# CHAPTER 1

# INTRODUCTION

## 1.1 General

For thousands of years man's knowledge of the universe outside the earth came from visual observations. The invention of the optical telescope in the early seventeenth century and the application of photographic methods in the last century, made rapid advances in astronomy possible. Around 1930, a major breakthrough was made by the creation of new branch of astronomy called "Radio Astronomy", as a result of which observations made at radio wavelengths have added immensely to our knowledge of the universe.

Ground based astronomical observations can be made only through the transparent bands of the earth's atmosphere and ionosphere. The optical "window" extends from 0.4 to 0.8 micron wavelength, while the radio "window" extends from 1 cm to 10 metres wavelength with some "holes" in the millimetre wave region. The short wavelength limit is caused by molecular absorption in the atmosphere and the long wavelength limit by ionospheric reflection (Kraus, 1966).

As long as the observations were all ground based, only two branches of astronomy, namely, optical and radio astronomy existed. However, with the advent of artificial earth satellites located far above the ionosphere, it has now become possible to carry out satellite based astronomical observations using almost the entire electromagnetic spectrum. Thus gamma ray, x-ray, ultraviolet and infrared astronomy have come into existence.

Radio astronomy enables one to study objects located very deep in space because radio waves radiated by these objects are not absorbed by intervening dust clouds which render optical observations extremely difficult, if not impossible in these directions. A study of very remote objects helps one to understand, among other things, the evolution of the universe.

In view of the importance of radio astronomy, its techniques have been much improved and refined in recent years. Sophisticated radio telescopes employing aperture synthesis techniques and on-line data processing using digital techniques have been developed, and used at a number of observatories around the world.

## 1.2 Historical Review

In the year 1932, Karl Guthe Jansky, a radio engineer at the Bell Telephone Laboratory, while working on a project on thunderstorm static, accidentally discovered radio waves which he proved to be of extra-terrestrial origin (Jansky, 1932; 1933; 1935). He thus founded Radio Astronomy, but lacking encouragement from his employer, he could not pursue this field further. Some years later, Grote Reber, a young amateur radio engineer from Illinois was inspired by Jansky's work and constructed a parabolic reflector of 31 feet diameter in his backyard with his own funds. He succeeded in detecting celestial radiations at 160 MHz in 1939 and published a series of articles on Cosmic Static (Reber, 1940a; 1940b; 1942). He took up a systematic survey of the sky and published the first maps of the radio sky (Reber, 1944) as seen at 160 MHz. He continued to work at short wavelengths and published sky surveys at 480 MHz (Reber, 1948).

Following a suggestion from Jan H. Oort of Leiden Observatory, Henrick Van de Hulst of the same observatory theoretically investigated the possibility of receiving line radiation at radio wavelengths. He reported that neutral hydrogen in interstellar space was a likely source of 21.1 cm wavelength (1420 MHz) line radiation (Van de Hulst, 1945). On March 25, 1951 Ewen and Purcell (1951) of Harvard University detected this line in emission. Almost simultaneously Muller and Oort (1951) also detected this line in emission at Leiden Observatory. Subsequently, the line was detected in absorption by Hagen and Mc clain (1954) at the US Naval Research Laboratory. Observations of the hydrogen line have led to spectacular success in mapping the detailed structure of our galaxy, only a small part of which was formerly accessible through optical observations.

As the interest in radio astronomy grew and the need for obtaining a better idea of the radio sky was felt, building radio telescopes with higher and higher resolution became a necessity. The resolution of a radio telescope may be increased either by increasing the aperture of a single antenna, or by employing interferometric principles. Bolton and Stanley (1948) using an interferometer observed the Cygnus region and found that the radio source discovered earlier in it by Hey (1946a; 1946b) had an angular diameter of $\lesssim$ 8' of arc. This was the first intimation that at least some of the radio radiation comes from sources of very small angular extent. This led to the development of a phase switched interferometer and its application to the observation of weak radio stars as reported by Ryle (1952). Mills and Little (1953) also reported the development of a high resolution antenna system using correlator receivers.

In the year 1957, the University of Manchester, England, constructed a 250 - foot diameter radio telescope at Jodrell Bank. For many years this was the largest steerable radio telescope in the world.

Although three even larger diameter paraboloidal telescopes have since been built elsewhere, it has been clear that the future lay in the exploitation of interferometric techniques. This led to the development of long base line interferometry yielding angular resolutions of a few seconds of arc (Allen, Palmer, Rowson, 1960). The Very Large Array (VLA) in America and the Multi-Telescope Radio Linked Interferometer (MTRLI) in England are the two best currently operating systems, each consisting of many fairly widely spaced antennas. In recent years very long base line interferometers (VLBI) with baselines of order of earth dimensions have been used to push angular resolutions to about a millisecond of arc (Redhead, 1978; 1979).

It may be noted that the observed radio brightness distribution of the sky is related to the response of an antenna system, which depends on the aperture for a single antenna system, and on the baseline for an interferometer system. By varying the baseline of an interferometer, different Fourier components of the brightness distribution may be measured. Combining many such measurements with different baselines to make a map of the sky brightness is the basic principle on which aperture synthesis radio telescopes operate.

