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Proposal for an international institute for space sciences and electronics and for a giant equatorial radio telescope as a collaborative effort of the developing countries*

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Abstract. It is proposed to construct a 2 km long and 50 m wide cylindrical radio telescope at a site close to the earth's equator. By placing the long axis of the cylinder in the north-south direction at the equator, its axis of rotation would become parallel to that of the earth. Thus, it would be possible to track celestial radio sources for about 12 hr a day by a simple mechanical rotation of the radio telescope. The beam will be steered in declination by electrical phasing. The radio telescope would be operated at a few discrete bands protected for radio astronomy in the range of about 38 to 328 MHz. Along with a proposed 14 km × 12 km synthesis radio telescope, it would become a unique facility for radio astronomy at meter wavelengths. It is likely to lead to many outstanding astronomical discoveries.

Suitable sites for the proposed radio telescope have been located in Indonesia and Kenya. The design and construction of the radio telescope as a collaborative effort will provide valuable training to scientists and engineers of the developing countries. Also it should lead to an excellent focal point for technical collaboration between the participating countries in the fields of space sciences and electronics.

Key words : giant equatorial radio telescope—institute for space sciences—collaboration in science

1. Introduction

The development of indigenous scientific and technical skills and their utilization for satisfying the social and economic needs of the people are a great challenge for the developing countries. In order to satisfy these needs, it is necessary to undertake regional and inter-regional cooperation among developing countries in as many areas

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as practical with the aim not only of undertaking relevant task-oriented projects but also for building up local scientific and technological self-reliance capabilities.

It is proposed that an International Institute for Space Science and Electronics (INISSE) be established as a joint effort of a number of developing countries, to develop programs around one area of the basic sciences and one related area of applied research. The two areas proposed are : radio astronomy, and space communications and applications technology. In due course, INISSE can undertake training and applied research work in other fields of electronics. These areas can act as an excellent catalyst for collaboration amongst the developing countries in terms of technology development in different areas of space applications technology and electronics and yet are practical, and not too costly, to realize with indigenous efforts.

An investment over a billion US dollars has already been made by the developing countries in the field of space technology. The expenditure made by these countries to date in all the fields of electronics and radio communication exceeds 15 billion US dollars and is estimated to exceed 40 billion US dollars over the next decade. Most of this continues to be imported. Development of indigenous skills in these areas certainly seems highly desirable. Projects which would lead to high level manpower training and free flow of information and know-how in these areas are not easy to identify. It is believed that the plans described in this proposal fulfil this criterion. They would bring together scientists and engineers under a conducive environment allowing growth of competence and self reliance.

Radio astronomy deals with the study of a variety of celestial bodies on the basis of their natural radio emission. It is not only a frontier area of science but also has contributed and continues to contribute to competence-building in several areas of electronics such as large antenna system, low noise receivers, digital electronics and sophisticated data analysis involving information processing of complex radio signals by computer. Thus advances in communications engineering have benefited radio astronomy and vice versa. It is therefore hardly surprising that work in the field of radio astronomy has given rise to considerable technological spin-offs in several countries.

In this paper we confine to a brief description of a proposed Giant Equatorial Radio Telescope, GERT, and its scientific objectives. In sections 2–4 are described the technical aspects of the proposed radio telescope, its potentialities for growth and its value for joint observations with radio telescopes located in other countries by very long baseline interferometry. The scientific objectives are described in section 5. The present status of the proposal (Swarup *et al.* 1979) as an international collaborative effort between the developing countries and its training potential are given in section 6.

2. Giant equatorial radio telescope (GERT)

The proposed radio telescope has a unique design which is effective for use *only at a site close to the earth's equator*. It will consist of a 2 km long and 50 m wide cylindrical antenna with a 3 cm × 3 cm wire mesh as its reflecting surface, and will be oriented in a nort-south direction so as to make its axis of rotation parallel to that of the earth. Thus, by a simple mechanical rotation of the antenna along its long

