewave Radio Telescope (GMRT) which will be the world's most powerful radio telescope operating at metre wavelengths. Consisting of 30 fully steerable parabolic dishes of 45 metre diameter each, GMRT has been designed to investigate a variety of outstanding astrophysical problems in modern astronomy and cosmology. It is one of the most challenging projects in basic sciences undertaken by Indian scientists and engineers.

GMRT is a thoroughly Indian project. The 30 large antennas are being built using an indigenous technological breakthrough in the design of light-weight low-cost dishes. The choice of the metre wavelength part of the radio spectrum which has remained largely unexplored, also takes full advantage of the fact that there is much less man-made radio interference at these wavelengths in India compared to the western world.

This booklet introduces the reader to the fascinating world of radio astronomy and to the currently operating Ooty Radio Telescope and the Giant Metrewave Radio Telescope under construction. It also summarises the Graduate Studies Programme of NCRA for the information of potential research scholars.

Contents

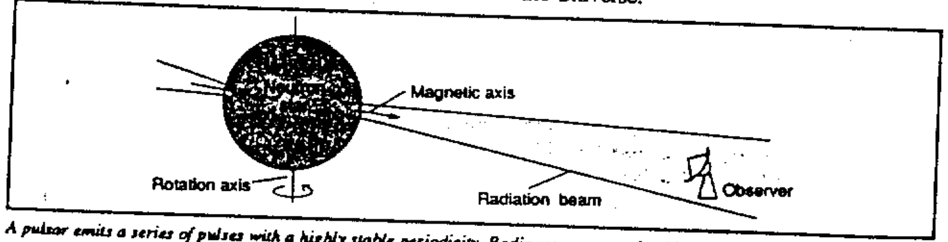
NCRA
National Centre for Radio Astrophysics
TATA INSTITUTE OF FUNDAMENTAL RESEARCH
Poona University Campus,
P.O. Box 3, Ganeshkhind,
Pune 411 007, INDIA



The electromagnetic spectrum. Earth's atmosphere is transparent only to optical and radio waves. The ionosphere reflects radio waves longer than about 15 m in wavelength.

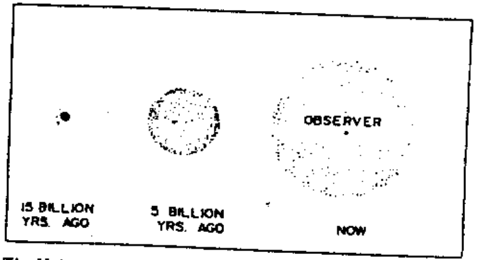
Solar system! Black holes are objects so highly condensed that nothing - not even light - can escape out of their strong gravitational pull. Their study is one of the most fascinating and challenging problems in modern astronomy.

Another very important development thanks to radio astronomy was the discovery in 1965 by Penzias and Wilson of the 3 K microwave background radiation. It is observed to be coming isotropically from all directions in the sky and is believed to be the relic radiation from the early hot Big-Bang phase of the Universe. This important discovery has given a great impetus to the study of the origin and evolution of the Universe.



A pulsar emits a series of pulses with a highly stable periodicity. Radio waves are emitted in a narrow beam by highly energetic electrons in the strong magnatic field of the star. A pulse is observed every time the rotating beam sweeps past the observer.

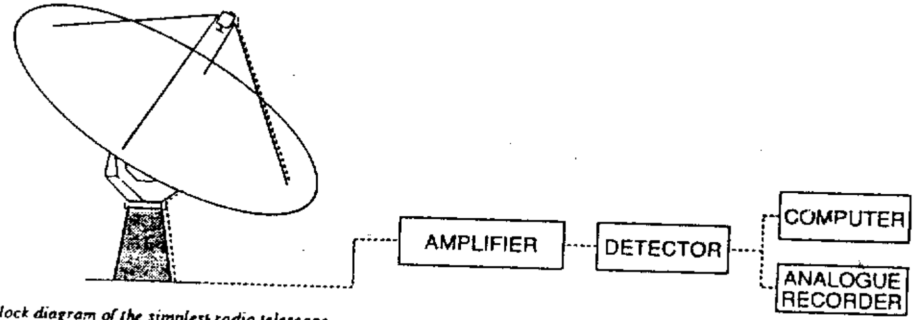
Spectral lines : Apart from continuum radio waves (covering a wide range of radio frequencies), atomic and molecular processes also give rise to line radiation confined to a relatively narrow frequency range. The most important of these lines occurs at 1420 MHz (wavelength of 21 cm) due to a hyperfine transition in the atoms of neutral Hydrogen - the most abundant constituent of our Universe. The study of this line radiation has not only provided a wealth of information on the structure of our own as well as of other nearby galaxies, but also has the potential of revealing the state of the early Universe before the formation of galaxies. The detection of radio lines from many other molecular transitions, including those from complex organic molecules, indicates that conditions favourable to the development of life may exist at many places in our Galaxy.



The Universe is believed to have originated about 15 billion years ago and has been expanding ever since.

Tools and Techniques of Radio Astronomy

A radio telescope, the basic tool for exploring the radio Universe, consists essentially of a reflector antenna, a feed and a receiver system. The reflector focuses the radio waves from a celestial object on to the feed (usually a dipole or a horn) which collects the radio signals and feeds these weak signals to a sensitive low-noise amplifier to be further processed by a sophisticated electronic receiver system. The two most important characteristics of a telescope are : (i) high sensitivity to detect the weak radio waves from distant celestial objects and (ii) high angular resolution to distinguish features close together in the sky. The larger the size or 'collecting area' of a telescope, higher are its sensitivity and resolving power.