The first synthesis telescope capable of mapping an arbitrary distribution of sources was built at Cambridge by John Blythe (1957). This telescope which had a beamwidth of $2^{o}.2$ provided the first detailed maps of the galactic emission at long wavelength (7.9m). Using the aperture synthesis principle, many new telescopes have been built since then in different parts of the world, and operating at different frequencies (Ryle, Hewish & Shakeshaft, 1959; Ryle and Hewish, 1960; Christiansen & Wellington, 1966; Jones, 1973; Hogbom & Brouw, 1974; Casse & Muller, 1974; Van Someren Greve, 1974).

Along with the developments in radio telescope systems described above, the receivers have also gone through a series of modifications. The function of a radio telescope receiver is to detect and measure the radio emission from celestial sources, the flux levels of which are of the order of a few milli-Janskys to tens of thousands of Janskys ($1\ Jy = 10^{-26}\ wm^{-2}\ Hz^{-1}$).

In most cases, the emission consists of incoherent radiation, whose statistical properites make it indistinguishable from the noise generated in the receiver or from the Galactic background radiation.

Early radio telescope receivers were conventional receivers based on the superheterodyne principle. The capability of such receivers was limited to detecting radiation levels which are comparable to that of the receiver noise or background radiations. The sensitivity of such an instrument may be improved by collecting radiation over wider bandwidths, and by averaging the output over as long a time as possible. Dicke (Dicke, 1946) invented a receiver, whose input was switched alternately between the antenna and a reference load (noise source); the outputs were then compared. This method almost eliminates the effect of variations in gain and bandpass characteristics, of the receiver, thereby providing a greater sensitivity.

In a correlation receiver (Blum, 1959), the outputs from the two elements of the interferometer are multiplied and integrated. This results in an increase of the sensitivity of the receiver. Such a receiver can be used to produce a pencil beam by correlating the signals of the two fan-beams of a cross telescope (Mills & Little, 1953; Mills, 1963; Mills et al, 1963). The sensitivity of various types of total power and correlator type receivers has been discussed by Kraus (1966).

Special receivers have also been developed for detecting line radiations. In one type of such receiver called a Multichannel-Filter Spectrometer, the full radiation band is divided into a number of narrower bands using bandpass filters, and the spectral shape of the line radiation is obtained by comparing signals integrated in each narrow band.

Since a Fourier transform relationship exists between the autocorrelation of a random noise signal and its power spectrum, another kind of line receiver, called an Autocorrelation Spectrometer is also used. Economical digital techniques have been developed for the effective use of such spectrometers (Weinreb, 1963; Cooper, 1970). In these receivers, the signal from the antenna is down converted to video band, sampled at a rate not less than the Nyquist rate, and then quantized before further processing. The advantages and limitations of correlators using various levels of quantization as compared with those of analog correlators has been discussed in detail in the literature (Weinreb, 1963; Cole, 1968, Cooper, 1970; Klingler, 1972; O'Sullivan, 1980; Kulkarni & Heiles). The resolution and coverage of autocorrelation spectrometers has seen continuous improvement from the early 256-channel receivers to the proposed 10240 channel systems using very high sampling rates (Weinreb, 1963; Bos, 1979; Bos, 1980).

In view of their high reliability, precision and cost effectiveness, digital correlation techniques find increasing use in interferometry and spectral line observation in radio astronomy. Another advantage of digital systems is that the data is already in a compatible format for further processing in computers or transfer to peripheral devices like a magnetic tape unit, video monitor etc. for recording and display purposes.

In addition, the digital techniques have given rise to processing of signals on an on-line basis. Kenderdine (1974) has discussed a Fourier transformation System with only 8 antennas on an East-West line forming 16 interferometers. Direct transform hardware for processing of synthesis data was reported by Frater (Frater, 1978; Frater and Skellern, 1978). Two dimensional representations for the three dimensional interferometer measurements were also reported by Frater (1979). Clark (1979) has given different digital processing methods for aperture synthesis observations.

The impetus for the enormous developments in radio astronomy techniques was provided by the many important discoveries that were made during the half century history of this branch of astronomy. Some of them are mentioned briefly below.

That some of the radio sources fluctuated in intensity was first noted by Hey, Parsons and Philips

(Hey et al 1946a; 1946b) but they thought the fluctuations were inherent in the source. However, Hewish (Hewish et al, 1964; Little & Hewish, 1966) later established that such variations, called scintillations, were mostly from radio sources subtending an angle of 1 arc second or less and are caused by the relative motion of intervening plasma clouds in the interplanetary medium. In the pursuit of these scintillation studies, Hewish, Jocelyn Bell and others (1968) many years later accidentally discovered radio sources which emit radiation in the form of pulses; these sources have therefore been named 'Pulsars' (pulsating radio sources). A remarkable feature of such sources is that the interval between successive pulses from them is found to be constant to an astonishingly high accuracy (Manchester, 1980) over intervals of years or more.

The optical identification of radio sources has always been important, initially out of curiosity as to the nature of the sources, and later on, as the only way of fixing the distances of the farthest radio sources. Graham Smith (1951) at Cambridge University obtained a very precise position for the radio source, Cygnus A, and a rigorous search was made for an optically observable object which may be identified with it. Walter Baade of Mt. Palomar Observatory identified a faint distant galaxy (Baade & Minkowski, 1954) at these coordinates and studies of its spectrum gave an estimate for its distance of about 600 million light years. Later on, many radio sources were searched for optical identifications which led to the discovery of "Quasars" (Hazard et al, 1963; Schmidt, 1963; Greenstein & Mathews, 1963; Matthews et al, 1964). Quasar, a short name for "Quasi-Stellar Radio Source", is a star-like object with a large red shift emitting enormous quantities of radio energy.