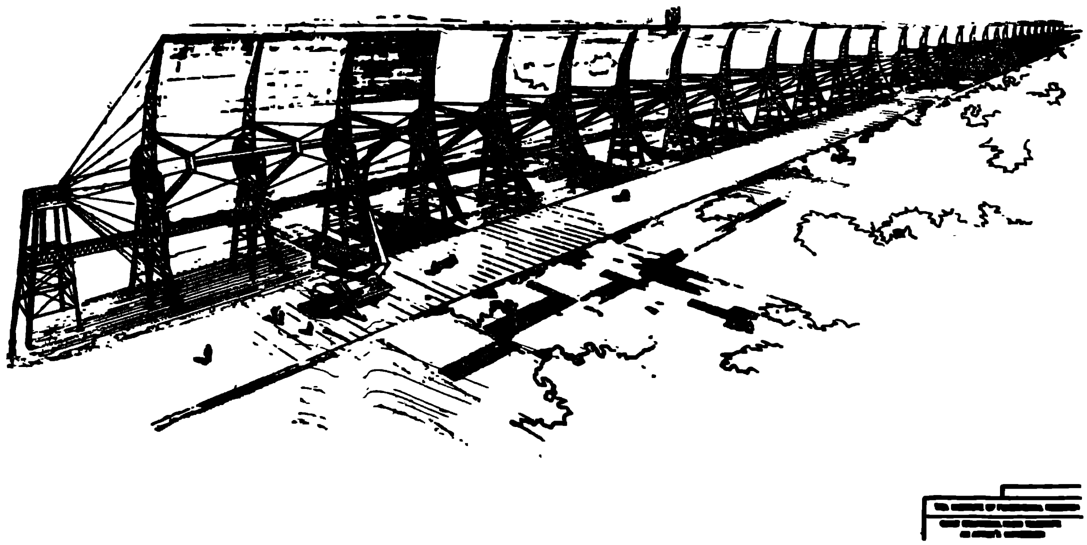

Figure 1. Artist's sketch of the proposed 2 km × 50 m giant equatorial radio telescope.

axis, its gain will remain constant during the tracking of a celestial radio source up to about 12 hr a day, as is required for the proposed radio astronomy observations. However, the antenna beam will be steered by electronic means in the north-south direction for pointing towards sources of different declinations. Its collective area will be equal to that of a parabolic dish of 350 m diameter. It would consequently become *the largest steerable radio telescope in the world.* Favourable sites for the radio telescope have been located tentatively in Kenya and Indonesia—sites that lie close to the geographic equator, are readily accessible and are free of high winds.

The telescope beam would be steered in declination over a range of ±45° by means of diode controlled phase-shifters placed along the focal line of the parabolic cylinder. In the first instance, the telescope will be operated simultaneously at 38 MHz and 325 MHz. A crossed-dipole system (about 4000 pairs) operating in the band 322-328.6 MHz will be placed at the focus of the parabolic cylinder, with dipoles oriented at ±45° to the long axis of the cylinder. This arrangement should provide a good polarization capability. The 38 MHz system will consist of about 480 dipoles. An RF amplifier will be placed either after every dipole or after a group of dipoles, with phase-shifter at every dipole. The electronic system of GERT will use the latest available analogue and digital techniques so as to make optimum utilization of the large sensitivity and steerability of GERT.

A 530 m × 30 m parabolic cylinder placed on a hill with a slope of about 11° in the north-south direction to make its axis of rotation parallel to that of the earth was set up by Indian scientists and engineers at Ootacamund in South India during 1966–70 (Swarup *et al.* 1971). It was designed and fabricated fully indigenously. As discussed in section 6, it is proposed that GERT be designed and fabricated as a collaborative effort by several developing countries.

3. 14-km synthesis radio telescope

The long north-south dimension of GERT allows the synthesis of a large aperture by placing several antennas at remote locations in fixed positions and by tracking for about 12 hr. Such a design is particularly advantageous for observing low declination sources from a location near the geographic equator. Therefore, in the second phase of this project, it is proposed to construct an aperture synthesis interferometer around GERT at a relatively small additional cost by adding 14 parabolic cylinders of smaller dimensions (say 50 m × 15 m) on a baseline measuring 14 km east-west and 12 km north-south. We may consider choosing the same width for these antennas as for GERT which would improve the performance of the synthesis telescope. For this purpose, GERT will be divided into 10 or 20 parts and all the antennas will be cross-correlated. The narrow field of view of each sub-sections of GERT (say 1°.2 × 0°.25 or 1°.2 × 0°.5) will minimize stray responses from stronger radio sources in the sky than the source being observed, thus leading to a large dynamic range of the radio maps. In addition the diode phase-shifters will allow rapid calibration of the system by observing nearby strong point sources.