Block diagram of the simplest radio telescope.

Interferometry and aperture synthesis: Because of the very long wave-lengths of radio waves (ranging between about 1 cm and 10m) compared to less than a millionth of a metre for visible light, the resolution of even a large single radio telescope is relatively much poorer. At a wavelength of 1 metre for instance, a parabolic dish with a diameter of about 1 km would be required to obtain even the modest resolution of the human eye. Radio astronomers have overcome this severe limitation by the development of the clever technique of 'interferometry' in which the voltage outputs of a pair of modest sized radio telescopes are brought together to a common point and multiplied together. By using an array of telescopes spread over tens of kilometres such interferometric techniques can be used to synthesize much larger telescopes with effective diameters equivalent to the maximum separations or 'baselines' between the most distant antennas in the array. This process of 'aperture synthesis' is greatly aided by the rotation of the Earth which constantly changes the orientation and effective lengths of different interferometric baselines as seen from the radio source.

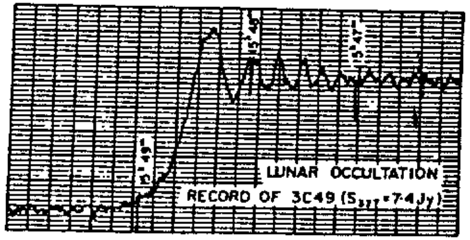
Radio astronomers can in fact now obtain resolutions as high as a thousandth of an arc second - much higher than possible with optical telescopes - by the technique of Very Long Baseline Interferometry (VLBI), in which radio signals are independently recorded by telescopes separated by thousands of kilometres and subsequently correlated in a computer.

A variety of large radio reflectors as well as multi-element aperture synthesis arrays have been built in UK, Netherlands, Italy, Germany, Australia, Japan, Canada and USA. India has not lagged behind in this respect. While the Ooty Radio Telescope is among the largest single reflectors in the world, the Giant Metrewave Radio Telescope now under construction will be the world's most powerful aperture synthesis array operating at metre wavelengths (30 to 1500 MHz).

The Ooty Radio Telescope (ORT)

The Ooty Radio Telescope was the first major facility in India which firmly established the country on the world map of radio astronomy. The novel design of this parabolic cylindrical telescope, 530 m long and 30 m wide, made full use of India's proximity to the geographical equator. The reflecting surface is made up of 1100 thin stainless steel wires running parallel to each other for the entire length of the cylinder. The surface is supported by 24 parabolic frames 23 m apart.

Two of the 24 parabolic frames of the Ooty Radio Telescope. The streak of light in the middle is sunlight reflected by the stainless steel wires forming the reflecting surface.

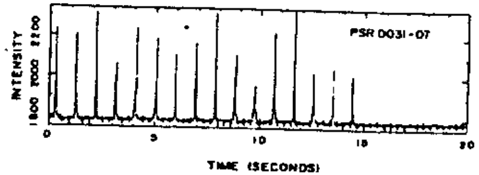


Lunar occultation of radio source 3C 49 observed with the Ooty Radio Telescope.

The unique feature of this telescope is that its long axis is aligned in the north-south direction along a hill which has a natural slope of about 11°, the geographical latitude of Ooty. This makes the long rotation axis of the telescope parallel to the earth's rotation axis, enabling the telescope to track radio sources in the sky by a mechanical rotation of the parabolic frames in the east-west direction. In the north-south direction the beam of the telescope can be steered in declination by introducing appropriate phase shifts between the 1056 dipoles along the focal line of the parabolic cylinder.

Designed and built indigenously, ORT came into operation in 1970 and has been in use more or less continuously since then. The sensitivity of the telescope has recently been improved by another factor of 4 by installing a new feed system with a low-noise RF amplifier and phase shifter behind each dipole.

Over the last two decades, ORT has produced many important astronomical results on radio galaxies, quasars, supernovae, pulsars, interstellar and interplanetary medium etc. Special mention may be made of the success of the Lunar Occultation programme which led to important results in observational cosmology, providing new evidence in support of the 'Big-Bang' model of the Universe.