Perhaps the greatest discovery in the field of radio astronomy is the detection of the $3^{o}K$ background radiation. Penzias and Wilson (1965) in systematically accounting for the system temperature of their receiver discovered an excess of $\sim 3^{o}K$ due to background radiation, which is now generally accepted as the relic of the big bang which created our universe.

The discovery of more, and different types of radio sources led naturally to attempts to understand the physical origin of the radiation. The spectra of the various sources were observed over as large a wavelength region as possible to provide clues to the mechanisms of radiation. Some radio sources like Cassiopeia A and Cygnus A have spectra in which the flux density falls off with frequency, while for some other objects like the moon, Mars, etc., the flux density increases with frequency as would be expected for thermal radiation from a black body. Alfven and Herlofson (1950) proposed that the non-thermal type of radiation, from radio sources originates from relativistic electrons moving in the magnetic field of a star. Kiepenheuer (1950) suggested that the electrons are in fact the electron components of the cosmic rays and that the radiation occurs during their interaction with interstellar magnetic fields. Shklovsky (1960) gave the theoretical basis for the non-thermal emission process now generally called synchrotron radiation.

Some radio sources like the Orion nebula appear to have a spectrum of the thermal black body type at lower frequencies, but which becomes flat at higher frequencies (Kraus, 1966). Radio radiation in this case is from free electrons which passing near protons are accelerated and caused to emit. This type of mechanism is called free-free emission and is prevalent in ionized hydrogen clouds (H II clouds).

Radio Astronomy at wavelengths greater than 3 metres is still in a poorly developed stage compared to that at decimetre and centimetre wavelengths (Erickson, 1975). This is because at the long wavelengths, we still have telescopes with angular resolutions of only tens of minutes of arc, not seconds of arc. The decametric radio region contains a variety of astronomical sources, which are weaker or not detectable at higher frequencies. From decametric radio spectra, one can derive the magnetic fields and electron energy spectra in various types of sources. Free-free absorption in H II regions becomes significant at lower frequencies and observations of them can give the electron densities in these ionised regions. Below 100 MHz, refraction in both the interstellar and interplanetary medium is very strong and hence detailed investigation in this frequency region can unravel the properties of the ionised media involved (Fisher, 1972).

## 1.3 Scope of the present work

A low frequency radio telescope operating at 34.5 MHz has been set up at Gauribidanur (Latitude — $13^{\circ}36'12''$ N and Longitude-$77^{\circ}26'07''$ E) in the form of T-shaped array antenna. It consists of a 1.38 kilometre long array of 160 elements along the East-West line, and a 90 element array extending southward from the centre of the East-West array. When the output of the East-West array is correlated with that of the North-South array, a beam of 26' in right ascension and 38' in declination is produced. The telescope is a meridian transit instrument with a capability for tilting the beam in the meridian.

To take advantage of the aperture synthesis technique in mapping large regions of sky in a single scan, a Digital Correlation receiver system has been designed, constructed and incoporated into the above mentioned instrument. In this system, the output of the East-West array is simultaneously correlated with each of the 90 spatial frequency components of the sky brightness distribution corresponding to the spacings of the North-South elements from the East-West array. A brightness distribution map for various zenith angles can then be computed by taking the inverse Fourier transform of the measured correlation coefficients. A fast, on-line, hardware Fourier Transform (FT) processor has been designed and constructed. The Digital Correlation Receiver system has been designed to provide delay, phase corrections and weighting of the Correlation Coefficients on an on-line basis.

A microcomputer has been designed and constructed for use as a peripheral controller to acquire the data from the FT processor and to display the brightness distribution map on a video monitor, or to record the data on magnetic tape for further processing.

The Digital Correlation Receiver System has been tested by carrying out field trials and the results are presented.

# Chapter 2

## SYSTEM DESCRIPTION

A low frequency meridian transit type radio telescope with a capability of tilting the beam in the meridian, and operating at 34.5 MHz has been set up at Gauribidanur (Latitude-13°36' 12" North, Longitude-77°26' 07" East). A brief description of this radio telescope is given below:

### 2.1 Antenna System

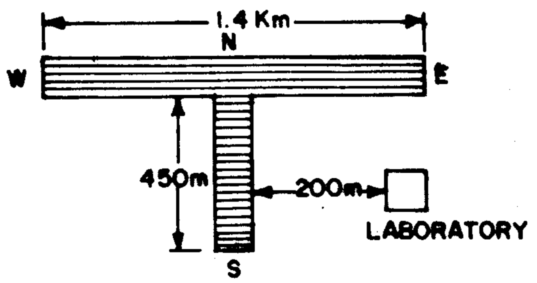
The radio telescope is a T-shaped array antenna consisting of a 1.38 km long array along the East-West line and a 0.45 km long, 90-element array extending southward from the centre of the East-West array as shown in Fig. 2.1.

#### 2.1.1 East-West array

The East-West array consists of 4 parallel linear arrays each of 160 horizontal 0.736 $\lambda$ dipoles, oriented East-West with an interdipole spacing of 0.989 $\lambda$. The spacing along the North-South direction between the four East-West linear arrays is 0.575 $\lambda$ as shown in Fig. 2.2.

