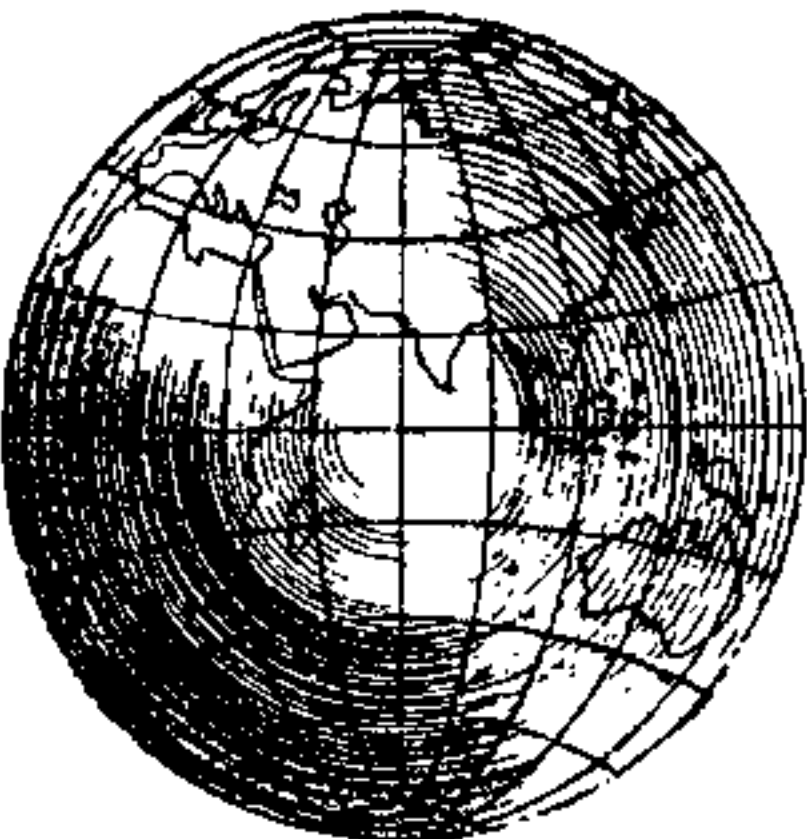


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THE EARTH'S MAGNETIC FIELD

THAT the earth has an associated magnetic field has been known for many centuries, and its effect on a small freely suspended magnet has long been used as a navigational aid. Such an arrangement can equally well be used for discovering the properties of the earth's magnetic field, in particular its form over the surface of the earth or—by a sufficient refinement of the apparatus—any fine details or small changes that may be found at a chosen locality. During the first half of the nineteenth century, the German mathematician Gauss found it possible to separate the total magnetic field measured at the earth's surface into two distinct components, one of internal and the other of external origin. The field due to internal origin is by far the larger component of the two. It has a similar form to, though not identical with that produced by a bar magnet with its axis inclined at a small angle of about 11° to the axis of rotation of the earth.

The field to be measured is never large; the maximum strength is about 0.7 gauss and often, the details of interest are one-thousandth of this value. The external field is transient in character and exhibits a most complex structure depending upon the relative configuration of Earth, Sun, and Moon, the season of the year, and on the physical state of the Sun, in contrast to the main field which is independent of all these variables. The source of the transient field has been traced to the atmosphere.

The main field has a number of components of which that corresponding to a dipole field is the most prominent. The best fit dipole field has an equatorial horizontal component of 0.312 gauss and a magnetic moment of 7.06×10^{25} c.g.s. units. There is some empirical evidence to suggest a decrease of magnetic moment, by a few per cent. during the last century.

The deviations of all the elements from the corresponding dipole form are time-dependent, a fact discovered empirically and expressed in terms of a secular variation. The average annual change at each location is about 50γ ($\gamma = 10^{-5}$ gauss).