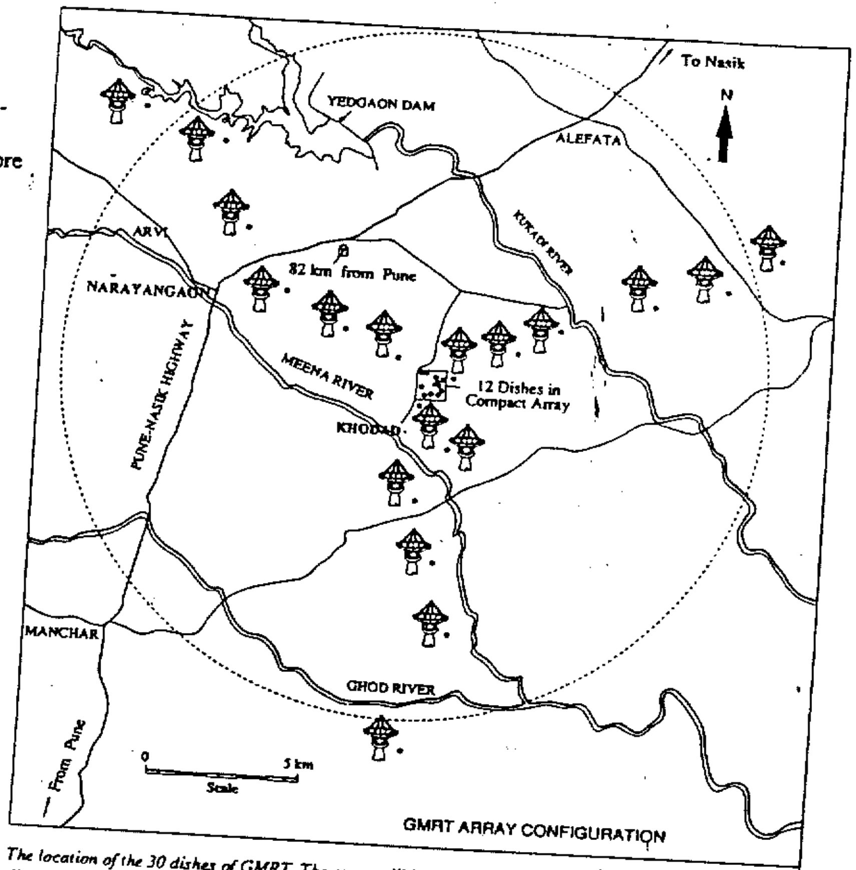


The pulsar, PSR0031-07 with a period of 0.94295078486 seconds observed with the Ooty Radio Telescope.

The Giant Metrewave Radio Telescope (GMRT)

The experience gained in building and operating the Ooty Radio Telescope, led TIFR radio astronomers to think of a much bigger and more
6 versatile telescope capable of working on a variety of challenging problems during the 1990s and beyond. This thinking has crystallised into what is now known as the Giant Metrewave Radio Telescope (GMRT), under construction near Khodad, about 80 Km north of Pune. It is being built as a national facility and is expected to become fully operational by early 1995. Consisting of 30 fully-steerable parabolic dishes of 45-m diameter each, GMRT will truly mark a Giant leap forward in radio astronomy.

The site : The site for GMRT, about 10 km east of Narayangaon town on the Pune-Nasik highway, was selected after an extensive search in many parts of India, considering several important criteria such as low man-made radio noise, availability of good communication, industrial, educational and other infrastructure nearby, a geographical latitude sufficiently north of the geomagnetic equator in order to have a reasonably quiet ionosphere and yet be able to observe a good part of the southern sky as well.

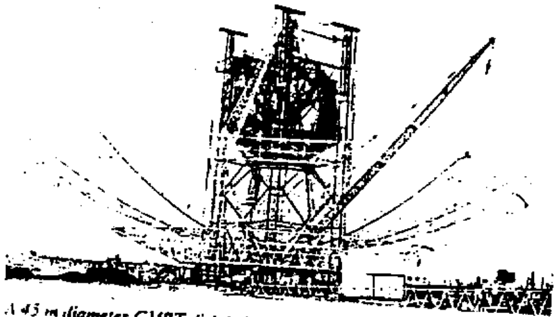


The location of the 30 dishes of GMRT. The array will image the sky with a resolution equivalent to that of a single dish with a diameter of 25 km. The size of the equivalent dish is shown by the dashed circle.

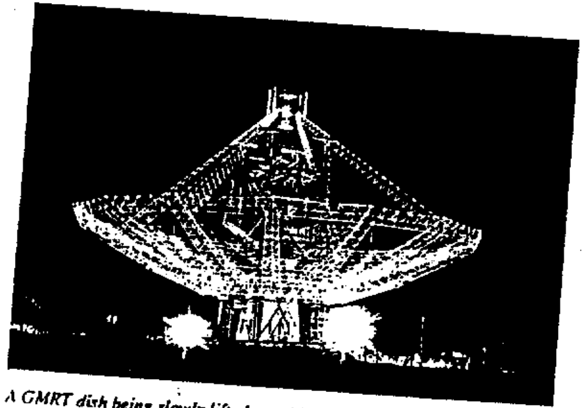
Active regions on the radio sun imaged with VLA. (Courtesy NRAO/AUI)

The Crab Nebula. Remnant of a supernova that exploded in 1054 AD.

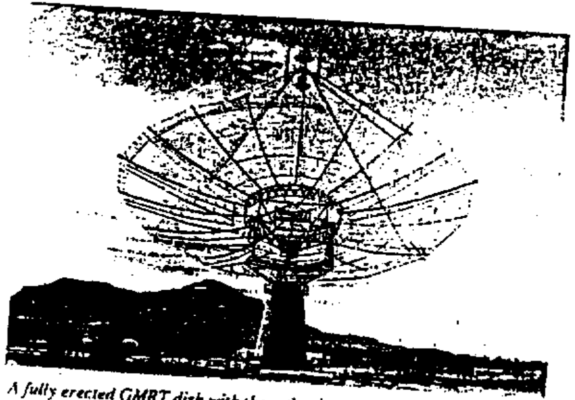
A radio image of the Crab nebula made with the VLA.



A 45 m diameter GMRT dish being assembled on the ground around the concrete tower that forms its pedestal.

