# AN INVESTIGATION
# OF THE
# RADIO EMISSION
# BY THE PLANET JUPITER
# on 18 Mc/s & 22 Mc/s

A thesis presented for the degree of
Master of Science of Rhodes University,

by

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Plate I. The Rhodes University Radio Astronomical Observatory near the Jameson Dam - Grahamstown.

# SUMMARY

This Thesis describes the investigation carried out of the radio noise emitted by the planet Jupiter on 18 Mc/s and 22 Mc/s.

Chapter I gives a brief introduction and outlines radioastronomical as well as astronomical ideas concerning Jupiter. A detailed survey of the research done to date including some of the hypotheses formulated by previous workers is presented in Chapter II.

Chapter III deals with the apparatus used in this research. Two similar sets of apparatus were used. The aerials were folded dipoles. The signals were fed to the receiver, an R 206, via a 300 ohm impedance line. To increase the gain an extra I-F. stage was included. This gave a gain of better than a 120 dB. To match the signals into the recorder a cathode follower was used.

The operating procedure appears in the fourth chapter. The results obtained are discussed and tabulated at the end of the chapter. They agree with the findings made by previous workers, within the experimental limit. Histograms of the occurrence probability versus the revised System III coordinates are presented for each frequency and compared to previous ones.

The final chapter contains the author's interpretation of the observed effects. A model based on a radiation analogous to the Čerenkov effect is found to be not inconsistent with the available data. Ending the chapter suggestions for further research are made.

Except where it is clear from the text that I am describing the work of others, or where it is obvious that I am making a survey of existing knowledge about Jupiter's radio noise, the work described in this thesis is my own.

"There is no more thrilling experience for a man than to be able to say he has learned something which no other person in the world knew before him."

Vannevar Bush.

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Plate II. Jupiter, blue light. 24 October 1952 7:41 U.T., taken with the 200" telescope on Mount Palomar Observatory.

# JUPITER !

Turning I perceived
The whiteness round me of the temperate star
The sixth, whereinto I had been received.
And in that torch of Jove, I was aware
Of Sparkles from the love within it warm....
O sweet star, with how many and rare a gem
Didst thou prove that the justice we obey
Proceedeth from the heaven thou dost begem!

DANTE, Paradiso,
Canto XVIII, 67-71, 115-117.

# CHAPTER I.

## 1.1 GENERAL INTRODUCTION.

This project was started in 1961, at the suggestion of Mr. S.F.H.J. Archer, who was at that time lecturing at this University.

Although observations were attempted during 1961, it was not until July, 1962, that the author was sure that signals from Jupiter were actually received at the Rhodes University radio-astronomical site. Observations were carried out from June until October this year for a total of 120 days.

A detailed summary of the work done to date on the Jovian radiation is given in Chapter II. Results obtained during the period of observation are presented. The results evaluated are in agreement with observations by previous observers in respect of the type of burst and the apparent location of the source on the planet.

A possible theory of the mechanism of production of the decametre radiation is put forward. Attempts are made to explain most of the phenomena observed by the author and other workers.

An amateur radio astronomer from East London, Mr. M.C.Bosch, was working in cooperation with us and supplied us with his records of Jupiter's noise on 18 Mc/s. (16.6 m). The availability of a recording from a different area enabled us to eliminate, with certainty, noise from local sources, which might otherwise have confused the interpretation of our records.

## 1.2 ASTRONOMICAL INTRODUCTION. (1., 2., 3.)

It is recorded that the inhabitants of ancient Babylon, Egypt and other cultured lands observed the heavens regularly. They found that certain laws seemed to govern the movement of the heavenly bodies, and that these could be used to fix the times of religious festivals as well as public and farming life.

The Egyptians, from about 3000 B.C., divided the day between sunrise and sunset into 12 parts. Simple sunclocks were already known to them. The measurement of the times of night were made with the aid of known star positions. By 1700 B.C. the Babylonians had divided the day into 24 equal hours.

The ancient Greeks thought that the Earth was at the centre of the Universe. Most of the conclusions that they came to, were arrived at by "deductive reasoning" rather than experiment. They already knew of five planets. Aristarchus of Samos (310 - 250) was the first to propose the "heliocentric system". This put the sun at the centre of the Universe, with Mercury, Venus, Earth, Mars, Jupiter and Saturn revolving around it.

Although lenses were known at least 2300 years B.C. in Troy, where they were only used as magnifying glasses and as ornaments, it was not until the 13th century that the English scientist Robert Grosseteste (1175 - 1253) remarked in a Paper on the rainbow that such lenses could be used to bring things closer.

Why more than four centuries had to pass till the first simple telescope was constructed, no-one knows. It seems that the discoverer of the telescope is the Dutch spectacle-maker Hans Lipperhey, who applied on 2nd October 1608 for a patent to manufacture these instruments for a period of 30 years. In the same year the first telescope was put up for sale at the Michaelisfair at Frankfurt by a Belgian merchant.

On the 7th of January 1610 Galileo Galilei discovered three moons of Jupiter using a telescope which he had built himself. This was the beginning of modern astronomy. Galileo's type of telescope is still in use today as an opera-glass. It was Johannes Kepler who published in 1611 in the magazine "Dioptrik" the design and calculations for his telescope and really opened the way for observations of the heavens.

Today we know of nine great planets, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto. In addition to these about 5000 Planetoids have been observed to date. It is likely that another large planet exists, whose distance from the sun, revolution and position have been calculated by astronomers. However it has not as yet been discovered. It is named at the moment "Transpluto".

We are concerned in this discussion only with the planet Jupiter. Let us, therefore, give a little more detail about this planet.

Jupiter is the largest of the nine great planets. Its mass is nearly two and a half times that of all the others added together. It has often been not inappropriately referred to as the Giant Planet.

The distance of Jupiter from the Sun is rather more than five times that of the Earth and it completes one revolution in just under twelve years. Thus it will be seen that the Earth must pass almost directly between the Sun and Jupiter about once every thirteen months, since the angle between the planes of their respective orbits is only a little more than one degree. At such times the planet will be most favourably placed for observations; for not only will its distance from the Earth be near a minimum but it will be on the meridian at midnight and above the horizon all night long.

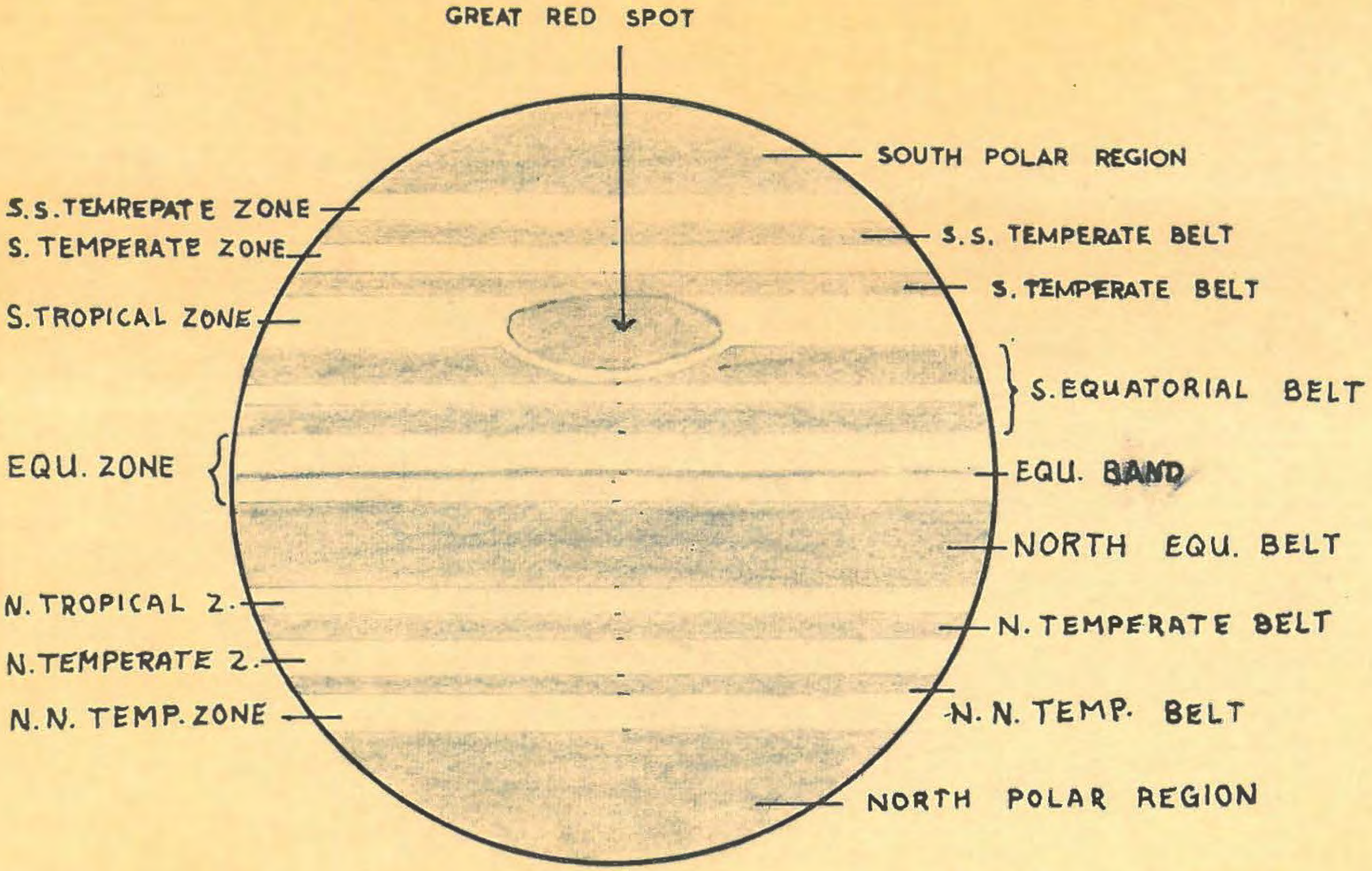
Owing to the rapid rotation of Jupiter, its period being less than ten hours, its polar diameter is less by about one part in fifteen than that measured through the equator.

The inclination of Jupiter's equator to the plane of its orbit around the Sun is little more than three degrees.

The solid surface, if such exists at all, is surrounded by an atmosphere that is quite impenetrable either visually or photographically. The general arrangement of the cloud formation, which is all that astronomers have so far succeeded in observing, is at first glance little more than a series of dark and light bands.

Figure I shows diagrammatically an aspect of Jupiter's "surface". The dark strips are called belts and the light ones zones; the thin grey line sometimes seen threading the middle of the Equatorial Zone is known as the equatorial band.