Outputs from every 16 dipoles are first combined employing corporate feeds using appropriate transformers, amplifiers and phase shifters, giving a single "Subgroup" output. Thus there are 10 x 4 subgroups. The outputs of

ARRANGEMENT OF THE ANTENNA ARRAY




LATITUDE — 13° 36' 12" N

LONGITUDE — 77° 26' 07" E

INSTRUMENT ZENITH — 14° 6'N

OPERATING FREQUENCY — 34·5 MHz.

E W ARRAY

4 ROWS IN NS DIRECTION.
160 DIPOLES IN EACH ROW.

NS ARRAY

90 ROWS IN NS DIRECTION.
4 DIPOLES IN EACH ROW.

ALL DIPOLES ARE IN A PLANE TILTED AT 0°29'48" TO THE HORIZONTAL & ARE ORIENTED ALONG THE E-W DIRECTION.

INTERDIPOLE SPACING — 8.6m (0.989λ) IN E-W DIRECTION
— 5.0m (0.575λ) IN N-S DIRECTION

BASIC DIPOLE

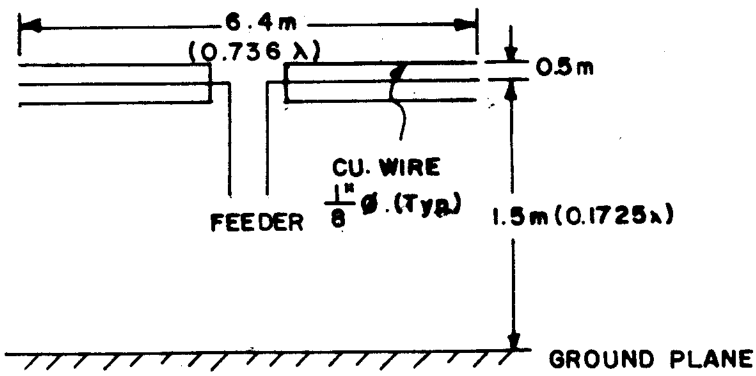



FIG. 2.1 RADIO TELESCOPE SYSTEM AT GAURIBIDANUR.

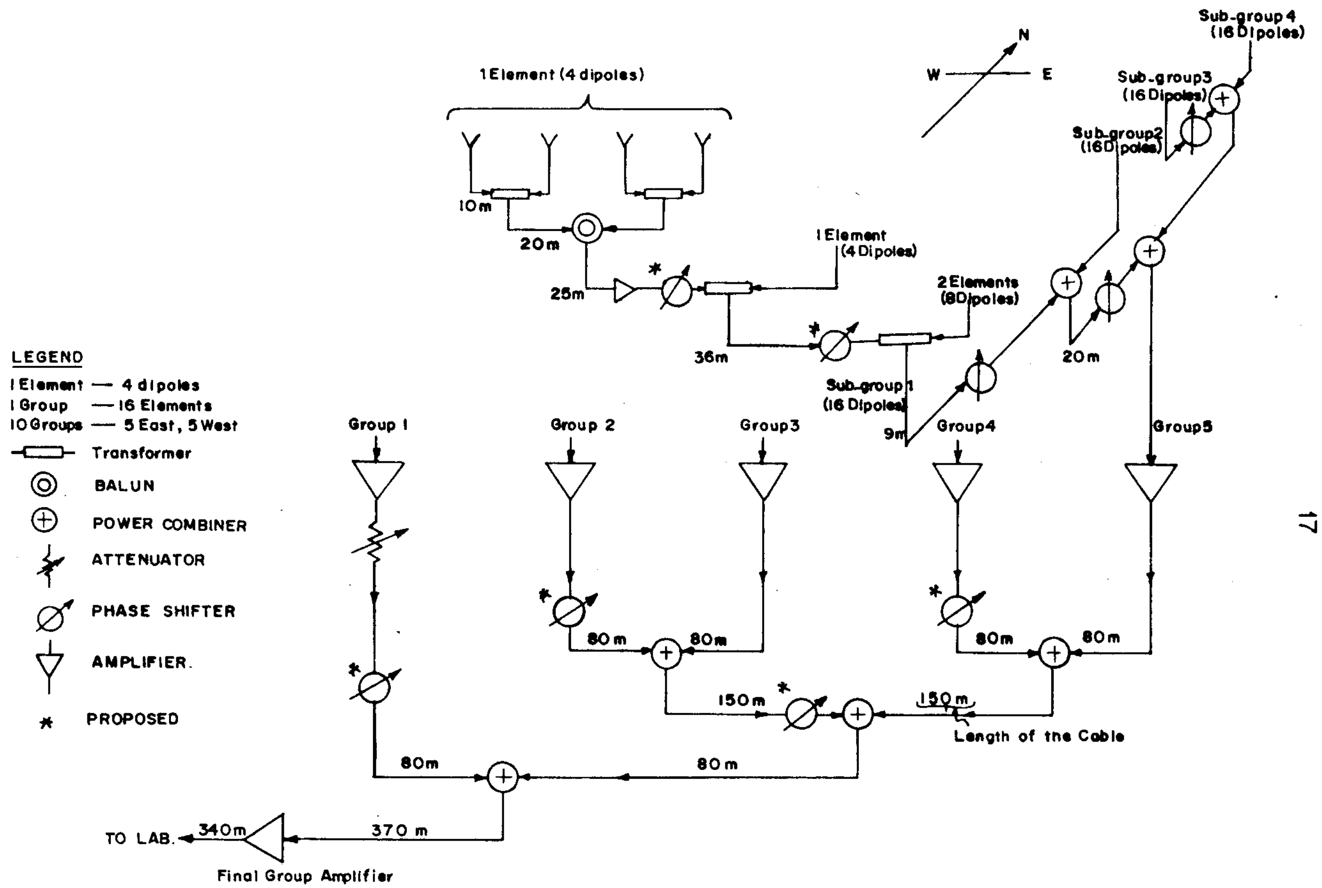



FIG. 2.2 EAST-WEST ARRAY (WEST ARM) SCHEMATIC DIAGRAM.