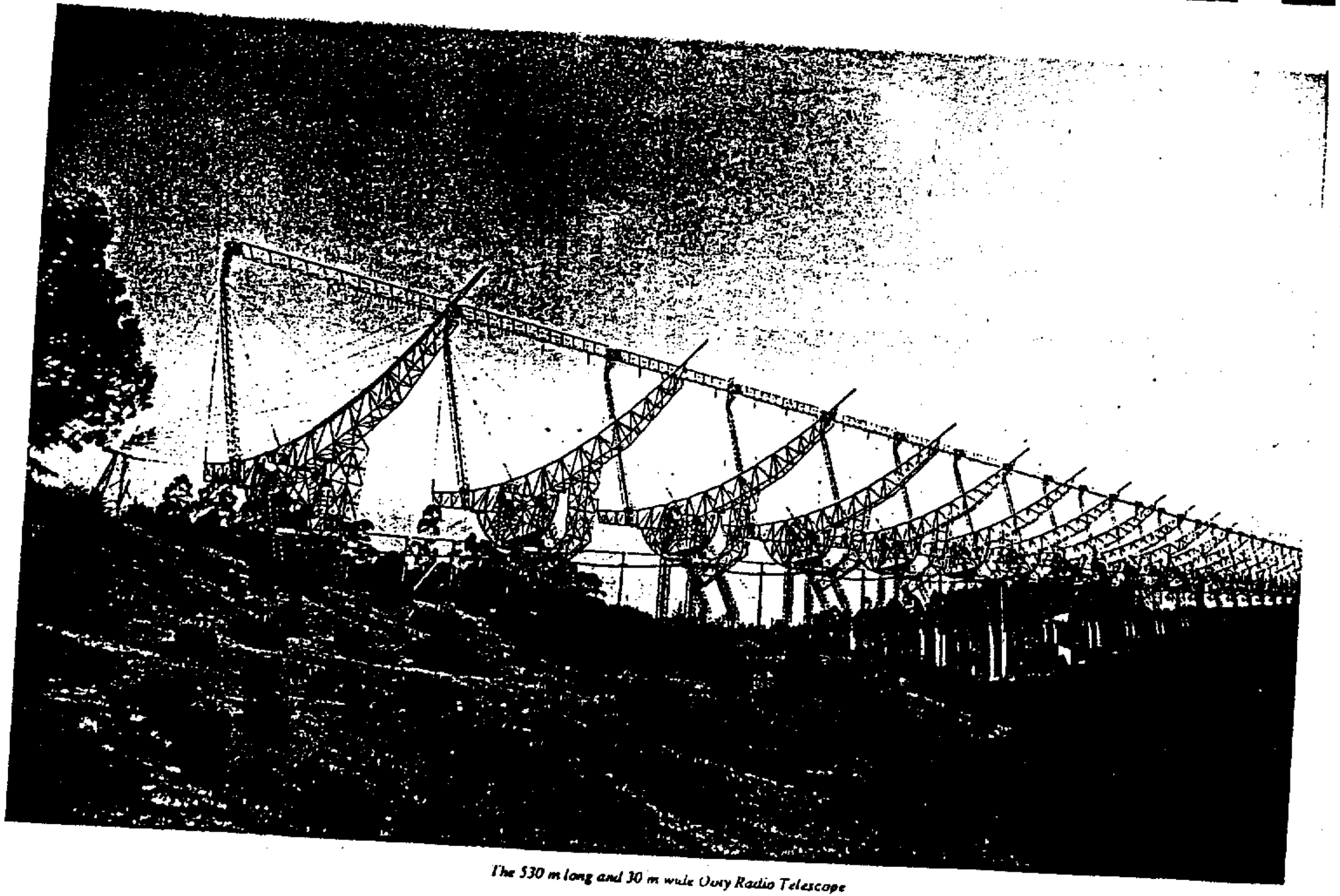


A GMRT dish being slowly lifted up with the help of 4 temporary erection towers and mechanical winches.



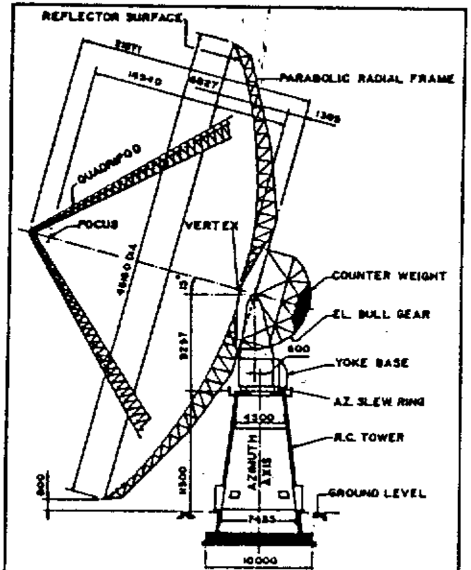
A fully erected GMRT dish with the reflecting mesh in place. The low solidity of the dish is quite apparent in the picture.

Eight of the 30 GMRT dishes that have been erected as of July 1993.