One of the most obvious features is the well known Red Spot. Attention was first drawn to it in 1878, but it could be traced back on older drawings as early as 1831. It is about 41000 km long and 14000 km wide. It changes its colour and has at times even been white and yellow; during a couple of years it was even invisible. It seems to drift in the Jovian atmosphere with a velocity of about 12 m/sec, which seems to suggest that it is not part of the atmosphere



VISIBLE FEATURES OF JUPITER.

Fig. I.Jupiter's visible features.

but rather something more solid. Further surface features, though not so easily observable, are the so called "three white spots".

In astronomy, longitudes on a planet are referred to an arbitrary, standard, zero meridian. On Earth this meridian passes through the position once occupied by the central web of the old Transit Circle at the Royal Observatory, Greenwich. But on Jupiter no solid surface is visible and it is impossible to choose a standard meridian that can be defined by the everchanging configurations of the clouds in the planet's atmosphere. From observations of these clouds astronomers have inferred that the solid body of Jupiter rotates on its axis in just under ten hours and the only convenient way of selecting a standard meridian is to choose more or less arbitrarily one that rotates in space about the planet's axis in approximately this period. So long as the period is convenient and strictly uniform, its exact value is immaterial.

Early observers of Jupiter, e.g. Cassini (1690), discovered that rotation periods derived from markings near the equator were in general about five minutes shorter than those given by the features in temperate and polar latitudes. This difference is great enough to render the use of a single zero meridian quite unsuitable as a reference plane for both regions. Two standard meridians, which with their respective rotation periods are known as System I and System II, are therefore employed, all spots lying within about $10^o$ of the equator being referred to System I and the majority of those beyond these limits to System II. The rotation periods of the standard meridians are in System I $9^h50^m30^s.003$ and in System II $9^{h}55^{m}40^{s}.632$. Since the choice of period is arbitrary, it may seem curious that the times are not rounded off to the nearest second; the reason for this absurdity is that they have been calculated from adopted rotations of exactly $877^{\circ}.90$ and $870^{\circ}.27$ in longitude in twenty-four hours for System I and System II respectively. The latter represents very closely the rotation of the Great Red Spot between oppositions of 1890 and 1891.

## 1.3 RADIOASTRONOMICAL INTRODUCTION.

It is only a relatively short time since radio techniques have been applied to astronomy. It was in December 1931 that the American Radio engineer K.G.Jansky tried to investigate atmospheric disturbances which were observable in Radio receivers as a sort of "whooshing" sound. Very much to his surprise he found that one particular source of disturbance seemed to move through the sky in a regular fashion. Detailed investigation showed that the noise source was the milky way. (4.)

Technical difficulties made progress very slow. Only the advances during the second world-war made it possible for radioastronomy to become an important part of science.

Various celestial objects have now been shown to be sources of radio emission. In most cases this emission is simply the low frequency end of the thermal spectrum of a hot body and hence is called "thermal emission". The received radiation is compared with that of a hypothetical black body which subtends the same solid angle as the visible disc of the emitting object. The "apparant black-body disc temperature" is the temperature which must be assumed for the black body in order that the intensity of this radiation should equal the observed one.

Early observations of Jupiter at about 3 cm (10000 Mc/s) gave black body disc temperatures similar to those expected on the basis of the infrared radiometric observations. It was only after Burke and Franklin (5.) reported having observed noise being radiated by Jupiter on 22.2 Mc/s (13.5 m) that observations of radiation on centimeter wavelengths were continued and intensified. Sloanmaker and McClain discovered in 1959 (6.) that emission by Jupiter at 10.3 cm (2900 Mc) was unexpectedly intense. The steady radio emission of Jupiter has now been observed over a relatively wide range of wavelengths, from about 3 cm (10000 Mc/s) to about 70 cm (429 Mc/s). The values for the black body disc temperatures computed from flux density are shown in fig II plotted against the wavelengths on which the observations took place. Normally one would expect the radiation to fall off rapidly with increasing wavelength according to Planck's Law for a certain fixed temperature; in fact the flux density of the radiation from Jupiter is nearly constant. In addition to the rapid increase in black-body disc temperature with increasing wavelength, the observations suggest that the radio emission may change with time. It seems therefore probable that this radiation is non-thermal in origin. (7.)

Jupiter thus seems to be the origin of three different types of radiation:

i) At very short wavelengths, one observes "Thermal radiation".

ii) At decimeter wavelengths, the continuous non-thermal radiation.

iii) At decameter wavelengths, non-continuous, very "bursty" in nature non-thermal radiation. It can be observed over a wide frequency band ranging from 4.8 Mc/s (65m) (8.) to 43 Mc/s (7 m) (9.) and seems to emanate only from three different places on Jupiter.

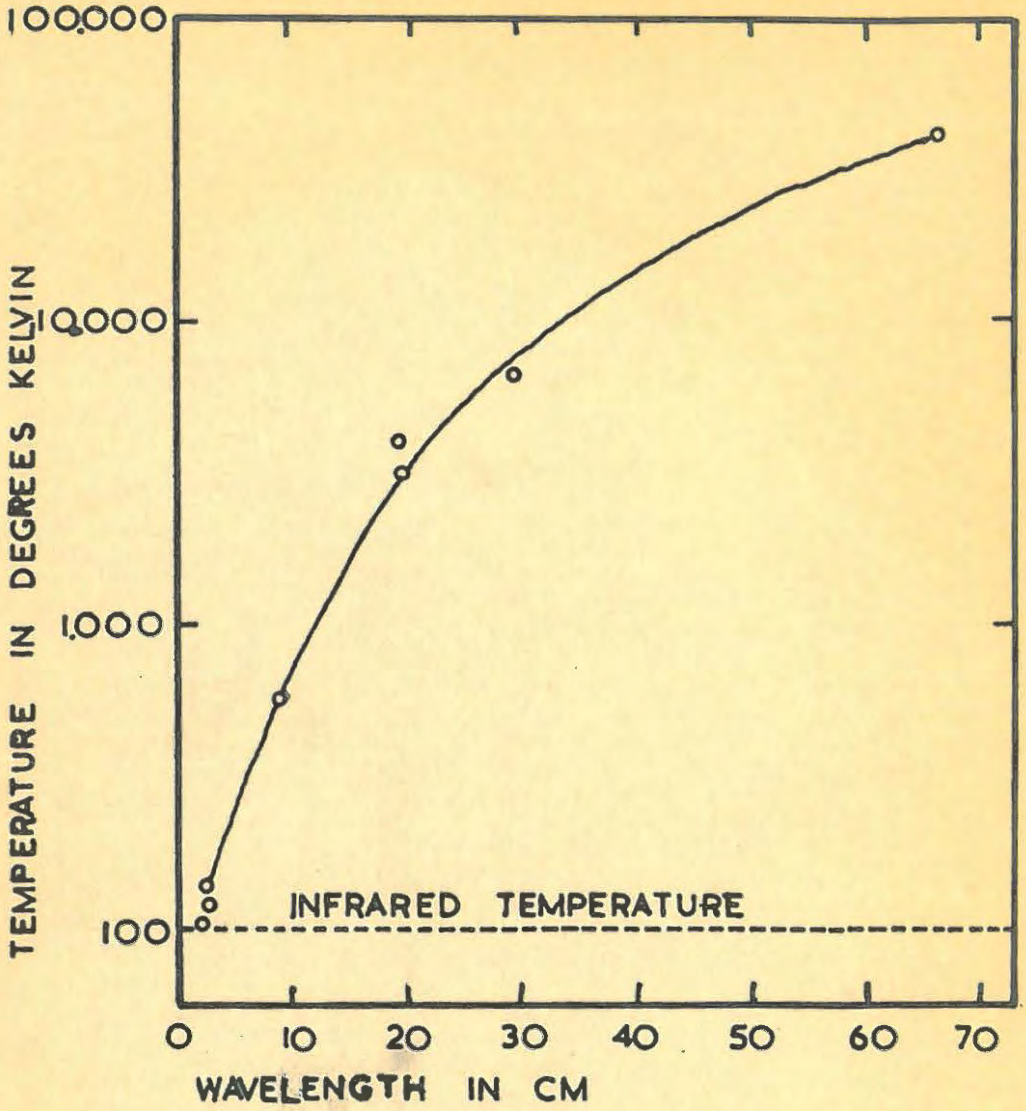


Fig. II. A plot of the improbable way in which "temperature" of Jupiter increases with wavelength, if the observed microwave energy is interpreted as being entirely of thermal origin. The points are mean values reported by various observers. Individual measurements fluctuate widely about these means, and in most cases it is not yet clear whether the variations are real or merely due to the uncertainties of these difficult observations.

The last type is the one that we shall investigate in this discussion. More details of the work done to date by other experimenters, as well as our own contribution will be given in later chapters

# CHAPTER II

## 2.1 WORK DONE BY PAST WORKERS.

Early in 1955 Burke and Franklin (5.) discovered that noise was radiated by Jupiter on 22.2 Mc/s. They were using the 22 Mc/s "Mills Cross" antenna system, inspired by a design by Mills and Little (10.), and a phase-switching principle first described by Ryle (11.), to make detailed observations in declination strips containing the Crab Nebula. The aerial consisted of 66 dipole linear arrays, each 2047 ft. in length, arranged to form a slightly flattened X. The direction of the effective pencil beam could be changed by appropriate phasing of the dipoles of the arrays. By tapering the dipole feeders the side-lobe responses were reduced and the resultant beam had a width of $1^{\circ}.6 \times 2^{\circ}.4$ at half-power-points.

On inspecting their records, they found that on a number of occasions interference patterns appeared for a brief time, the duration of which was about the same time as a point source would take to travel through the aerial beam. The pattern suggested a variable noise source, the mean position agreeing closely with the position of the planet Jupiter.

They determined the power density received on earth at a frequency of 22.2 Mc/s to be of the order of $5 \times 10^{-23}$ w.m.$^{-2}$cps$^{-1}$. From this they suggested that the radiated peak power per burst must be at least 300 watts per cps of bandwidth.

Records which had been taken in June, 1954, previous to the discovery, showed that at least once a source which could be identified as Jupiter had been observed at 22.2 Mc/s, while at a higher frequency of 38.7 Mc/s no traces of any similar signals were found. From this Burke and Franklin deduced that the radio noise emitted by Jupiter is limited to the low frequency range below 38 Mc/s.

Immediately after Burke and Franklin had published their discovery, Shain of the division of Radio Physics, C.S.I.R.O. at Sydney began observations, while at the same time searching through old records of cosmic noise for any signs of Jupiter radiation (12.).