The data on the past field are also of great interest, and recently these have begun to be inferred from a study of the remnant magnetism of certain natural rock formations, either sedimentary or igneous, containing small grains of ferromagnetic impurity such as Hematite or Magnetite. Before a rock is formed, the impurity grains behave as small suspended magnets and get oriented in sympathy with the local field. On subsequent compression or cooling, the particle orientation is preserved, thus, leaving a magnetic record of known geological age. Data are now available covering the range 800 million years ago to historical times, and a smooth link with the modern results has been obtained by the study of artificial architectural structures, and of volcanic lava of accurately known age. From a study of the values of dip certain important conclusions have been drawn. It is found that the dipolar axis has changed gradually with time. The evidence is in favour of considerable wandering: for example, some 800 million years ago the North magnetic pole would have been in Central North America: from here it moved south-westward across Pacific Ocean to near the Marshall Islands, then towards Japan and finally across Siberia to its present position (76° N., 102° W.). Measurements made both in Europe and North America lead to paths of the same form, and this result is interpreted as due to continental drift. The present obliquity angle between the geographical and magnetic pole though small is likely to represent 'a maximum value, and in the past seems to have been rather smaller. Although the orientation of the earth's axis of rotation is fixed in the main relative to the plane of the ecliptic, the rotation axis appears to have kept company with a wandering magnetic axis; the total evidence is intelligible only if the terrestrial surface features have moved relative to the solid mass of the earth which has remained unaffected in space. A slow relative slip between the mantle and core is, therefore, a reasonable conclusion on dynamical and mechanical grounds. Implicit in it is the assertion that the source of the magnetic field is to be found in the core.

When we consider the dip direction, another surprising result emerges out namely, the polarity reversal. Observational data imply that the

polarity of the total dipole field has in the remote past reversed not once, but many times with time reversals of the order of 10^6 years.

Recent astrophysical work has shown conclusively the general occurrence and fundamental importance of magnetic fields in the Universe and these fields often show polarity reversals. It is well established that the Sun possesses a general stable small dipole field in addition to local fields of the magnitude 10^3 gauss, connected with sun spots. Polarity reversal has been observed not only in the Sun but also in some magnetic stars, characterised by an associated strong variable, non-sinusoidal magnetic field of the order of 10^3 gauss.

It is well known that the magnetic field in a conductor decays exponentially, depending on the electrical conductivity and linear dimensions of the conductor. If the conducting sphere has the same size as the earth, the decay time is of the order of few times $\times 10^4$ years; and if the sphere has stellar size, the decay time is increased to 10^{10} years. Therefore, it can be said with confidence that for objects of astronomical size the decay time is appreciably greater than the present accepted age of the Universe (5×10^9 years), the cosmic magnetic fields being essentially permanent features and the electrical conductivity effectively infinite.

The following conclusions are to be drawn at the present time concerning the occurrence of magnetic fields:

(i) Electrically conducting matter in motion has associated magnetic fields; so that the problem of production and amplification of such fields is very likely to involve also considerations of the dynamics of matter; (ii) The problem of maintaining an already established field arises only in condensed bodies of planetary size; (iii) Because the earth is the only planetary body known to have a magnetic field, its study must proceed independently; and (iv) Nevertheless, polarity reversal is found generally and the earth's field might ultimately be found to form one special manifestation of a more general cosmic feature.

Theories of origin of the main terrestrial field based upon the presence of magnetised materials either in the main body of the earth or the crust does not seem to be valid, for, the temperature inside is much above the Curie point and the crustal specific magnetisation is much larger than the measured values respectively. An alternative approach is the possible inadequacies of Maxwell's equations for regions of large volumes and for such systems, conventional equations must be augmented by terms which associate the magnetic moment

with material angular rotation. Laboratory investigations by Blackett and others have unanimously decided that the magnetic rotation effects are absent.

The other conventional source of the magnetic field is an electric current system within the earth. This approach is concerned with the details of the possible production and location of such a current system, along with the investigation of its properties and those of the associated magnetic field. The electrical conductivity must be a controlling factor, since internal energy sources for electromotive forces are limited. For this reason, the core is electrically the region most likely to act as a source for the observed magnetic field and the importance of this in this connection was inferred before, on the basis of pole wander. Further, the essential importance of fluid flow for the problem of the magnetic field follows immediately from the failure of the mechanisms depending on the solid phase. The assertion that the origin of the field at the surface is traceable to the intricate three-dimensional fluid core notions has no significant competitors. The fact that part, if not all the core is liquid must add physical weight to the argument.

The theory of the earth's field is then reduced to a study of the mutual interaction between an electrically conducting fluid and a permeating magnetic field. The movement of a conducting fluid across a magnetic field is known to induce an electromotive force in the fluid which gives rise to electric currents; these interact with the permeating initial magnetic field, providing what amounts to an electromagnetic body force to act on the fluid, in addition to the purely hydrodynamic body forces that are independently present. The complex of phenomena can be analysed with a new branch of physics known as magneto-hydrodynamics. The introduction of the ideas of magneto-hydrodynamics at once envisages new effects, the significant one being the ability of an electrically conducting fluid immersed in a magnetic field to withstand shear in a more permanent manner than when the field is not present. For this reason the fluid is able to transmit transverse waves in addition to the longitudinal waves, normally to be expected and these are known as hydrodynamic waves. Seismic data clearly support these ideas and the inner core was recognised by its ability to carry transverse waves. On this assumption the theory leads to an inner core magnetic field of 10^5 gauss as an order of magnitude. The absence of transverse waves in the outer core