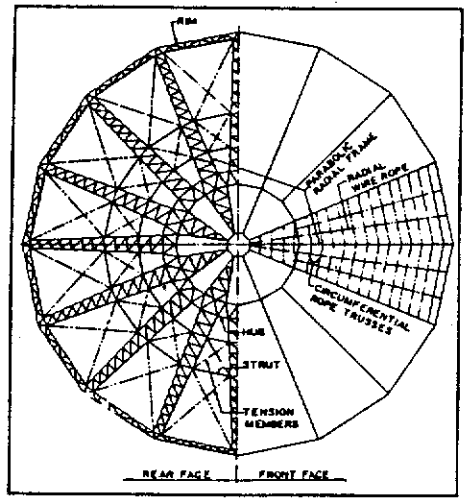


The 530 m long and 30 m wide Ooty Radio Telescope

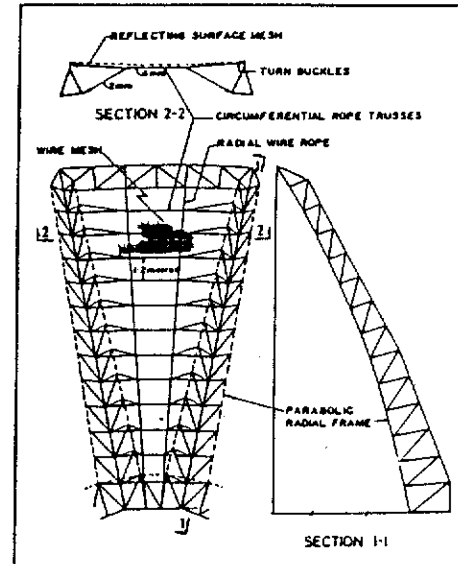
Antenna configuration : The number and configuration of the dishes was optimized to meet the principal astrophysical objectives which require sensitivity at high angular resolution as well as ability to image radio emission from diffuse extended regions. Twelve of the thirty dishes are being located more or less randomly in a compact central array in a region of about 1 km x 1 km. The remaining eighteen dishes are spread out along the 3 arms of an approximately 'Y'-shaped configuration over a much larger region, providing interferometer baselines as large as 25 km. The multiplication or correlation of radio signals from all the 435 possible pairs of antennas or interferometers over several hours will thus enable radio images of celestial objects to be synthesized with a resolution equivalent to that obtainable with a single gigantic dish 25 kilometer in diameter! The array will operate in the six frequency bands around 50, 153, 233 327, 610 and 1420 MHz. The highest angular resolution achievable will range from about 60 arcsec at the lowest frequencies to about 2 arcsec at 1.4 GHz.



Sectional view of a GMRT dish.



Front and rear schematic view of a GMRT dish



A section of the dish illustrating the SMART (Stretched Mesh Attached to Rope Trussess) concept.

The Design breakthrough : What is truly remarkable about GMRT is its modest cost in spite of its giant size. This has become possible, thanks to a significant new technological break through achieved by Indian scientists and engineers, in the design of low cost metrewave antennas, based on a concept nicknamed SMART (for Stretched Mesh Attached to Rope Trusses). Basically, the dish has been made light-weight and of low solidity by replacing the conventional back-up structure by a series of rope trusses (made of thin stainless steel wire ropes) stretched between 16 parabolic frames made of tubular steel. The wire ropes are tensioned suitably to make a mosaic of plane facets approximating a parabolic surface. A light-weight thin wire mesh (made of 0.55 mm diameter stainless steel wire) with a grid size varying from 10 x 10 mm in the central part of the dish to 20 x 20 mm in the outer parts, stretched over the rope truss facets forms the reflecting surface of the dish. The low-solidity design cuts down the wind-forces by a large factor and is particularly suited to Indian conditions where there is no snowfall in the plains. The overall wind forces and the resulting torques for a 45-m GMRT dish are similar to those for only a 22-m dish of conventional design, thus resulting in substantial savings in cost .

The dish is connected to a 'cradle' which is supported by two elevation bearings on a yoke placed on a 3.6 m diameter slewing-ring bearing secured on the top of a 15 metre high concrete tower. The salient parameters and specifications of each dish are summarized in the Table.

The large size of the parabolic dishes implies that GMRT will have over three times the collecting area of the Very Large Array (VLA) in New Mexico, USA, which consists of 27 antennas of 25 m diameter and is presently the world's largest aperture synthesis telescope operating primarily at centimeter wavelengths. However, VLA was primarily designed to work at cm and dm wavelengths and hence provides considerably higher resolution. At 327 MHz, GMRT will be about 10 times more sensitive than VLA because of the larger collecting area,

Important Parameters of 45 m Dishes

Reflector diameter	45 m
Focal length	18.54 m
Mounting	Altitude-azimuth
Elevation limits	15° to 110°
Azimuth limits	± 270°
Slew rate: azimuth	30° per minute
elevation	20° per minute
Design wind speeds:	
operation upto	40 kmph
slew upto	80 kmph
survival	133 kmph
Wire mesh size	20 mm x 20 mm outer 1/3 area
	15 mm x 15 mm middle 1/3 area
	10 mm x 10 mm inner 1/3 area
Maximum rms surface errors (at wind speed of 40 kmph)	20 mm, outer 1/3 area
	12 mm, middle 1/3 area
	8 mm, inner 1/3 area
Tracking and Pointing accuracy	1 arcmin rms at winds <20 kmph
Weight of each dish (excluding concrete tower)	116 tons

higher efficiency of the antennas and a substantially wider usable bandwidth because of the very low level of man-made radio interference in India.

Electronic Frontends and Backends : GMRT is one of the most challenging projects in the basic sciences that has been undertaken by Indian scientists and engineers. Apart from the novel low-cost design of the parabolic dishes, the instrument will have state-of-the art electronics systems developed indigenously and consisting of the following main sub-units.