corresponding subgroups of each of the 4 East-West linear arrays, are again combined using corporate feeds and appropriate phase shifters, power combiners and a group amplifier giving the 'group' output. Thus there are 5 group outputs available from the eastern half of the East-West array and 5 group outputs available from the western half of the East-West array. 4 of the group outputs are once again combined using a corporate feed and appropriate power combiners. This output is combined with the output from the 5th group of the same half, the latter being suitably delay-and amplitude-corrected. This output which arises from (16 x 4) x 5 dipoles is amplified at the antenna site and routed via a coaxial cable to the laboratory for processing. Similarly, the output from the other half of the East-West array is also available in the laboratory.

### 2.1.2 North-South Array

The arm of the array extending southward from the centre of the East-West array, hereafter to be referred to as the North-South array, consists of 90 elements spaced 0.575 $\lambda$ along the North-South direction as shown in Fig 2.3. Each of the elements in the North-South array consists of 4 horizontal, 0.736 $\lambda$ dipoles oriented along the East-West direction with an interdipole spacing of 0.989 $\lambda$ . The output from these 4 dipoles is combined

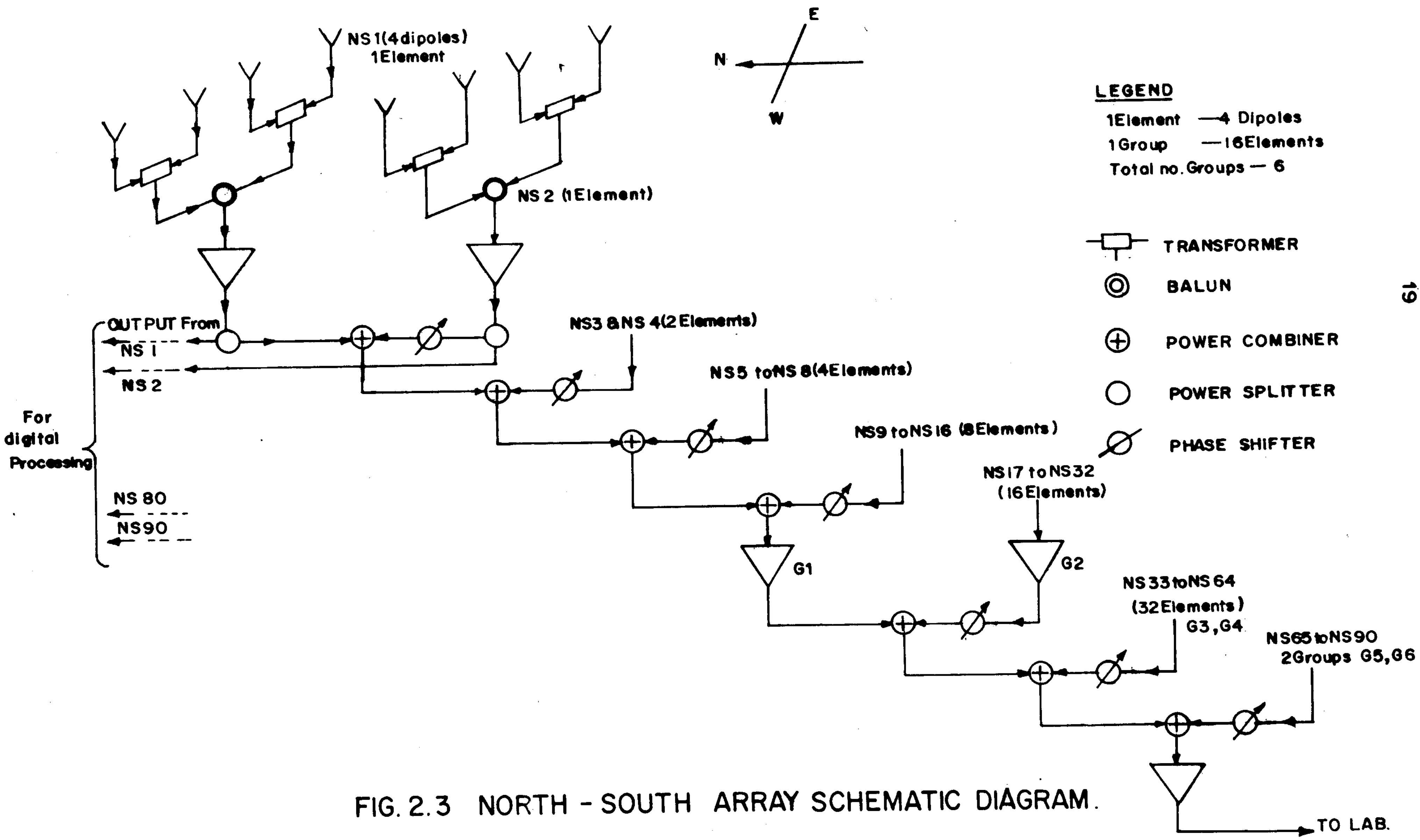



FIG. 2.3 NORTH - SOUTH ARRAY SCHEMATIC DIAGRAM.

by a corporate feed using 2 balanced transformers and a BALUN, and the output is then amplified giving the 'element' output.