Records taken at 18.3 Mc/s in 1950 - 51 showed a series of bursts of very high intensity which had previously been passed over as terrestrial interference. Detailed analysis of these records showed that Jupiter could be identified as the source of the radiation, thus confirming Burke and Franklin's discovery.

Shain also attempted to find a correlation between any visible feature and the observed radio emission. This he was unable to do, but he did calculate the rotational period of the main source and found it to be slightly longer than that of System II. He estimated the period of rotation to be $9^h55^m13^s \pm 5^s$.

In November 1955 Franklin and Burke (13.) started to make further observations of Jupiter. They carried on with their investigation till March 1956, observing mainly on 22.2 Mc/s using a phase-switching interferometer. Their aerials consisted of two arrays, separated by 20 wavelengths along an east-west line. Each array had eight half-wave dipoles. Phase shifts were introduced to shift the maximum response approximately 30° south from the zenith. Early in 1956 a third dipole array was added, consisting of eight dipoles and arranged in a north-south direction. The additional array, used with one of the other arrays, made it possible for them to detect the presence of circularly polarized radiation.

Also making use of interferometer records taken by their colleague Wells, Franklin and Burke found that there was definite evidence of at least three centres of activity on the planet, rotating approximately with the non-equatorial regions. A correlation of radio noise with visible features was unsuccessfull. The rotational period was estimated to be $9^h55^m33^s$. Most of the radio noise received was found to be circularly polarized. For the most active region, Burke and Franklin observed only bursts of right circular polarization.

Gallet (14.) gave a lecture to the National Academy of Sciences on the 3rd Sept., 1957 in which he analised the Jupiter observations to that date from three standpoints:

1) Synoptic data, in which only the length of time of the observations are noted.
2) Measures of radiated power.
3) Fine structure. Many of the bursts seemed to be composed of very short pulses.

He also stated that the observations are consistent with a source whose emission does not change markedly, but whose reception at the earth is limited by the Jupiter ionosphere. The size of the cone through which the radiation can escape is decreased by increased solar activity.

In an article by Gallet published in the series "Planets and Satellites" (15.), he tries to explain the phenomena on his hypothesis of a Jovian ionosphere. For emission to occur below the maximum of ionospheric ionisation, the outward propagation of a wave of frequency f is restricted to a cone, whose axis is the vertical of the emission point. The semiangle a of the cone is given by

$$\cos a = \frac{f_c}{f} \quad \text{where } f_c = \text{critical frequency}$$

The critical frequency is related to the maximum electron density in the ionosphere $N_{max}$, according to

$$f_c^2 = \frac{N_{max}e^2}{m}$$

where e = charge on electron
m = mass of electron

If observations are made at two frequencies simultaneously, the cones of emission are such that $a_2 > a_1$ if $f_2 > f_1$.

Franklin and Burke (13.) combining their data with those of Gardner and Shain (16.) found that the above hypothesis was not supported by these observations.

Gardner and Shain (16.) found the peak intensities of radiation received from Jupiter on earth to be very high and of the order of $10^{-19}$ w.m$^{-2}$ .cps$^{-1}$. They also reported that two receivers situated about 25 km apart in an east-west direction gave recordings which were not consistent; From this they concluded that the terrestrial ionosphere has a considerable effect on the time variation of Jupiter radiation and a lot of the "burstiness" of the radiation received might be due to the earth ionosphere. Having made the observations on three different frequencies, namely 14 Mc/s, 19.6 Mc/s and 27 Mc/s they came to the conclusion that there existed a peak of intensity and frequency of occurrence at 19.6 Mc/s (Fig.III).

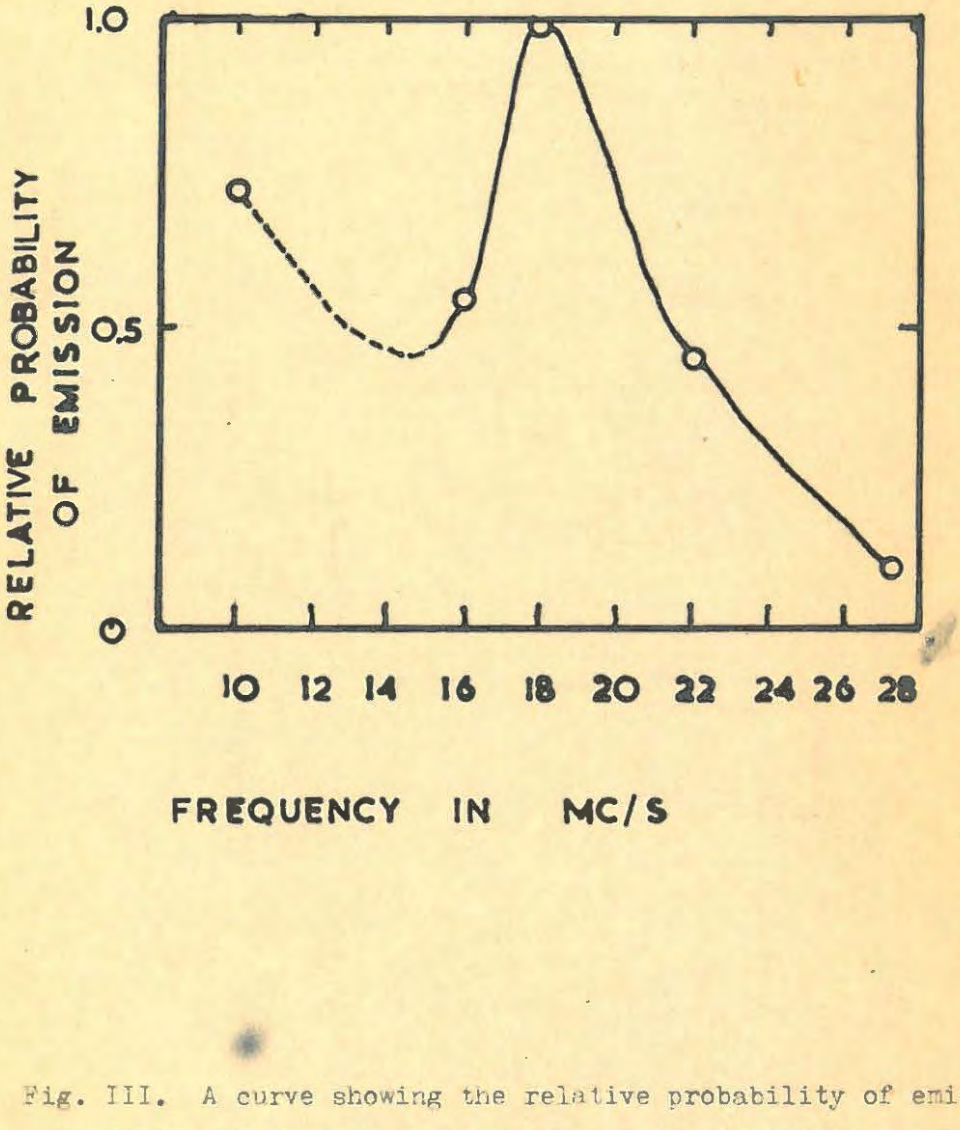


Fig. III. A curve showing the relative probability of emission of radiation from Jupiter at various radio frequencies. The peak of the curve corresponds to an absolute probability of about 10% i.e. the 18 Mc/s signals were detected during approximately ten percent of the observing time.

John D. Kraus (17.) observed Jupiter on a frequency of 27 Mc/s during 1956 and early during 1957. He used an interferometer antenna consisting of two collinear arrays each made up of six horizontal half-wavelength elements positioned one-quarter wavelength above ground. Each array was backed up by a reflector element, which formed with the ground, a rudimentary corner reflector. Later a three helix lobe-sweeping antenna was put into operations, the centre helix being fixed while the outer two rotate in opposite directions. Depending on the direction of rotation the rotation of the helix advances or retards the phase of the received wave by an angle equal to the angle through which the helix is turned. This system is well adapted for observing variable radio sources especially those, which emit sporadically for only a few minutes at a time.

Kraus's main interest was the study of the structure of the radiation received from Jupiter. He classified it into two main types: one which may persist for several seconds and produces a rumbling sound in the loudspeaker and another which is of very short duration (10 millisecond or less) and produces a cracking or clicking sound. He found that many of the short pulses consist of distinct pairs or triplets which fall into two main groups, one having pulse separations of about one-quarter of a second and the other pulse separations of about a tenth of this value. He postulated that some sort of echo mechanism might be the cause of the observed structure, the signals being reflected from the solid surface, or doubly reflected first from the ionosphere and then from the solid surface. Kraus also stated that the stronger Jupiter pulses indicate a peak radiated power at the source of the order of 10 kilowatts per cps bandwidth.

Carr et al. (18.) found that the components of a doublet or triplet are similar in amplitude, and the weaker frequently preceded the stronger pulses. This would seem to mitigate against an echo phenomenon. A superficial resemblance to terrestrial lightning, where multiple strokes are the rule rather than the exception, seems to exist. They noted early in their programme that the Jovian activity seemed to occur in cycles oonsisting of 3 or 4 days of sporadic radiation followed by a like period of relative inactivity. Plotting the daily activity versus the earth date a striking periodicity of eight days was observed.

In 1958 Carr et al. (19.) proposed that a so-called "System III" be adopted, the reason being that if a Jovian rotational period of $9^{h}55^{m}28\overset{s}{,}8$ was assumed the longitude of the region of maximum noise activity was essentially the same during three apparitions (oppositions between sun and Jupiter), for which data were then available. This longitude system was coincident with System II at $0^h$ U.T. on January 1, 1957. The System III longitude of the central meridian of Jupiter at $0^h$U.T. on Julian date "J" can be found from the published System II longitude (19.) for the same time by means of the formula

$$L_{III} = L_{II} + 0.28845 \; (J - 2435839.5)$$

Julian date is the number assigned to a day in the continuous count which is defined to be zero for the day starting at Greenwich mean noon on January 1, 4713 B.C. It was instituted to facilitate chronological reckoning of astronomical days, beginning at Greenwich noon. The zero was chosen as a time far in the past to precede the historical period (20.).

Smith and Carr (21.) using their own data collected during the period 1955-58 as well as those of Gardner and Shain (16.) tested the constancy of the rotational period of the noise source referred to System III longitude and found that they were in excellent agreement.