Antenna feeds at six different frequency bands between 30 MHz and 1500 MHz, having good polarization characteristics as well as multiband operation;

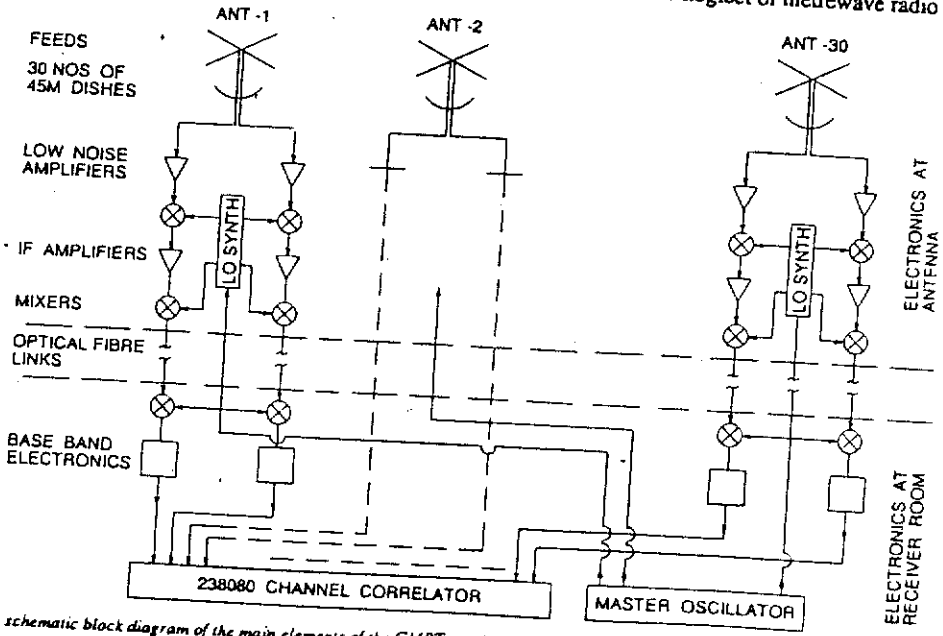
Low-noise amplifiers, local oscillator synthesizers, mixers, IF amplifiers and backends;

Optical fibre analog transmission links over the whole array. These will be used both for the control and monitor of the dishes and electronic systems as well as for providing local oscillator phase reference at each antenna and for return IF to the receiver room;

A digital 2,40,000-channel FX-type correlator providing upto 256 spectral channels covering a maximum bandwidth of 32 MHz;

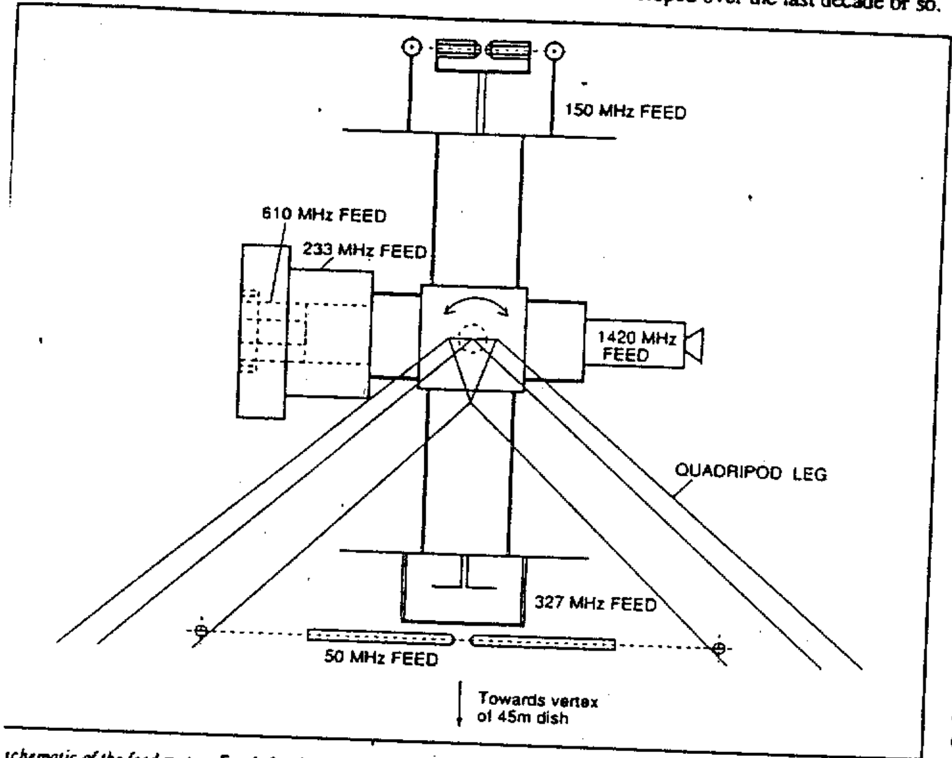
A 64-node parallel-processing super computer, specially developed in collaboration with C-DOT, Bangalore for imaging of GMRT data.

Elimination of ionospheric distortions and man-made radio noise: As already mentioned, GMRT has been specially designed to exploit the metrewave part of the radio spectrum which has remained largely unexplored even though there is no dearth of exciting and challenging astrophysical problems that are best studied at these wavelengths. The much stronger man-made radio interference at metre compared to centimeter wavelengths in the western world and the increasing distortions at longer wavelengths in the incoming wave fronts caused by ionospheric irregularities have largely been responsible for the neglect of metrewave radio



A schematic block diagram of the main elements of the GMRT receiver system.

astronomy. Fortunately, radio interference is not a serious problem in India at present and the harmful ionospheric effects can be almost entirely overcome through the use of powerful calibration and image formation techniques that have been developed over the last decade or so.