In the North-South array also, the 90 elements are grouped into 6 groups - 5 groups of 16 elements each and 1 group of 10 elements only, employing corporate feed and using appropriate phase shifters and power combiners to give a 'group' output. The group outputs of these 6 groups are further combined to give a single North-South output and taken to the laboratory for analog processing. However, for digital processing of data using the system to be described here, individual outputs from the 90 elements of the North-South array are taken separately to the laboratory via open wire lines as shown in Fig 2.3.

It may be mentioned that all the dipoles, (160 x 4)+ (90 x 4) in number, are in the same plane, but which is slightly tilted with respect to the horizontal for reasons of terrain. The instrumental zenith is thus at declination $14^{\circ}\ 6'$ N instead of that corresponding to the latitude of the site. At $0.17\lambda$ below the plane of the dipole, a counterpoise earth system has been laid.

### 2.1.3 Parameters of the antenna

If the outputs from the eastern and western arms of the East-West array are combined, a fan beam of $0^{\circ}\ 26'$ in Right Ascension (RA) and $30^{\circ}$ in declination

(DEC) is produced. The North-South array produces a fan beam of $25^{o}$ in RA and $1^{o}$ 9' in DEC. If the output of the East-West array is correlated with that of the North-South array in a correlation receiver, an effective Cosine beam of 26' in RA and 38' in DEC is obtained. The total collecting area of the T antenna system described above is about 19,000 square metres.

## 2.2 Receiver system

The digital receiver system to be described, and which has been designed and constructed for use in the Gauribidanur Decameter radio telescope will replace/ supplement the existing receiver system which is an analog one. Before taking up the digital system, however, a brief description of the analog receiver system is given below.

### 2.2.1 Analog Receiver System

Individual signals from the eastern arm and the western arm of the East-West array, described in Sec. 2.1.1 are combined and passed through a 35 dB amplifier as shown in Fig 2.4. The amplified signal is then heterodyned with the local oscillator signal at 46 MHz to produce an intermediate frequency (IF) signal at 11.5 MHz. The IF signal passes through a variable bandpass filter of 30 KHz to 200 KHz bandwidth and is further amplified by 30 dB in an IF amplifier. The signal from the North-South array