This synthesis radio telescope would be the most powerful instrument operating at a metre wavelength and its high sensitivity would imply front-line capability for several decades. Its great value is likely to be in studying features of low surface brightness of those radio sources which have steep spectrum and are therefore much more prominent at metre wavelengths than at shorter wavelengths. These steep-spectrum features arise due to the population of the oldest relativistic electrons in the universe. The high resolution studies at metre wavelengths are therefore very important for understanding the evolution of both galactic and extragalactic radio sources. In view of these potentialities, one must consider both GERT and the 14 km × 12 km synthesis telescope as integral parts of this proposal.

4. Very long baseline interferometry

Very long baseline interferometers (VLBI) have provided resolutions of about 0.3 to a few milliarcsec at centimetre wavelengths and about 10 to 100 milliarcsec at metre wavelengths. This technique uses antenna systems which are separated by thousands of kilometres with independent receiver systems, the video outputs of which are recorded digitally on magnetic recorders and cross-correlated later using a computer system or a special correlator system. It requires local oscillators which are synchronised to an accuracy of about 1 part in 10^{12} using rubidium clocks at longer wavelengths or hydrogen maser frequency standards at shorter wavelengths.

Observations at centimetre wavelengths made in Europe and the USA have been made mainly for studying compact central components associated with optical galaxies or quasars identified with high luminosity radio sources. VLBI observations at 325 MHz with GERT and other existing large radio telescopes and/or smaller radio telescopes placed in some of the participating countries will provide extremely high sensitivity at metre wavelengths. These will be very valuable for finding the spectrum of compact central components and for studying 'hot spots' in the outer components of powerful extragalactic radio sources (Kapahi & Schilizzi 1979). The high sensitivity will be useful for the studies of nuclei of galaxies, compact components in galactic objects, proper motion of pulsars etc.

5. Scientific objectives

There are many astrophysical phenomena which are prominent or seen only at metre wavelengths. However, the exploitation of this part of the electromagnetic spectrum requires radio telescope with large collecting area because of the high galactic background noise. Also, special techniques such as lunar occultation observations and interplanetary scintillation studies are required to achieve a high resolution of a fraction of arcsec at these long wavelengths. The proposed design of GERT satisfies the above objectives and allows one to achieve large sensitivity and steerability at a relatively low cost.

Our initial motivation for proposing the construction of GERT was to study the large scale structure of the universe and also to investigate the nature of radio galaxies and quasars, which are the most energetic events seen in the universe (Miley 1980). It soon become clear that an attractive feature of GERT would be its great versatility which would enable its use for variety of astronomical investigations. As typical examples, we list here several interesting programs.

(i) *Solar system* : GERT will be a valuable instrument for studing radio emission from the sun and the planets. It would also be an outstanding facility for studying the characteristics of the ionospheres and the magnetospheres around planets, the plasma around comets and the solar-streamers in the interplanetary medium. These studies can be made by observing scintillations and occultations of distant radio sources as their radiation traverses the plasma around the above bodies. As pointed out by Professor A. Hewish, GERT will enable interplanetary scintillation observations to be made at smaller solar elongations than any other instrument (Swarup *et al.* 1979, p. 8). Therefore, these observations should lead to long-range predictions (over one week) of geomagnetic storms due to high-speed solar wind streams, providing an early warning system of considerable importance in adequate planning of radio communications around the world.

(ii) *Our galaxy* : GERT will be an invaluable facility for studying many of the rapidly varying phenomena seen in our galaxy, including enigmatic objects such as SS433. Besides, studies with the proposed synthesis radio telescope and lunar occultation observations will provide wealth of data about H II regions, planetary nebulae, supernova remnants and the Galactic Centre. Some programs of special interest are given below :

(a) Pulsars : Pulsars are one of the most exotic objects discovered in recent years and have provided valuable information about the physics of matter under extreme conditions of density and magnetic field (Manchester & Taylor 1977). GERT is likely to discover a few hundred new pulsars up to the farthest extent of our Galaxy and perhaps in Magellanic clouds. GERT will allow detailed investigations of individual pulses from pulsars. Pulsars research will be one of the most important programs of GERT.

(b) Radio stars and flare stars : The most extensively studied stars at metre wavelnegths are UV Ceti type flare stars which give rise to optical and radio bursts having hundreds of times more energy than from the sun (Lovell 1971; Spangler & Moffett 1976; Nelson *et al.* 1979). Many successful observations of radio emission from novae have been made. Extension of spectrum of emission line stars of type P Cyg to metre wavelengths is of considerable importance for understanding the nature of their coronae and mass outflow of gas. Radio emission has also been detected from some other types of stars. These observations are valuable for understanding the physics of stars and are likely to be pursued extensively during the next decade.