is, on the new interpretation taken as evidence for the smallness of any field there. The severe restriction of the strong field to inner core region implies the presence of special fluid flow patterns in the outer core, derivable on the basis of hydromagnetic arguments and the dipole fluid observed at the earth's surface is to be regarded as a secondary effect. The fact that the surface field has a strength of only $\frac{1}{2}$ gauss is not incompatible with the model: in the solar case the surface field is as small as 1 gauss although a strong internal field is present. It is to be concluded, therefore, that the empirical evidence supports the full appeal to magneto-hydrodynamics in treating the dynamic problem.

Field decay occurs through Joule heat losses which is an irreversible effect, and any augmentation of an existing field must involve the conversion of kinetic into magnetic energy according to the rules of magneto-hydrodynamics. Bullard in an important paper established, by reference to a special model, that a hydromagnetic dynamo mechanism is able to maintain a stationary field, once established. Independently, Elsasser has attempted to obtain solutions of the hydromagnetic equations which are directly applicable to the earth.

On purely qualitative grounds, however, the several terrestrial effects can be correlated. The core-mantle coupling which must be of viscous origin associated with the last stage of the decay of turbulent motion, will depend on the magnetic conditions in the core. If the secular variations be associated with fluid motion in the outer core and the westward drift of the surface field be ascribed to a differential rotation between the mantle and the core, then changes of the magnetic conditions in the core can be expected to affect the coupling: the observed correlation between anomalies of the secular change and terrestrial rotation becomes intelligible.

Polarity reversal remains unexplained and falls within the range of arguments concerned with the initial production of magnetic fields. That the turbulent motion is intimately connected with the production of magnetic fields is usually accepted to be true. The production of magnetic fields in Nature still remains an unsolved problem, and it has not yet been unambiguously demonstrated that turbulent motion can spontaneously give rise to a magnetic field and that such a field can be amplified. The origin of the earth's main field is still not understood but it is clear that the first steps of a theoretical treatment have been taken. It is virtually certain that the effect is

hydromagnetic and located in the core, and that the non-linear form of the theory is fundamental.

Further progress is expected to be made during the International Geophysical Year since

the earth's magnetism is one of its highly interesting and important properties.—(Based on an article by G. H. A. Cole, *Science Progress*, 1957, Vol. XLV, pp. 628-45.)

THE NEW AUSTRALIAN RADIO TELESCOPE

A NEW radio telescope designed by Dr. Wilbur Christiansen of the Radio Physics Division of Australia's Commonwealth Scientific and Industrial Research Organisation, Sydney, has been completed and put into operation, in time for the opening of the International Geophysical Year which commenced in July 1, 1957. The task of building a high precision radio telescope with an extremely high angular resolution was undertaken by Dr. Christiansen in 1954, and the telescope is located near the small industrial town of St. Mary's on an abandoned airfield; about 30 miles from Sydney.

The new telescope is the outcome of a previous interferometer built and used by Christiansen, known as "Christiansen interferometer" which consisted of 32 parabolic dishes, each 6 ft. in diameter arranged in a line 700 ft. long. The dishes constituted a kind of coarse diffraction grating that gave a reception diagram formed by narrow and widely-spaced fringes. As the Sun crossed the field of the instrument each fringe scanned the disc, somewhat as the exit slit of a spectroheliograph, and localised sources of radio emission could be pin-pointed with considerable accuracy.