Smith et al. (22.) decided to investigate the inconsistencies of records made with spaced receivers reported by Gardner and Shain (16.). They repeated the experiment using a much longer baseline. One set of apparatus was situated at their own institution, Florida University, while the other was located at the Maipu Radioatronomical Observatory of the University of Chile. The separation was 7040 km. Similar receivers were used and both were frequency controlled making use of a crystal-oscillator. Brush high speed mechanical oscillographs with a response time of the order of 0.02 sec were operated at a paper speed of 5 mm/sec. Examination of the records confirmed that a striking difference existed between signals received at the two sites. Some sections of the recordings differed so radically, that it proved impossible to correlate the records without reference to the time marks. Careful study showed that many of the differences could be explained as the result of alternate fading (scintillation) at the two stations.

H.G. Booker (23.) made a study of the use of radio stars to study irregular refraction of radio waves in the ionosphere. He attributed some scintillation effects to a drift in irregularities in electron densities in the ionosphere. By using three receivers spaced in the form of a triangle, he was able to deduce from the observed effects the magnitude and direction of the velocity drift. Again other scintillations could be correlated with the ionospheric phenomenon known as the spread F. This effect involves a situation in which the usually well defined traces on an ionogram become diffuse and no sharp edges to the echo can be recognised. The ionospheric E layer might also contribute by causing scintillation. The most striking puzzle in connection with radio star scintillation is the cause of the night time maximum of scintillation. The periods are reported to vary from 8 sec to 2 min. and are apparently independant of the wavelength at which the observations are made. The scintillation amplitude increases at lower radio frequencies and for sources of small angular widths.

Smith et al. (22.) supposed that the observed scintillation effects of Jupiter radiation was of similar nature. It also seems that the scintillation frequency increases with increasing geomagnetic activity index K.

During the first half of 1960 James W.Warwick (24.) observed Jupiter from the High Altitude Observatory at Boulder, Colorado. He found a strong positive correlation between Jupiter's decametre emission and solar decametre continuum emission. Jupiter emission followed solar emission with a time delay of one to two days. Warwick therefore suggested that fast solar particles, travelling at velocities of the order of a tenth of the velocity of light, on entering Jupiter's ionosphere or magnetic field, cause the radiation to be emitted. That a magnetic field is involved is shown conclusively by the presence of one state only of circular or elliptical polarization in the bursts received. If interplanetary high energy electrons are the cause of Jupiter's decametre emission, we should expect some similar effects from these same electrons when they strike the earth and its magnetic field. Since the radiated energy varies as $H^2$ and assuming the 20 Mc/s radiation to represent a fundamental of Jupiter's radiation, Warwick stated that an emission two orders of magnitude less than 22 Mc/s, i.e. 220 Kc/s is to be expected from earth. Since the resulting electromagnetic waves propagate only away from the high-density, high-field regions, one would expect the earth, as seen from space, to be a source of sporadic emission in the medium frequency range, but comparable to Jupiter radiation in time and manner of emission.

Carr et al. (25.) observed Jupiter over the same period at their stations in Florida and Chile and came to similar conclusions, when evaluating their results. To account for the concentration of the noise sources into one or more relatively narrow longitude zones, which retain their rotational period for at least several years, the writers propose that there are one or more magnetic poles or other field anomalies, near the solid surface of the planet, which are some distance from the geographical poles. The charged solar particles tend to spiral into the magnetic poles, causing a local increase in particle concentration and more radiation would be expected from such regions.

Barrow (26.) explained the observed polarization as being due to internal conical refraction in the upper atmosphere of Jupiter of one of the two components formed when the radiation passes through the Jovian ionosphere in the presence of a magnetic field. In a later paper Barrow (27.) applies the Magneto-ionic theory of Appleton (28.) to Jupiter. Assuming the critical frequencies of the ordinary and the extraordinary rays to be around 22 Mc/s, and the gyrofrequency to be less than that he obtains a value for the polar magnetic field of 7 ± 1 gauss. A mechanism of plasma oscillations in the Jovian ionosphere is found to be not inconsistent with available data.

In July 1960 Carr et al. (29.) published the results of their observations of Jupiter, Saturn and Venus made at a number of frequencies from both the Northern and Southern hemispheres of the earth during 1959 and 1960. From the histograms, which they compiled, they showed that there was a tendency for the peaks to become narrower the shorter the wavelength of reception. They also showed that there existed an inverse relationship between Jovian decametric emission and the average sunspot number (cf. Fig. IV). On plotting all results available to them from 1951 onwards versus System III coordinates, they found a correction to the retational period. The new relationship between System II and System III longitudes was given by the equation

$$L_{III} = L_{II} + 0.2747 \quad ( J - 2435839.5)$$

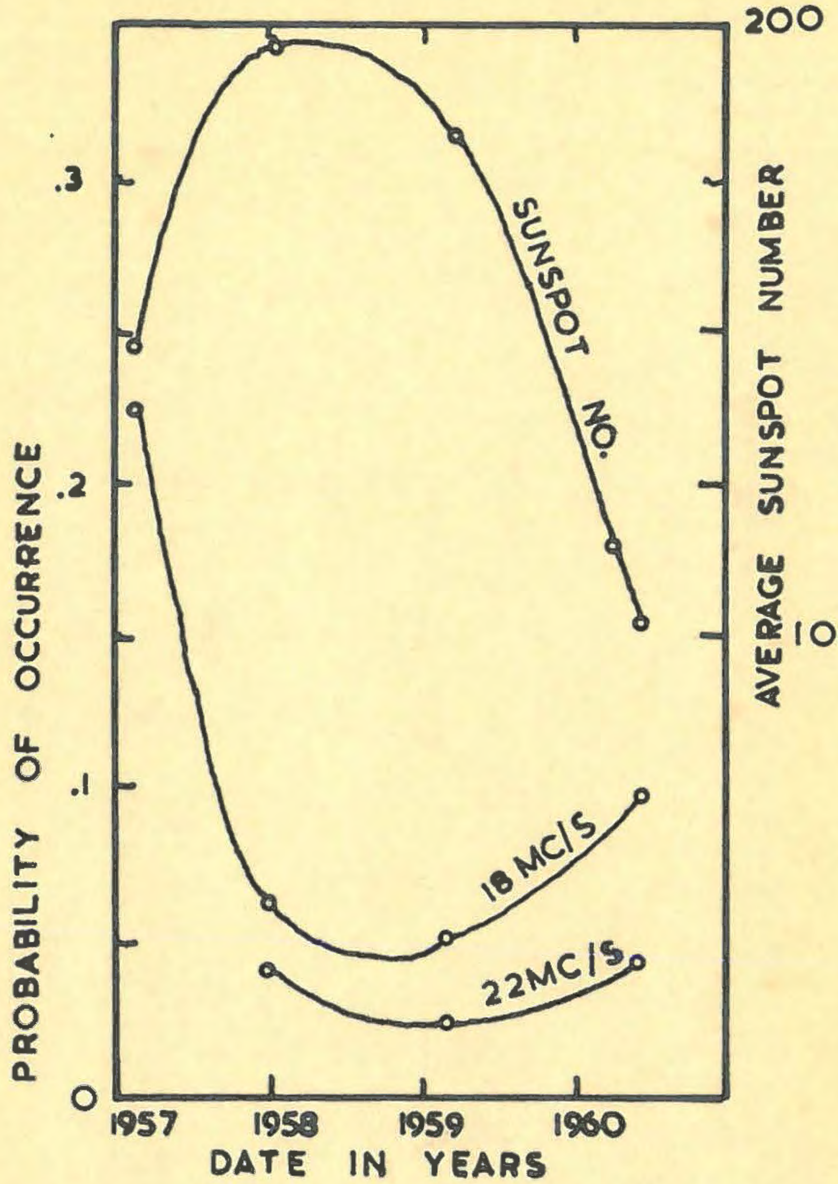


Fig. IV. Jovian radiation probability compared with sunspot number for various apparitions.

where J is the Julian Date. Observations on the polarization of Jovian radiation were also made. A majority of the pulses received at both stations were right-hand elliptically polarized, so that any ionospheric effects which may have been present did not appear to reverse the sense of polarization. Recordings made at both stations had a very bad amplitude correlation due to scintillation effects. Practically all pulses analised with the Chilean polarimeter occurred when the central meridian lay within one of the three principal sources or activity zones. Comparison of the daily Jupiter activity for five different frequencies with the geomagnetic activity index showed that a relationship with a certain time delay does seem to exist. This would indicate that the non-thermal radiation is caused by the arrival at the planet of solar particles, which would interact with the Jovian magnetic field or ionosphere emitting radio-frequency radiation..

Carr et al. (29.) also made photoelectric observations of Jupiter using a type 931-A photomultiplier tube mounted onto a 12½ inch reflecting telescope. The resulting signals were amplified in an amplifier whose lower frequency cut-off could be varied from 2 to 200 cps as a mean to eliminate the large-amplitude scintillation components which exist at the lower frequencies. The output of the photomultiplier circuit was displayed on one channel of a dual-channel recording unit operating at a paper speed of 5 mm/sec, while the 18 Mc/s radio signals were recorded on the second channel. Observations were carried out in white light and with a H-alpha filter. In no case was there any evidence of light pulses being received from Jupiter within the sensitivity limits of the equipment used.

The presence and correlation of fine structure in Jovian decameter radiation was studied by Douglas and Smith in March 1961 (30.). Their equipment consisted of four identical crystal-controlled total power receivers working at 22.20 Mc/s with 6 Kc/s bandwidth and identical antennas. Three sites were situated up to a distance of 100 km away from the central observing station at Yale observatory. The audio output was fed via telephone lines to the central station. During their spell of observations they noted the presence of numerous correlated fine structure components having durations of hundredths of seconds. In view of the correlation over the long base line this extreme fine structure has to be regarded as real. Similar fine structure had been reported earlier by Kraus (31.) and Gallet (32.) independently.

In a letter to the Editor of Nature (8.) Ellis of the University of Tasmania reported that he had managed to receive Jupiter radiation also at a frequency of 4.8 Mc/s. He pointed out that the possibility therefore existed that the spectrum extended downwards in frequency below 4.8 Mc/s. Any frequency in such a range would be very difficult to observe, due to absorption in the terrestrial atmosphere. The intensity at that frequency does not seem to differ significantly from the peak intensities reported by other workers at higher frequencies.

George B.Field made a theoretical study of the source of radiation from Jupiter at decimeter wavelengths (33.). He discussed mainly the radiation of wavelength ranging from 3 cm to 68 cm, but tried to link up his theory with the observed decameter radiation. He came to the conclusion that the radiation did not originate in the Jovian ionosphere, nor did it seem likely that it came from the atmosphere. It was also not due to synchrotron radiation* caused by cosmic ray electrons. But he suggested that electrons from the sun which are trapped in Jupiter's magnetic field may very well be the source. Observations to verify his theory are discussed. If measurements of the angular size of Jupiter, using radio observations, show that there is a broadening of the beam with respect to the visual observations,than one may rule out the origin of radio noise in the atmosphere or ionosphere. He maintained that the polarization observed also rules out ionospheric

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* Cyclotron radiation is due to non-relativistic electrons, while synchrotron radiation is due to relativistic electrons. The radiation is emitted while the electrons spiral around a line of magnetic flux.

or atmospheric origin of the decimeter radiation.