(c) Recombination lines : It has been shown that the intensities of radio recombination lines at low frequencies from cold dense clouds are considerably enhanced by stimulated emission caused by background continuum sources (Shaver 1975; Pedlar *et al.* 1978; Shaver *et al.* 1978). These observations provide valuable information about the interstellar matter. Because of the large sensitivity of GERT, these lines enhanced by stimulated emission from intervening galaxies could be observed from distant galaxy and quasars. Such studies would provide interesting information on physical conditions in the intervening regions, redshift estimates for unidentified sources and cosmological interpretation of quasar redshifts (Shaver 1978).

(d) Deuterium line : A search for radio emission from the predicted hyperfine transition of deuterium at 327.4 MHz in our Galaxy is of considerable cosmological importance. Recent measurements with Copernicus satellite gave a mean value of the deuterium-to-hydrogen ratio of 2×10^{-5} towards 9 nearby stars (Dupree *et al.* 1977). For a primordial origin, this value is insufficient to close the universe. The radio measurements made so far have given only an upper limit (Anantharamiah & Radhakrishnan 1979). By dividing GERT into 20 or more parts, each connected to a 128-channel line receiver, and then combining the resultant measurements, we should be able to verify whether the above ratio holds for different parts of our Galaxy; this would be valuable for our understanding of the nucleo-synthesis during the early epoch of the universe.

(iii) *Nearby galaxies and clusters of galaxies* : Detailed high resolution studies of the continuum radio emission from different classes of normal galaxies and their nuclei would provide very valuable data about evolution of galaxies. In view of extensive optical surveys of faint galaxies being made by several groups and also detailed observations of nearby galaxies to be made by the space telescope which is to be launched by the USA in 1985, radio observations with GERT would provide valuable complementary information. Studies of halos around individual galaxies and around cluster of galaxies provide important information about the diffusion of relativistic electrons and their confinement. Recent x-ray observations have shown that there exists considerable fine-structure in x-ray emission from clusters and it would be important to study any correlations with radio emission. There are many other interesting questions such as distribution of head-tail galaxies in the clusters which GERT would allow to be investigated.

(iv) *Radio galaxies and quasars* : One of the most important problems in radio astronomy today is to understand the origin and evolution of radio galaxies and quasars. In these sources, truly gigantic amount of energy, about 1 part in 10^5 of the entire rest-mass energy of a galaxy, is radiated at radio wavelengths. Typically, a radio galaxy consists of two extended radio lobes located about a hundred kilo persec away on either side of the optical object. Recently, the very large array (VLA) in USA has started providing high resolution maps of a large number of radio galaxies and quasars with a resolution of about 0.15, 0.4 and 1.2 arcsec at wavelengths of 2, 6 and 20 cm respectively. Observations with similar resolutions in the wavelength range of about 1 to 10 m would be extremely valuable for understanding the evolution of radio galaxies and quasars.

These observations would provide detailed information about the relative spectra of hot spots, radio lobes, tails and bridges, contributing very significantly to the physics of radio galaxies and quasars.

One of the primary scientific objectives of GERT will be to make a detailed study of hundreds of radio galaxies and quasars with a resolution of about 0.1 to 0.5 arcsec at 325 MHz, and a few arcsec at 38 MHz, using the method of lunar occultation (Swarup *et al.* 1971). It is not practical to achieve such high resolutions at metre wavelengths using long baseline radio interferometry because of the limitations posed by the ionospheric scintillation. Further, the method of occultation allows studies of extended features such as bridges and tails of double radio galaxies. In view of the high sensitivity and steerability of GERT, one would get the above resolutions for components of only a few tens of mJy in strength at 325 MHz. For a full exploitation of the occultation method, one requires a large collecting area of the telescope, constancy of its gain and a low contribution by the moon's brightness temperature relative to that of the sky background. The special design of GERT, namely a long cylinder placed in a north-south direction at the equator and a suitable correlator receiver system, would allow the above objectives to be met quite sufficiently.

Further, in principle, GERT will be capable of surveying about 40,000 radio sources of greater than 0.25 Jy at 325 MHz in the declination range of about $\pm 45°$ in just 24 hours ! This fast capability of GERT will allow monitoring of the flux variability of galactic and extragalactic radio sources, discovery of new novae and supernovae and perhaps could even lead to serendipitous discovery of new kinds of transient radio sources (perhaps even from distant civilisation in our galaxy ?).