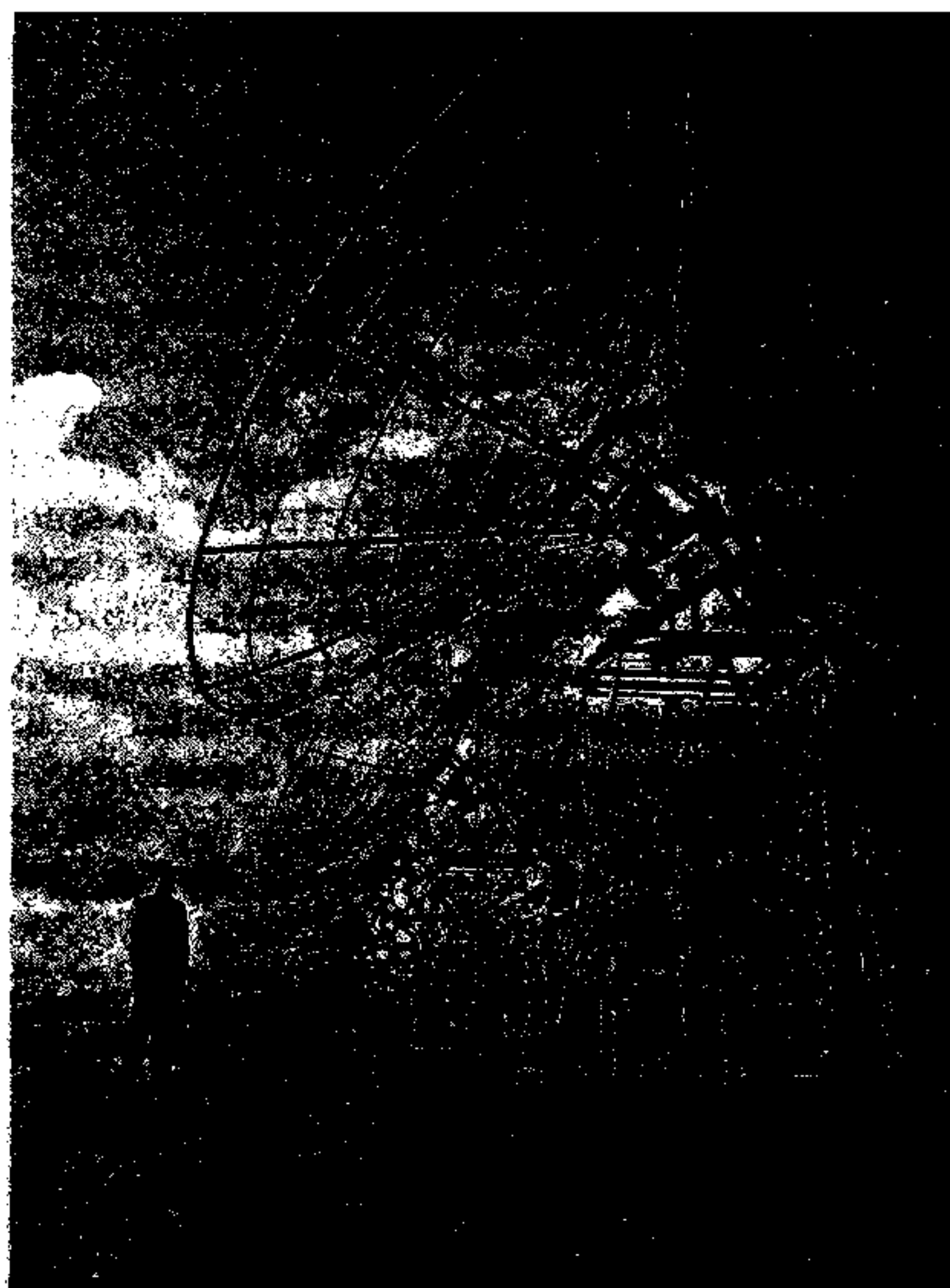
This instrument established in detail the origin of enhanced radio emission in active areas of the Sun marked by sunspots, bright hydrogen flocculi and other optical signs of disturbances in the solar atmosphere.

Minimum sunspot activity marked the period from 1951 to 1954, ideal for the multiple interferometer to function effectively. There was seldom more than one active region at a time on the Sun. Knowing the position of a sunspot, it was certain that a recorded peak came from that point and so the radiophysicists were able to get the information they sought for.

But after 1954, a state of maximum sunspot activity commenced and this created a large number of simultaneous active regions on the Sun. The "knife-edged" beam performance of the interferometer, receiving signals from narrow strips of the Sun, was not suitable for the new conditions. A shortcoming of the instrument was the fact that each beam received the total emission from the south-north strip that it scanned. This did not matter when it was

known, that only one active region lay in a strip, but it mattered very much when two or more regions were active in a strip.

In order to overcome the limitations of the above interferometer, Dr. Christiansen designed the present instrument which combines the principles of the former with the "Mills Cross" interferometer. The principle of Mills Cross is essentially the following. Two long intersecting aerial elements arranged in the form of a cross, produce a pair of intersecting beam and only the point of intersection is capable of receiving signal. By this arrangement, a high directivity for the aerial system is obtained though it is at the sacrifice of the collecting area.



Photograph of the Radio Telescope
By Courtesy of the Australian High Commission,
New Delhi.

The new telescope consists of 64 parabolic dishes, each 19 ft. in diameter and erected on an equatorial mount. Each arm of the cross consists of 32 dishes, with 40 ft. space between