In another paper (34.) Field discussed Cyclotron radiation by trapped electrons. He built up a model of Jupiter's radiation belt, based on the outer radiation, van Allen, belts, of the earth. He ignored any magnetic variations and assumed that Jupiter had a pure dipole field, and considered only non-relativistic electrons of roughly isotropic distribution trapped in a single magnetic surface. He calculated the spectrum and polarization of the cyclotron radiation emitted as the electrons move through the inhomogeneous magnetic field. The form of the spectrum compared well with the observed one, and the required electron densities are only 0.3% of those observed in the radiation belt around the earth. The required magnetic field is extremely large and at least 1.2 Webers/$m^2$ at the poles. If the emitting regions of the 20 Mc/s bursts are between $30^0$ and $40^0$ latitude, the observed polarization could be explained. He suggested that the bursts might have as their origin electrical discharges.

In a third paper in his series on theoretical considerations of Jovian radiation (35.), Field took into account all observations available to him of the polarization, spectrum, spatial extent and time variation of the Jovian decimeter emission and compared them with the characteristics of the model based on cyclotron radiation. He came to the conclusion that the cyclotron model is ruled out by the observations, as the facts did not seem to fit the theory very well. It seemed possible to Field that a model based on synchrotron emission could be made to explain the observations.

Plate III. The Apparatus.

# CHAPTER III

## 3.1 APPARATUS: (General Outline)

A site located near the Jameson Dam was investigated for low level of noise of terrestrial origin. For this purpose an ex-army receiver was used. This was connected via a crystal rectifier from a jackplug connection from the first audio stage to a moving-pen recorder. An "inverted L aerial" made from hard drawn copper wire was strung up between two trees at a height of approximately 30 feet.

The equipment was run for over a fortnight during which no noise was recorded on 18 Mc/s. The gain of the set was 72 dB, at a bandwidth of 8 kc/s. It was, therefore, concluded that the site was suitable for our experiments, and a hut was built. This hut is constructed from wood and asbestos boards and measures approximately 4 x 3 x 2 metres. It contains a workbench and an electricity supply board. Power was laid on from a supply line about 200 m. away.

For measurement of noise from Jupiter two similar receivers were used, one tuned to 18 Mc/s, the other to 22 Mc/s.

At sunspot maximum, Barrow and Carr (36.) estimated the total noise power received from Jupiter as observed on the earth's surface as $8.5 \times 10^{-20}$ watts.$m^{-2}$. $(cps)^{-1}$. For a folded half wave dipole the effective area is $1/8\lambda^2$ (37,). If we use in our calculations the mean wavelength i.e. 15 m. of the two wavelengths used in this survey and since the bandwidth of our receivers is 8 Kc., the total power input to the receiver is given by the product of the received power, the effective area and the bandwidth i.e.: $8.5 \times 10^{-20} \times 1/8\ (225) \times 8 \times 10^{3} = 1.913 \times 10^{-14}$ watts. The recorder having an internal resistance of about 300 ohms and requiring 1 ma for full scale deflection will therefore need $3 \times 10^{-4}$ watts to deflect fully. A total gain of 108 dB should therefore be of the correct order of magnitude.

On each channel, the signals are picked up by a folded dipole aerial, mounted at a height of approximately 15 m.

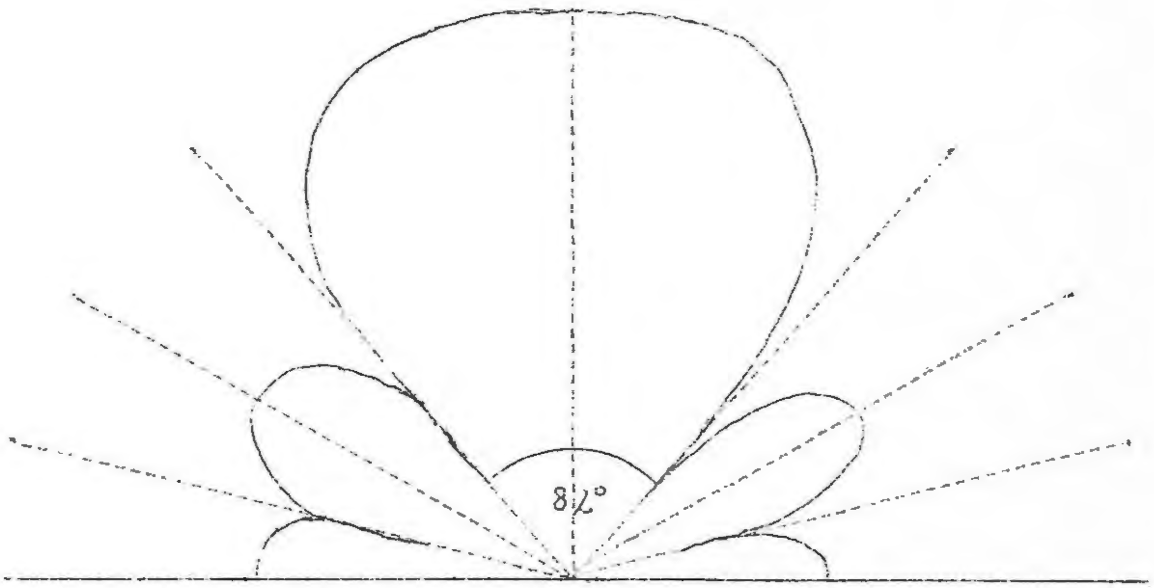
From there they are fed via a 300 ohm impedance line to the input of the receiver. There they are amplified and detected. The detected signals are fed through a cathode follower to the recorder.

## 3.2 THE AERIALS.

The design used was a folded dipole (length = 0.47 $\lambda$). It was constructed from hard drawn 12 gauge copper wire. The spacers were made from wooden dowels cut to a length of 15 cm, slotted at both sides and then boiled in wax to prevent their absorbing moisture, thus becoming conductors and also rotting. Holes were drilled at each end and some soft drawn copper wire inserted. This wire was used to fix the spacers to the aerial wire.

Both dipoles were mounted, end on to each other, between two trees, at a height of 15 m. The trees were in an approximately north-south direction, thus giving the aerial the best position for receiving signals from Jupiter, for the longest possible period according to their theoretical polar diagrams.

The height of 15 m. was chosen as it represented the mean value of the wavelength for both frequencies. This gives us a distance of two wavelengths between the aerial and its image below ground. For maximum response of the aerial, the path difference between the direct and the ground reflected ray must be an integral number of wavelengths, and for minimum an odd number of half wavelengths. This consideration gives us the following theoretical polar diagram for our aerial:



Comparing the response one would obtain with the "perfect" aerial to some experimental observations of solar noise as it passes through the beam of the aerial, it was found that between the theoretical and the practical polar diagram not much difference exists. As a matter of fact a source passes through the main beam of the aerial in about five hours; from theory one would expect such a source to take about five and a half hours, since it takes the Earth about $5\frac{1}{2}$ hours to turn through about $80^{\circ}$.

The impedance of the folded half wave dipole is approximately 300 ohms (37.). This enables the aerial to be matched directly into the 300 ohm moulded parallel wire transmission line which is commercially available. The spacing between the parallel arms of the antenna is not critical but must be small compared with the wavelength.

Theory predicts a value of $\lambda/2$ as the best for maximum transmission and reception, but by experiment it has been found that the length of 0.47 $\lambda$ gives better results, although this value is not critical since the bandwidth of the antenna is fairly large.

The theoretical gain of a folded half wave dipole is given as 2.4 dB maximum in the equatorial plane. (37.)

(Unfortunately one half of the aerial input was grounded. This was found out much too late for correction. The gain will therefore have been less than 2.4 dB. Before another run is attempted, it will be advisable to change the design.)

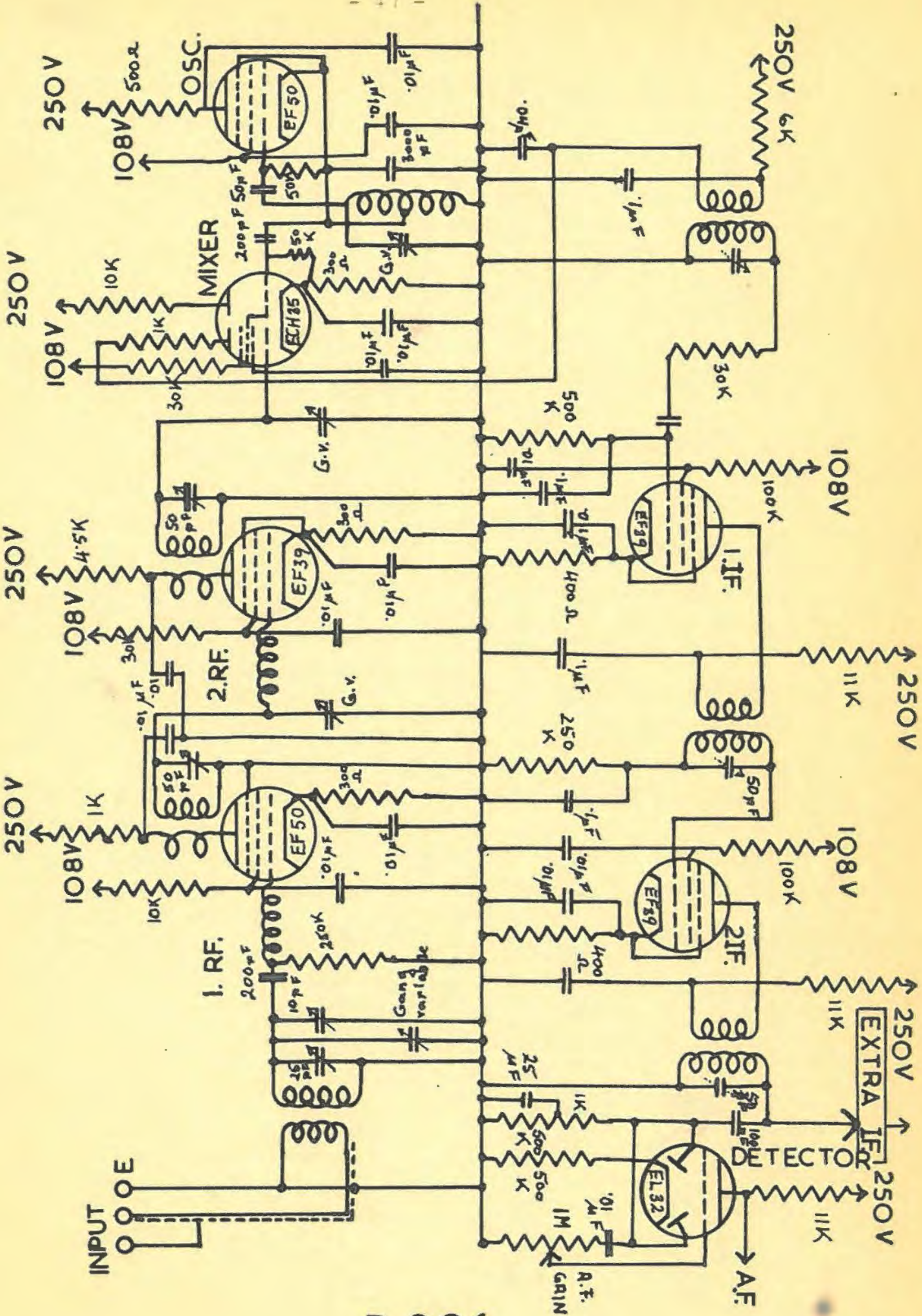
## 3.3 THE SUPERHETERODYNE RECEIVER TYPE R 206. (Fig.V)