(v) *Large scale structure of the universe* : Since radio galaxies and quasars have very high luminosities, they can be seen to enormously large distances in the univere. Therefore, their studies provide a great deal of information about the large scale structure of the universe. Radio source counts and optical identification statistics over a wide range of flux densities (Peacock & Gull 1981; Swarup *et al.* 1982) have indicated that the densities of radio sources were much higher, particularly for high luminosity sources, at earlier cosmic epoch. There is considerable uncertainty, however, about the parameters of the local luminosity function and the cosmological evolution. Particularly, it is interesting to enquire whether there is a cut-off or decrease in the density of radio galaxies and quasars beyond a redshift z of about 4 or 5 as some of the radio data indicates (Peacock & Gull 1981). There are also indications that the physical sizes of the double extragalactic radio sources were smaller at earlier cosmological epochs (Kapahi 1975; Kapahi & Subrahmanya 1981) but further studies are required to rule out the possibility that the observed dependence arises due to a correlation between luminosity and linear size (Downes *et al.* 1981; Masson 1980).

A very exciting possibility is to observe line emission from neutral hydrogen clouds of proto-clusters just before the formation of galaxies (Sunyaev & Zel'dovich 1975). Since the largest redshift observed for quasars is about 3.5 (Osmer 1981), the matter in the universe seems to have been condensed from the gas phase at epochs corresponding to redshifts z of about 3–10. Thus, the expected line emission from these clouds would lie in the metre wavelength range (about 100–350 MHz). Because of the low level of *CW* interference at sites near the equator and high sensitivity of GERT, it would be an excellent instrument, along with a multi-beam multi-channel receiver, to search for these proto-clusters. With GERT, we expect to achieve a sensitivity of at least 100 times better than that achieved at Jodrell Bank (Davies *et al.* 1978). Thus, there would be a good possibility of finding a proto-cluster with an expected mass of about 10^{13-14} solar masses.

6. Present status

A detailed proposal for INISSE/GERT written up in 1978 by G. Swarup (India), T. R. Odhiambo (Kenya) and S. E. Okoye (Nigeria) has been strongly endorsed by leading scientists from across the world. A workshop was held in India in 1979 April to consider the technical feasibility and scientific merits of the project. Full details about the proposal are available in the proceedings of the workshop (Swarup *et al.* 1979). It was attended by scientists from Egypt, India, Indonesia, Iraq, Kenya and Nigeria. Professors W. N. Christiansen of Australia and A. Hewish of U.K. attended it as UNESCO consultants. As Professor Hewish summarised 'it is clear that GERT will provide a front-rank instrument, competitive on a world scale; and the scientific case for building it is very strong'. The participants strongly recommended the project for support by their governments and interested international organisations. Resolutions for support of the project have also been passed by leading international organisations such as the International Astronomical Union, the International Radio Scientific Union and the Committee on Space Research. An expert team consisting of Professors A. Hewish, O. Malo, S. E. Okoye and the author visited Kenya, Nigeria and Senegal in 1981 January under UNESCO's auspices to discuss the project with leading scientists, engineers and government authorities. Considerable enthusiasm for the project was expressed by all concerned. Along with local scientists, the author has also visited sites near the equator in Indonesia and Kenya and has found several attractive possibilities for locating GERT. UNESCO has now approached several developing countries with a view to finding out their reaction to the proposal.

Based on a technical feasibility study, including a preliminary computer-aided design, the cost of GERT was estimated in 1979 as US dollars 15 million, which is moderate compared to the costs of other major radio telescope in the world. A sum of US dollars 5 million was estimated for INISSE for some task-oriented projects and its training facilities. There seemed to be some scope for optimization of the costs. It was considered that GERT can be designed and fabricated fully by the participating developing countries in about 5 years and the import content from the developed countries would be only about 20 per cent. A further sum of US dollars 2.5 millions is required for the Synthesis Radio Telescope. The above costs spread over a period of about 5 yr do seem to lie within the collective means of several developing countries.

Conclusion

Considering the wide range and in-depth investigation of many scientific topics which GERT would allow to be pursued, it would no doubt be a unique facility for conducting front line research in radio astronomy at metre wavelengths. Its indigenous design and construction will provide valuable training to scientists and engineers in several developing countries, which can be used in related fields of communication and remote sensing of earth's resources.

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