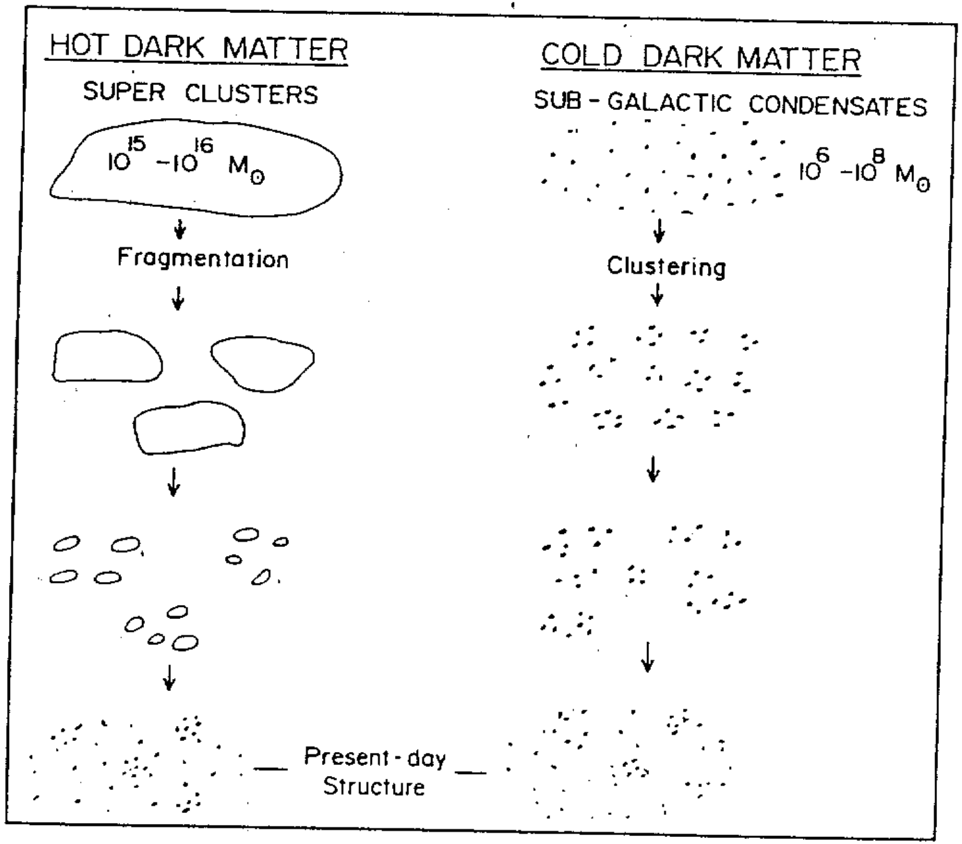


schematic of the feed system. Feeds for 6 different frequency bands are mounted on the 4 faces of a rotating turret at the dish cus.

Scientific Objectives of GMRT:

Although GMRT will be a very versatile instrument for investigating a great variety of radio astrophysical problems ranging from our nearby Solar system to the edge of the observable Universe, two of its most important astrophysical objectives are (i) to detect the highly redshifted spectral line of neutral Hydrogen expected from protoclusters or protogalaxies before they condensed to form galaxies in the early phase of the Universe and (ii) to search for and study rapidly-rotating Pulsars in our Milky Way galaxy.

Epoch of galaxy formation : Theories of the formation of structure in the Big-Bang Universe predict the presence of proto-galaxies or proto-clusters of galaxies made up of clouds of neutral Hydrogen gas before their gravitational condensation into galaxies. It should in principle be possible to detect these through the well known radio line emitted by neutral Hydrogen at a frequency of 1420 MHz. The line is however expected to be very weak and redshifted to meter wavelengths because of the expansion of the Universe between emission billions of years ago, and detection at the present epoch. For clouds of Hydrogen between redshifts 3 and 10 (corresponding to epochs when the Universe had attained only a few percent of its present age), the line should be observable between



Two different scenarios for the formation of galaxies and structure in the Universe

frequencies of about 350 and 130 MHz. Detection of such neutral Hydrogen clouds is of fundamental astrophysical importance and can provide very important constraints to the theories of formation of galaxies and clusters.

Pulsars and neutron stars : GMRT should also be an ideal instrument for the study of Pulsars (rapidly rotating neutron stars with extremely high densities of about 200 million tons per cubic cm). Its large collecting area can lead to a 3 or 4-fold increase in the number of Pulsars known in our Galaxy. A particularly important programme in Pulsar research will be the search for extremely rapidly rotating pulsars with periods in the range of only milli-seconds and for pulsars in binary systems. Because of the strong gravitational fields associated with them, such systems form excellent laboratories for testing gravitational theories such as Einstein's General Theory of Relativity. Accurate timing measurements to detect extremely minute changes in the pulse arrival times from a group of pulsars can also lead to the detection of a weak background of gravitational radiation believed to have been generated by asymmetries in the very early Universe when it was less than a billionth of a billionth of a billionth of a second old!

Galactic and extragalactic radio sources : Because of its large collecting area and wide frequency coverage. GMRT will be an invaluable and highly versatile instrument for studying many other problems at the frontiers of astrophysics. These include studies of Solar and planetary radio emissions; relationship between Solar activity and disturbances in the interplanetary medium; surveys of the Galactic plane to investigate the physics and evolution of clouds of ionized hydrogen associated with young stars as well as nonthermal emission from planetary nebulae and supernovae remnants associated with late stages of stellar evolution; exotic types of stars and stellar systems whose radio emission could be hundreds of times more intense than that of the Sun; monitoring the variability of extragalactic radio sources, supernovae in external galaxies and transient sources in the Galactic plane; detection of the Deuterium line and Hydrogen recombination lines in the interstellar medium; halos and large-scale structure in spiral galaxies; structures and spectra of quasars and radio galaxies and their use in cosmological tests; studies of Hydrogen gas in external galaxies and streaming motions in the nearby Universe.