The R 206 is an ex-army receiver built about 1940. The aerial input is fed through an aerial trimmer circuit which facilitates the matching of the antenna to the receiver. Measurement of the input impedance showed that on varying the aerial trimmer the impedance could be varied over a very wide range from about 30 ohms upwards. This measurement was obtained using a General Radio R.F. impedance bridge type 1606 A and a Marconi type TF 867 R.F. signal generator and a National HRO receiver as a detector.

The signals are then amplified twice in R.F. amplifiers. The first stage employs an EF 50 low noise wide band R.F. pentode, while the second stage uses an EF 39 pentode with variable mutual conductance.

One of the main reasons for choosing the R 206 for this investigation was the fact that the tuned circuits in the input and output of the R.F. and mixer stages were mounted in a movable turret, different circuits being used for different bands. The receiver had six different bands, 0.55 - 1.1 Mc/s, 1.1 - 2.2 Mc/s, 2.2 - 4.8 Mc/s, 4.8 - 10 Mc/s and 20 - 30 Mc/s. This construction is mechanically and electronically very good.

From the second R.F. amplifier the signals are brought into a mixer valve ECH 35, a triode-hexode, where they are mixed with



R 206

Fig.V. Circuit diagram of the R 206. Only the parts of the apparatus that were in operation are depicted, i.e. AVC, BFO, Filter etc. circuits are not drawn in.

an R.F. frequency, from an oscillator using an EF 50 pentode, to give the intermediate frequency of 465 Kc/s. The resultant I.F. is then amplified twice by two EF 39 pentode.

From the secondary of the last I.F. transformer the signals are brought out of the set by means of a screened cable which feeds them to the extra I.F. stages. The circuit of these is shown in Fig. VI. The amplifiers were two EF 95 sharp cut-off pentodes. Matters were arranged in such a way that either one or both tubes could be put into operation to obtain additional gain, as we were not sure what magnitude of signal to expect near sunspot minimum.

The values of the circuit components of the extra I.F. stages were calculated from data provided by the Philips Handbook. (38.). The I.F. transformers used were a miniature type, tunable by adjusting the core; they contained no trimmers, since the capacity necessary was provided solely by the self-capacitance of the coils.

The output of the I.F. stages was rectified by a Germanium diode, Mullard type OA 85. It can stand a peak inverse voltage of 115 V and passes a maximum current of 50 mA.

To amplify the power and to match it into the recorder a cathode follower was used. This is described in more detail in the following section.

The R 206 has also a beat-frequency oscillator, which is used to detect very weak stations or to receive C.W. morse broadcasts. Furthermore it contains an amplified A.V.C. circuit which can be brought into operation or switched off. A limiter and filter are also provided. None of these were used in the present research.

Three different values of bandwidth could be chosen, namely 8 kc/s, 2.5 kc/s, and 0.7 kc/s. Only the 8 kc/s band was employed.

The H.T. supply to the receiver was regulated. The power supply is described in detail in section 3.5.

## 3.4 THE CATHODE FOLLOWER AND RECORDING UNIT.

The cathode follower was used as a final stage to amplify the power and to match it into the moving pen recorder. The circuit diagram is shown in Fig. VI. The valve used was a 6J5 medium $\mu$ triode. The choice of the valve was governed by the requirements that the transconductance of the valve should be equal to the reciprocal value of the load resistor of the cathode follower for maximum matching. By switching in various values of grid resistors the time constant could be carried from 1 second to a couple of minutes. The pen recorder "Record" type D 1439/A2 with a range of 1 mA full scale deflection has a time constant of the order of one second. It was connected between the cathode of the cathode follower and a variable reference potential (Fig. VI), to allow one to adjust the zero level, while at the same time taking into account the general background noise.

### THEORY:

Let $I_1$ be the current through $R_1$
$I_2$ be the current through $R_2$
$I_3$ be the current through the Recorder of internal resistance r
$I_4$ be the current drawn by the valve
$I_5$ be the current through the load resistor R

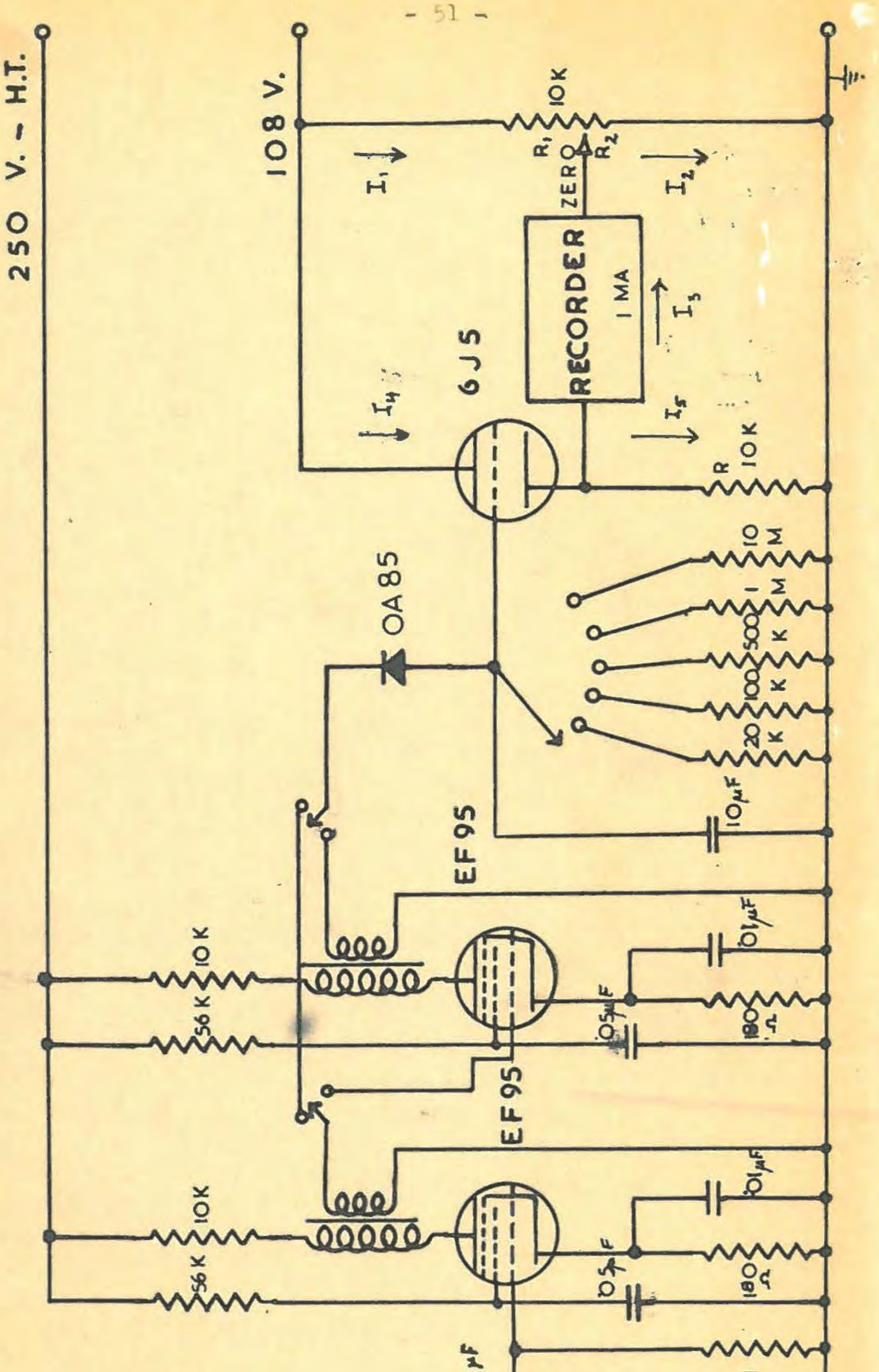


Fig. VI. Circuit diagram of the extra I.F. stages. Cathode follower and recording unit.

E be the potential applied to the valve and the potential divider $(R_1 + R_2)$. When the current flows through r, we obtain using Kirchhoff's Laws, that:

$$I_4 = I_3 + I_5 \qquad I_1 + I_3 = I_2 \qquad E = I_1R_1 + I_2R_2 \quad \text{.........(a)}$$

$$\therefore \quad E = I_1R_1 + (I_1+I_3)R_2$$

$$I_1(R_1+R_2) = E - I_3R_2$$

$$\therefore \; I_1 = \frac{E - I_3R_2}{R_1+ R_2} \quad \text{.........................(b)}$$

In the lower loops: $I_3r = I_5R - I_2R_2$

$$= (I_4-I_3)R - I_2R_2$$

$$I_3r + I_3R = I_4R - I_2R_2$$

$$= I_4R - E + I_1R_1 \quad \text{........ from (a)}$$

$$I_3(r + R) = I_4R - E + \frac{E - I_3R_2}{R_1+ R_2}R_1 \quad \text{...... from (b)}$$

$$I_3\left(r + R + \frac{R_1R_2}{R_2+ R_1}\right) = I_4R + E\left(\frac{R_1}{R_1+ R_2} - 1\right)$$

i.e. it is of the form $I_4 = AI_3 - B$ (where A & B are constants)..(c)

$$\frac{\partial I_3}{\partial I_4} = \frac{R}{r + R + \dfrac{R_1R_2}{R_1+ R_2}} = \frac{1}{1 + \dfrac{R_1R_2}{(R_1+ R_2)R} + \dfrac{r}{R}} \quad \text{................(d)}$$

Now $E_i = E_c + I_5 R = E_c + (I_4 - I_3)R$ where $E_i$ = input voltage

$E_c$ = grid cathode potential

$$= E_c + (AI_3 - B - I_3)R = E_c + I_3(A - 1)R - BR \ldots\ldots \text{(e)}$$

$\frac{\partial I_4}{\partial E_c} = g_m$ (where $g_m$ = transconductance) as long as we stay on the linear part of the characteristics.