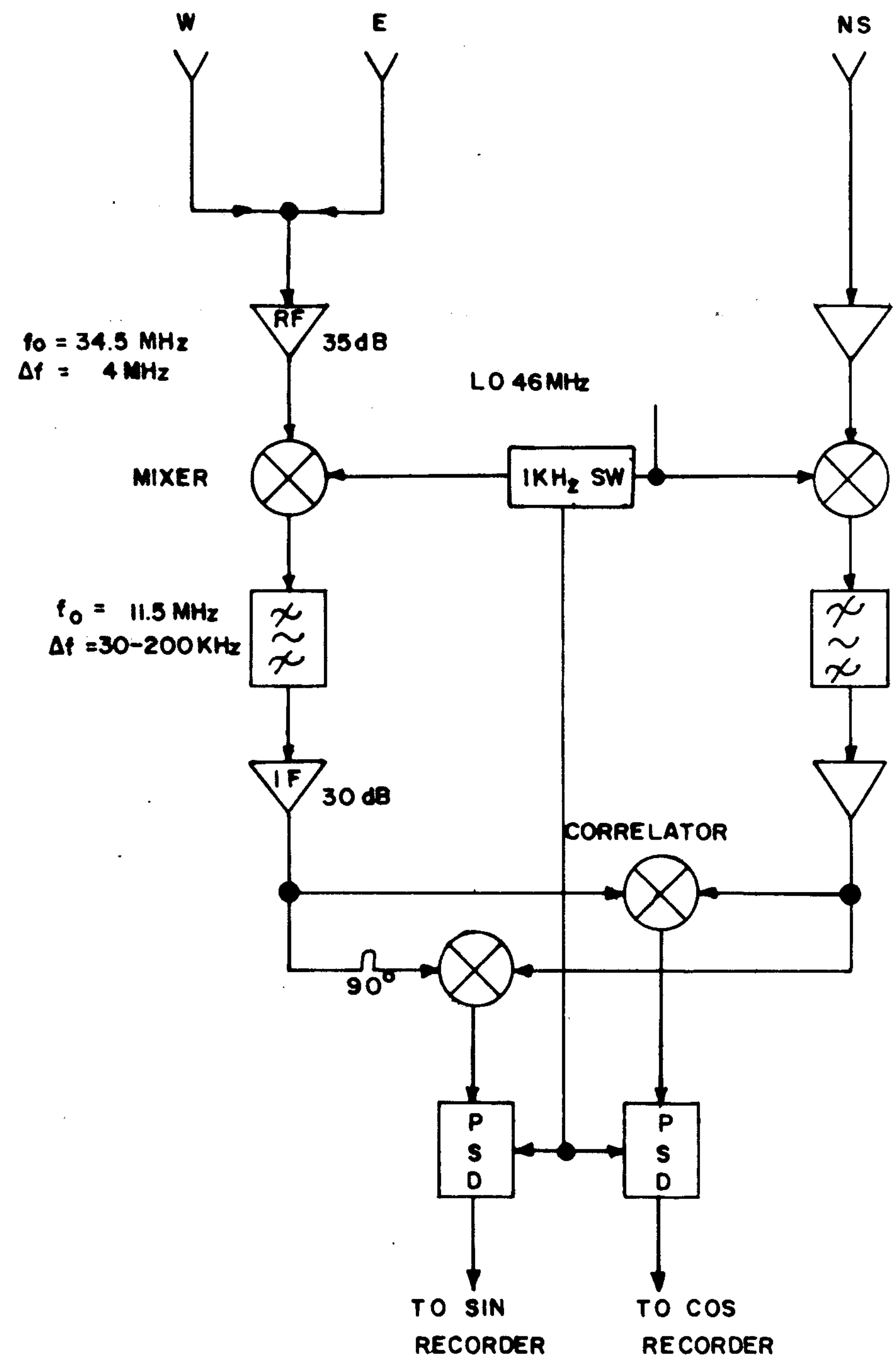



FIG. 2.4 ANALOG CORRELATOR

described in Sec. 2.1.2 is also amplified by a 35 dB amplifier and heterodyned with the 46 MHz local oscillator signal, the resulting 11.5 MHz IF signal being passed through a variable bandpass filter of 30 KHz to 200 KHz bandwidth and amplified by a 30 dB amplifier. This signal is then correlated with the signal from the East-West Channel. To eliminate the effects of drifts in the subsystems Dicke switching at 1 KHz is employed, and the output of the correlator is detected by a synchronous detector giving the 'Cos' component of the received signal.

The output of the North-South channel is also correlated with that from the East-West channel after shifting the latter in phase by $90^\circ$. The output from the corresponding synchronous detector gives the 'Sine' component of the received signal. Both the Cos and Sine components are recorded separately for further analysis.

Steering of the beam by $\pm 45^\circ$ zenith in the meridian plane with a resolution of $0^\circ.2$ is achieved by means of discrete phase shifters, which provide phase shifts in steps of $22^\circ.5$. No amplitude grading is applied. The sensitivity of the complete system described above is about 30 Janskys for an integration time of 10 seconds and a bandwidth of 30 KHz.

### 2.2.2 Digital Receiver System

In this system, instead of correlating the combined output of the North-South array, the output of each North-South element is separately correlated with the output of the East-West array. The output of each correlator is, thus, the output from a 2 element North-South interferometer, and gives a spatial frequency component of the sky brightness distribution corresponding to the spacing between the particular North-South element and the East-West array. Since all the elements in the North-South array are uniformly spaced, the spatial frequency components obtained are harmonically related to each other, and the correlation values give the Fourier components of the sky brightness distribution. The data thus collected may be processed digitally to yield the required information.

The Digital receiver system comprises:

i) The front-end of the receiver, where the signals are down converted and hard-clipped to produce 'one-bit' signals;

ii) The correlator system, where the one-bit signals are delay compensated and correlated;

iii) The Fourier Transform processor, where real-time processing is performed in computing the brightness distribution from the measured correlation coefficients; and

iv) The Microcomputer system, which is used as a peripheral controller to acquire the data from the FT processor, and to display the brightness distribution map on a video monitor or to record the data on magnetic tape for further processing.

Brief descriptions of the above subsystems of the digital receiver system are given below:

2.2.2.1 Front end of the digital receiver system

The signals from each element of the North-South array as also the combined East-West array are all down converted to an IF of 4 MHz through mixers using a local oscillator at 30.5 MHz, as shown in Fig 2.5. The signals are then passed through bandpass filters of fixed 600 KHz bandwidth for the North-South channels, and a variable bandpass filter on the East-West channel. The variable East-West filter is intended to eliminate interference by reducing the bandwidth at times when the band is cluttered.

The signals are then passed through zero-cross detectors, or clippers for obtaining 'infinitely clipped' signals. Then bandpass sampling is employed to obtain quadrature sampled signals for further correlation.