Search for extraterrestrial Intelligence : Another very exciting future prospect is the possible use of GMRT in the search for extraterrestrial intelligence by monitoring the radio signals from the direction of a large number of Sun-like stars in our Galaxy.

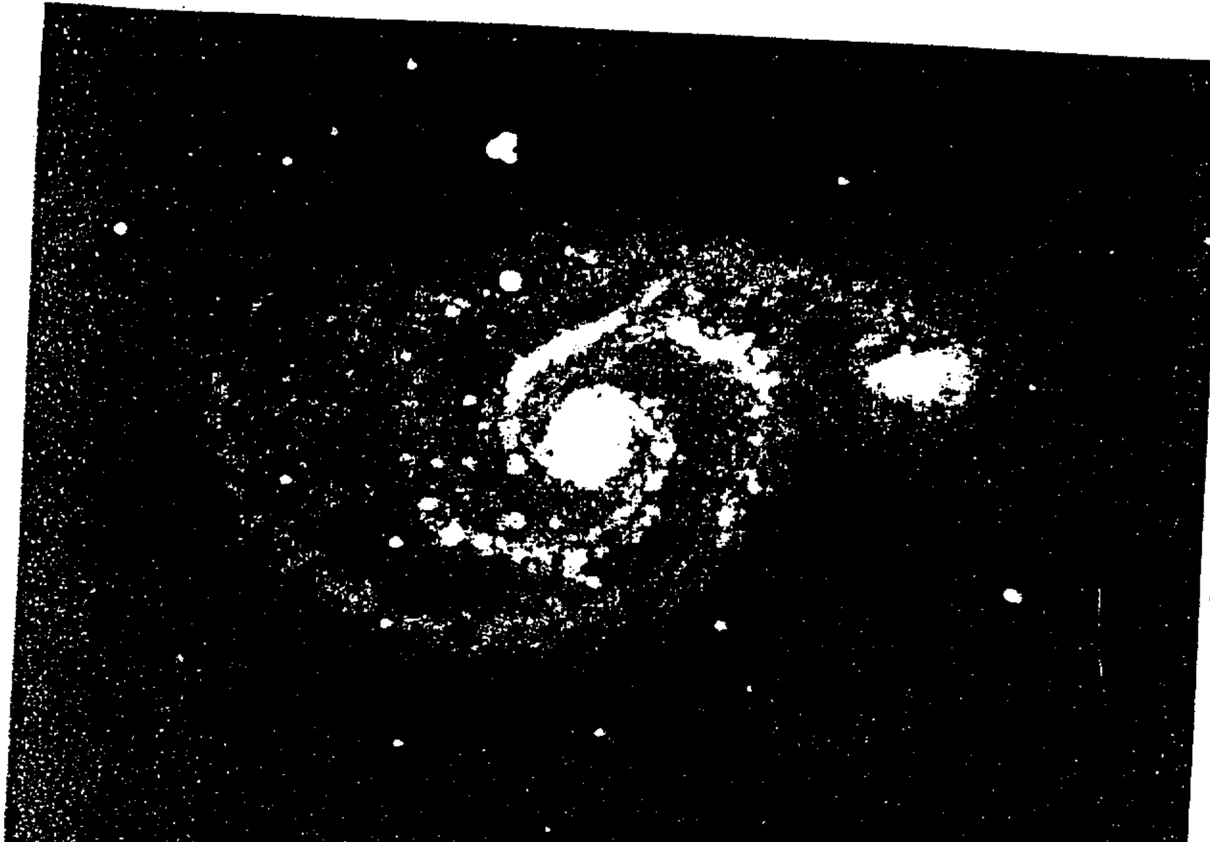
Graduate Studies and the Ph.D. Programme

The success of GMRT will depend on the enthusiasm of its user community consisting of young research workers and students. NCRA therefore, attaches a great deal of importance to a vigourous Ph.D. programme. To date about 25 Ph.Ds have been completed by researchers in the Radio Astronomy Group of TIFR.

The Ph.D. programme consists of formal course work followed by thesis research. Till recently the course work had generally to be carried out in the Physics Graduate School programme of TIFR at Bombay. Since 1991 NCRA has started a separate Graduate School programme in Astrophysics at Pune. This programme is being conducted jointly with the Inter-University Centre for Astronomy and Astrophysics (IUCAA) which is located adjacent to NCRA in the campus of the Poona University.

The NCRA-IUCAA Graduate Studies Programme offers core courses as well as specialized courses in a number of areas in Physics and Astrophysics. Research scholars generally complete the course work and research project assignments in the first two years before registering for a Ph.D. of either Bombay or Poona Universities. After completing their Ph.Ds (within about 5 years of joining the Programme) Research Scholars find post-doctoral assignments or staff positions at other institutions and universities in India and abroad. Some of the outstanding scholars are absorbed into regular academic positions. NCRA also has a visiting Post-Doctoral Programme.

Selection of NCRA Research Scholars is carried out through a written test and interviews generally held in late June or early July every year. Advertisements inviting applications are usually released in the month of March. The basic qualification for admission is a Master's degree in Physics or a B.E. or B.Tech Engineering Degree in Electronics with talent, motivation and aptitude for research in physics and astronomy. Research Scholars are provided good financial support.



The galaxy M51. Maps of continuum radio emission at 21 cm wavelength (green colour) and 21 cm line emission form neutral Hydrogen (blue color) have been superimposed on the optical image (red colour) (Courtesy NRAO/AUI)