If we integrate the above equation we get:

$I_4 = I_b = f_m E_c + f(E_{bk})$ where $E_{bk}$ = potential across the tube.

If $E_{bk}$ remains constant $f(E_{bk})$ = constant = C (say)

$$I_4 = g_m E_c + C$$

$$\therefore E_c = \frac{1}{gm} (I_4 - C)$$

Therfore $E_c$ is of the form $DI_4 + F$ (where D & F are constants)

Substituting from (c) $E_c = D(AI_3 - B) + F = GI_3 - H$ (where G & H are constants)

There if we substitute the above equation into (e) we get:

$$E_i = GI_3 - H + I_3(A - 1)R - BR$$
$$= I_3 (AR - R + G) - (BR + H)$$

i.e.: $E_i = X I_3 - Y$ (where X E Y are constants)

From the above equation it follows clearly that there exists a linear relationship between $E_i$ the input voltage and $I_3$ the current through the recorder.

## 3.5 THE POWER SUPPLY AND AUDIO AMPLIFIER.

The design of this power supply is given by Elmore and Sands in their textbook on Electronics (39.). The circuit has been modified to give an output of 250 V, which can be slightly varied to allow for ageing of tubes. The diagram of the actual circuit used is shown in Fig. VII.

The power pack is designed to supply a plate current of less than 150 mA. When delivering a current of 100 mA to an external resistive load, it has an RMS ripple voltage of 1.5 mV. The measured stabilization factor (the fractional change in input voltage divided by the fractional change in output voltage) is about 1200.

Both plates of the 6SL7 difference amplifier are at approximately the same potential (200 V) to obtain a symmetry in current and voltages between the two halves of the amplifier. Circuit analysis of the difference amplifier shows that any potential difference between cathode and grid, common to both tubes degenerates by a factor of $1/\mu$ compared to a signal fed into the amplifier between grid and ground. Therefore even if the heater voltage should vary by 10%, the output voltage of the power supply would remain fairly constant.

The second 6SL7 is a simple triode amplifier.

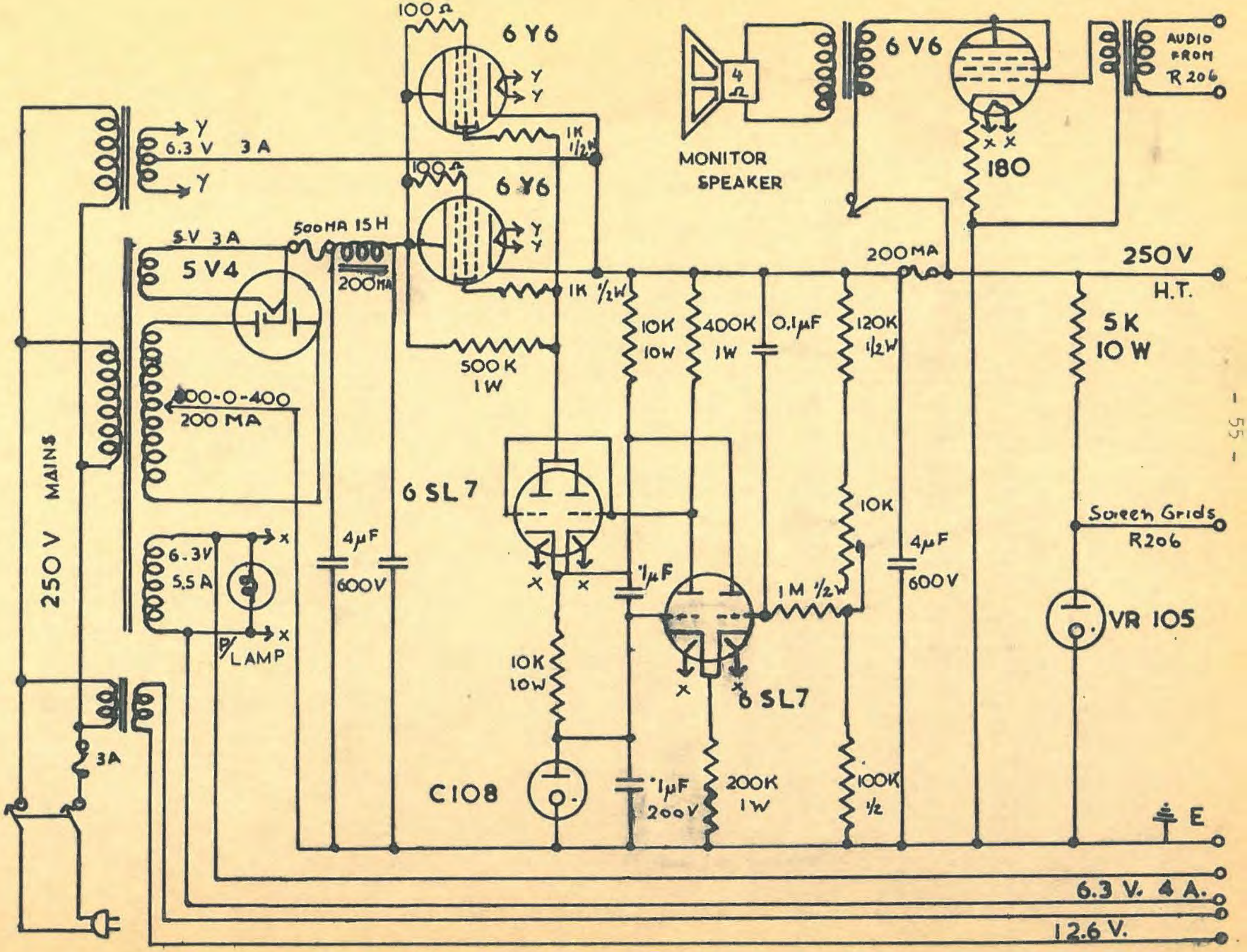


Fig. VII. Circuit diagram of the regulated power supply and the audio amplifier.

The current for the voltage regulator tube, a Philips 108 C, is obtained from the output side of the supply to ensure that the comparison voltage will not be subject to changes caused by a varying current through the VR tube.

A VR 105 and a 5K dropping resistor are used to supply the screen-grid voltages for the R 206.

The audio amplifier uses a 6V6 connected as a triode, since this gives larger current amplification. A switch has been provided to cut off the H.T. supply to the valve when no one is monitoring the recording, since the tube draws around 30 mA. This additional draw off would leave the power supply delivering the maximum permissible current and it is advisable to do this only for short periods, as the transformer would overheat and this might cause it to burn out. The transformer used was the only one obtainable at reasonably short notice in the Republic. Any other type would have had to be ordered from overseas and would have held up this investigation unduly.

# CHAPTER IV.

## 4.1 OPERATING PROCEDURE.

After having tested the site for absence of Radio interference the construction of the hut was started. The four walls were built in the Physics Department. The wooden structure was first painted with red lead to prevent rotting and then given a coat of glossy grey to finish off. The prefabricated sections are bolted together with six-inch bolts.

At the site, the ground was levelled and the sections put up. Before putting the roof on, a concrete floor was laid. As soon as the floor had dried, the roof was put up and the interior fittings mounted.

After the hut was completed, the apparatus was moved in. All apparatus had been built in the Physics Department beforehand and the construction of the individual parts of the final set up, as it is used now, has been described above.

To tune the apparatus the following procedure was adopted:

All I.F. stages were tuned to a frequency of 465 kc/s with a bandwidth of 8 kc. This was done using a Philips oscilloscope GM 5655 and a Philips modulator GM 2886, as well as a Hewlett-Packard type 606 A signal generator. The lay-out of the circuit and the method of tuning is given in the instruction booklets on the abovementioned Philips instruments. The principle of the method is to beat a frequency of 4.465 Mc/s (= 4 Mc/s + I.F. frequency) with a frequency swept by a saw tooth wave from slightly below 4 Mc/s to a little above at a certain repetition rate, and to display the resulting beat frequency, after it has passed through the set on test, on an oscilloscope screen, the sweep being provided by the same saw tooth wave. Thus the whole pass band is displayed on the screen.

Next the R.F. section was tuned. First the coils in each band of the oscillator were tuned so that the frequency shown on the scale was the same as the frequency of reception. This was done by feeding an R.F. signal of known frequency into the aerial input of the R 206 and alternately adjusting the inductance coil and the capacitor at the lowest and highest frequency of the band until the setting of the dial correctly indicated the frequency of reception.

Similarly the first and second R.F. stages were tuned by alternately adjusting the inductance coils and capacitors to give an equal and maximum gain over the whole band.

With the apparatus properly tuned an input Voltage of $0.3\mu$ V was necessary to give full scale deflection on the recorder, only one of the two extra I.F. stages being used. This means a total gain of better than 120 dB.

A timing mechanism was also constructed. This gave one pip every hour and a double pip every twelve hours. This was achieved by discharging a capacitor through the recorder to give negative pips. The clock was run off batteries to be independent of the mains supply. It was therefore possible to judge the exact time of recordings even if the mains supply had been interrupted.

To start recording all apparatus was switched on. After the warming-up period the tuning was checked. The chart paper was inserted in the recorders and the ink flow checked. The chart paper was now moved to a position such that the pen was placed in the right position according to the time and taking into account any backlash in the driving gears. The timing mechanism was checked by closing the contacts by hand and observing the deflection.

To match the aerial into the receiver the signal generator was connected to the second aerial and set to the appropriate frequency. The aerial trimmer was now adjusted to give maximum deflection on the pen recorder. The set was now ready for observations.

The apparatus was set up in June, 1962. Unfortunately the power supplies burned out shortly after that. The exact reason for this was never established, but it was thought to be due to the overloading of the mains transformer.

New power supplies had to be constructed. They were regulated and they have been described in greater detail in cChapter II.

The apparatus was checked every second day, ink flow, voltage stability and continuity of aerial being especially taken care of. After a week or so it was found that the zero setting of the recorders needed no further adjustment, and they were left alone even if the pen went off-scale.