2.2.2.2 Correlator System

The infinitely clipped signals pass through a

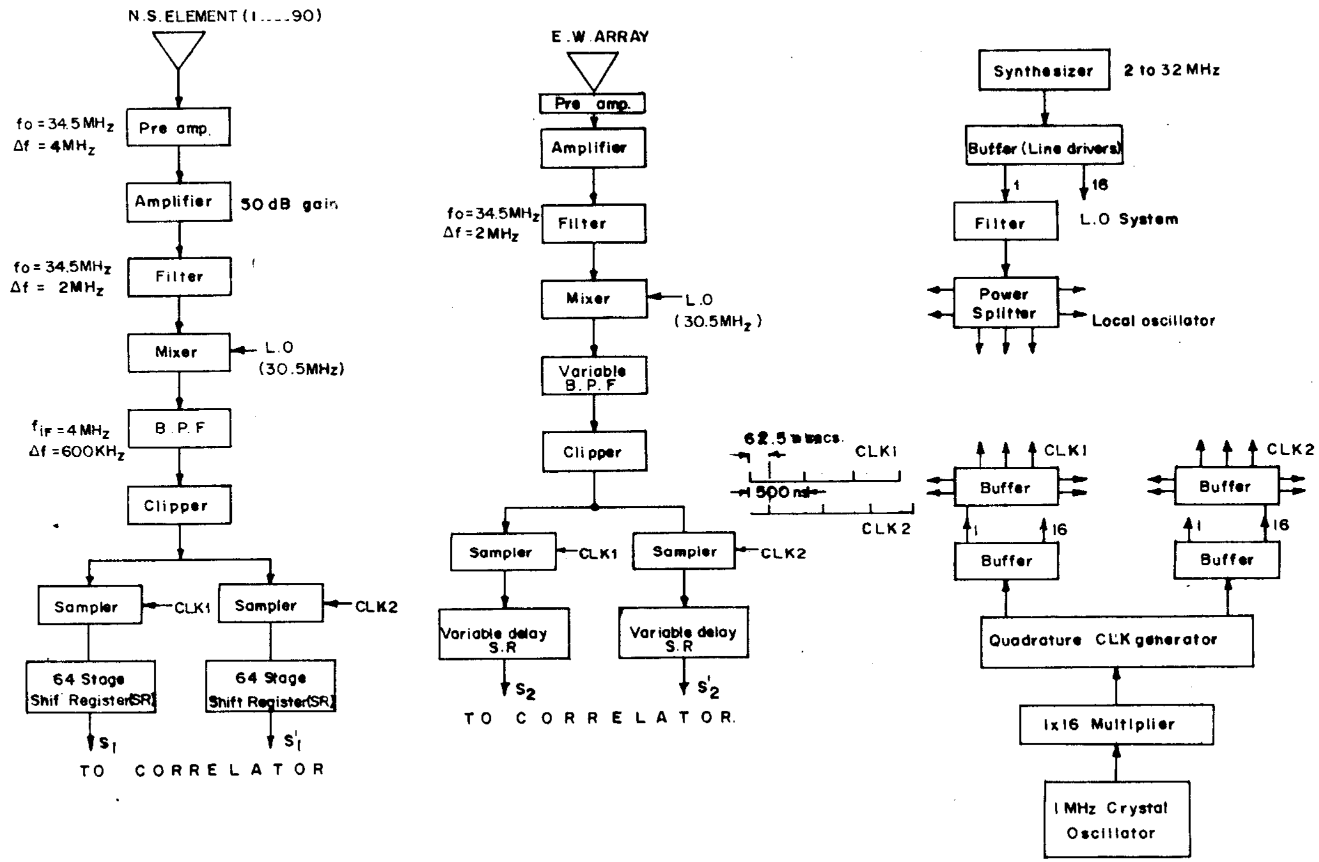



FIG. 2.5 FRONTEND OF DIGITAL CORRELATION RECEIVER. QUADRATURE CLOCK(CLK) GENERATOR.

shift register, where the delay is compensated in both the North-South array and the East-West array for different declination settings. The unequal cable lengths between each of the North-South elements to the laboratory are also delay compensated.

The outputs of each of the North-South array elements are then correlated using one-bit correlator circuits with the output of the combined East-West array. The output from each correlator circuit is then accumulated in a variable length counter of $2^n$ milli-sec integration time to provide 'pre-integration' where n may be choosen to be 1,2,3 .......8. The output of the accumulators gives the Cosine, $a_n$, and Sine, $b_n$, correlation coefficients. These coefficients are separately multiplexed and corrections for hard clipping are applied before further processing.

2.2.2.3 <u>Fourier Transform Processor</u>

The brightness distribution of the sky can be computed by taking the inverse Fourier transform of the measured correlation coefficients, as already mentioned in Sec. 1.3. In this manner, the brightness distribution may be computed for various pre-assigned zenith angles. This is equivalent to various positions of the beam of a steerable antenna. The FT processor thus computes 512 such beams from horizon to horizon in the meridian plane.

The FT processor comprises hardware control logic to implement a discrete Fourier Transform in real-time. The Correlation coefficients $a_n$ and $b_n$ are stored in "random access" memories (RAMs), and Sine and Cos tables necessary for the Fourier Transformation are stored in "read only" memories (ROMs). Phase correction and grading on the measured correlation coefficients are also implemented in real-time before processing. The phase correction coefficients and grading function tables are stored in other RAMs and ROMs.

The brightness value corresponding to each beam is stored separately in a final memory; an add-in memory feature provides 'post-integration'.

2.2.2.4 Microcomputer System

The data from the FT processor is displayed on a TV monitor and also recorded on an incremental magnetic tape recorder for further processing at the end of each post-integration period. The computed brightness values corresponding to various beams are displayed as a column of points. A two-dimensional brightness distribution map is obtained by real-time processing and displaying successive columns of points progressing leftward as the earth rotates from West to East. At maximum settings, a sky region of ~~15°~~ 60° in RA and ~~60°~~ 15° in declination can be displayed. The number of columns in each frame to be displayed is software selectable, and at the end of each frame the display is cleared before starting of the fresh frame. A microcomputer based on an RCA 1802 chip is used as a peripheral controller to perform the above operation.

In addition to the above, the microcomputer is also used to set system controls like the number of beams to be computed, the pre-integration time, the post-integration time and the type of grading function to be used. A console designed for the entire system, can also set the above controls independently.

The microcomputer is also used to set the control bits in the delay shift register discussed in Sec. 2.2.2.2. The delay table can be either a fixed table in the random access memory of the microcomputer, or can be computed in real-time depending on the range of beams to be computed for.