After the apparatus had run for some time it was found that during the day the 18 Mc/s equipment tended to record a lot of interference, causing the recorder to be fully deflected for considerable periods. To overcome this, a Venner time switch was installed to switch a bypass-resistor across the recorder during the day but it was disconnected during the night, giving the apparatus its full sensitivity.

The aerials gave a fair amount of trouble as the wind was rather strong on occasions and on at least four occasions the aerial had to be taken down and repaired.

The gain of the apparatus was checked a few times during the observing period. The method was the same as the one described above. On one occasion the receivers were given a full tune up, since the gain had deteriorated.

Observations were continued until the middle of October, when observing conditions became extremely unfavourable.

## 4.2 RESULTS.

A day by day tabulation of the radio noise observations and the events associated with Jupiter, expressed in longitude of Central Meridian in the revised System III coordinates, is presented in Table I. Observations are presented for 92 nights; signals identified as coming from Jupiter were observed on 38 nights and interference from thunderstorms, apparatus failure, etc., prevented useful recordings on 32 nights.

Using the data presented in Table I the drawing shown in Fig. VIII was prepared. It shows a plot of the noise sources expressed as longitude of central meridian versus the revised System III longitudes. Using this graph and the number of observations, which were clear of interference the histogram shown in Fig. IX was prepared. This shows the occurrence of probability for each $5^{\circ}$ interval of central-meridian longitude on Jupiter, in terms of the revised System III coordinates. The occurrence probability is defined as the ratio of the number of events occurring, while the central meridian lay in the $5^{\circ}$ interval concerned, to the total number of times during which the interval was under observations under interference-free conditions.

Both the 18 Mc/s and the 22 Mc/s histograms clearly show that there seemed to be three different locations of central meridian

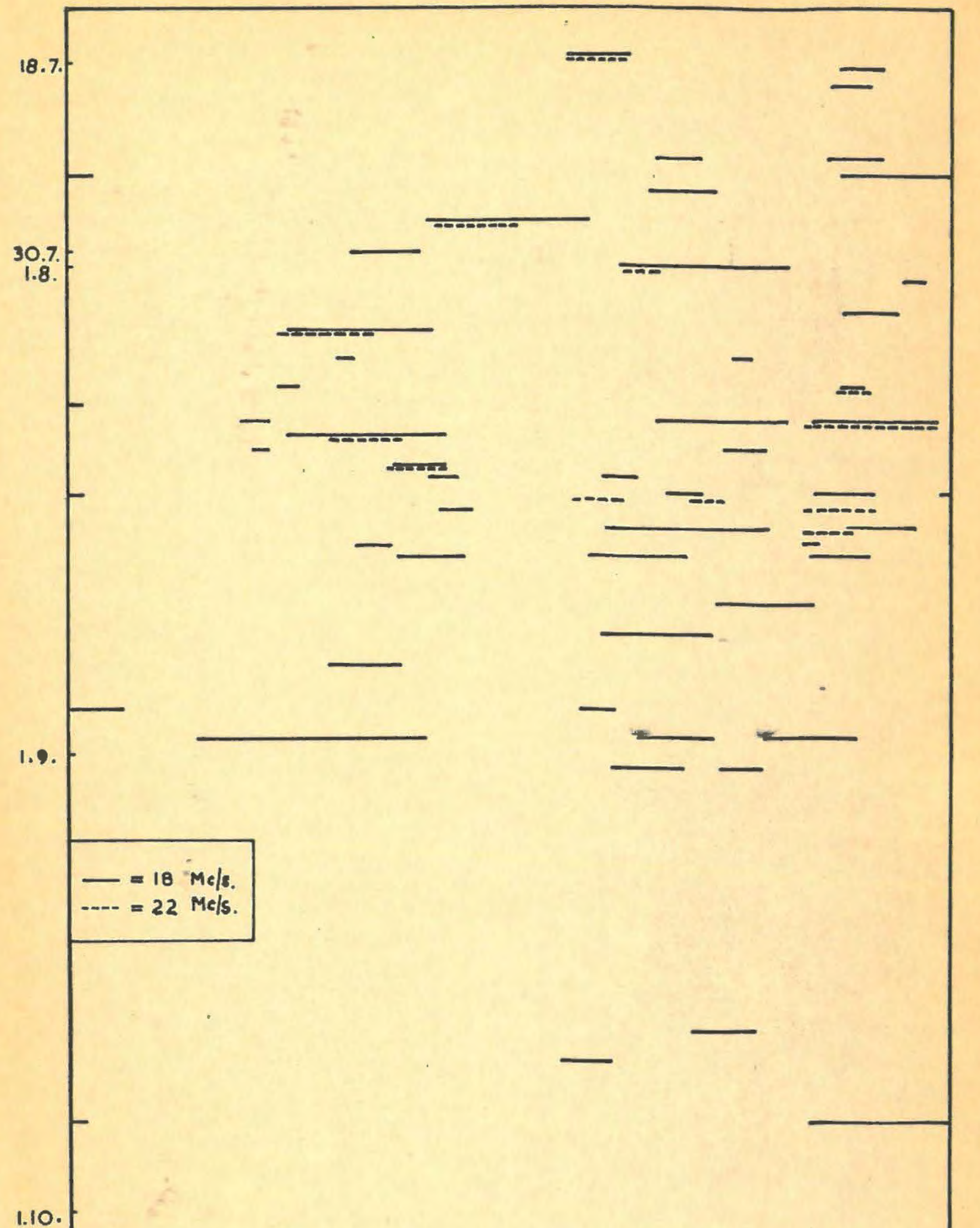


Fig. VIII. Diagram depicting the noise sources referred to the revised System III coordinates.

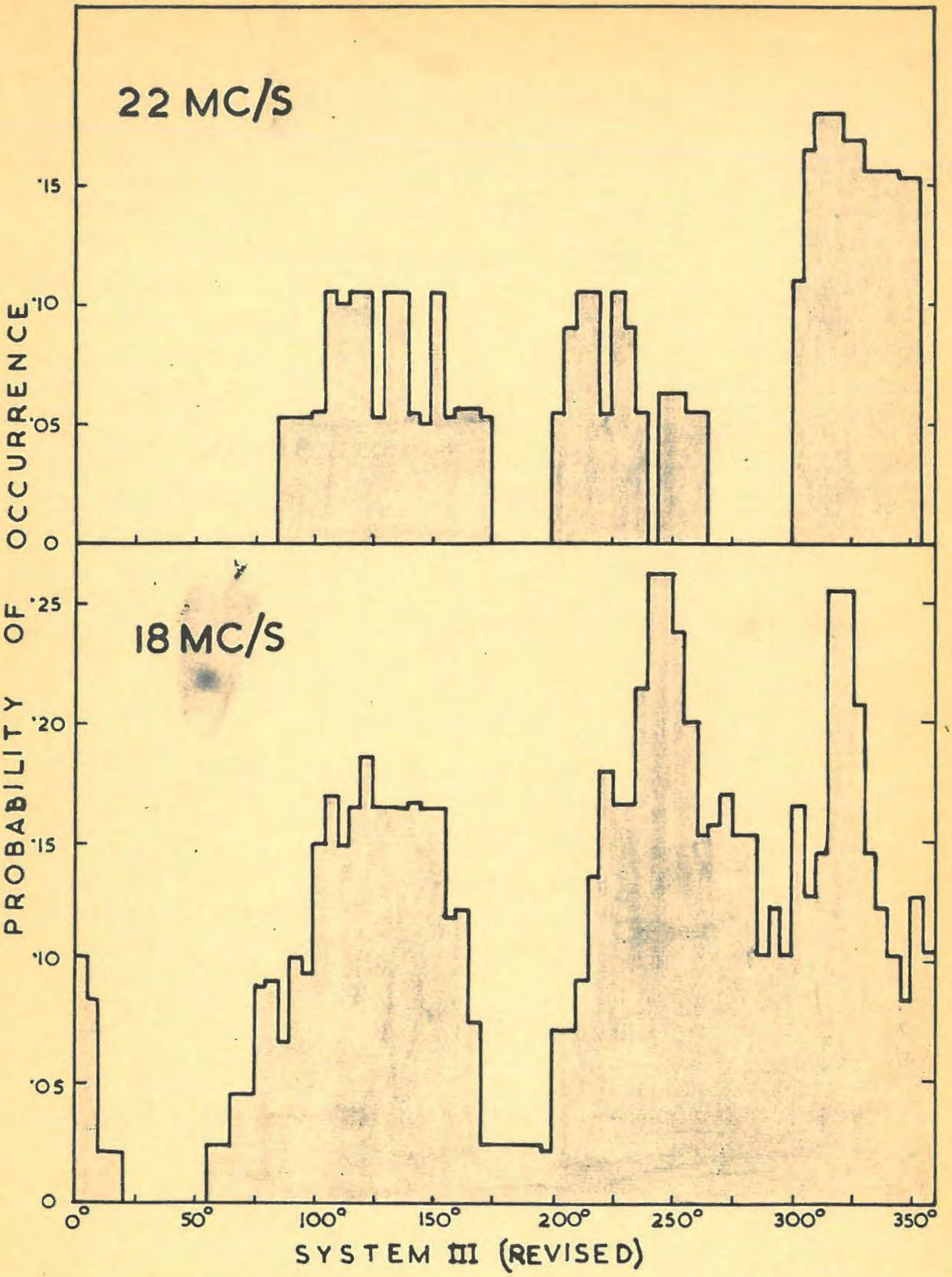


Fig. IX. Histogram compiled from the data given in Table I. It shows the probability of occurrence versus the revised System III coordinates for the radio noise received at the observatories at Grahamstown and East London.

where emission was observable. This is in close agreement with observations by previous observers. Fig. X shows some of the histograms compiled by various observers during the past few years, for observations close to 18 Mc/s.

The results presented in this thesis show that three sources exist on Jupiter. They are clearly separated and the radiation most probably emanates from locations around 120°, 240° and 320° longitude. The overall probability of occurrence seems to have increased with respect to the observations made in previous years. Comparing the 1960, 1961 and our own 1962 histograms, one finds that the source located around 320° longitude apparently has a much larger increase in the probability of occurrence than the other two. The "angular widths" of the sources has remained fairly constant at around 100°, 70° and 40° for the three sources respectively; the difference may arise from statistical variation. The main difficulty when drawing conclusions between results obtained by different observers, is one of comparison, as the apparatus will not have been identical. Therefore one cannot be sure what is a real and what is a statistical variation.

Observations were started in June, 1962. By that time, Jupiter was observable over the horizon from about midnight onwards. To observe during the day time, up to about one hour after sunset is

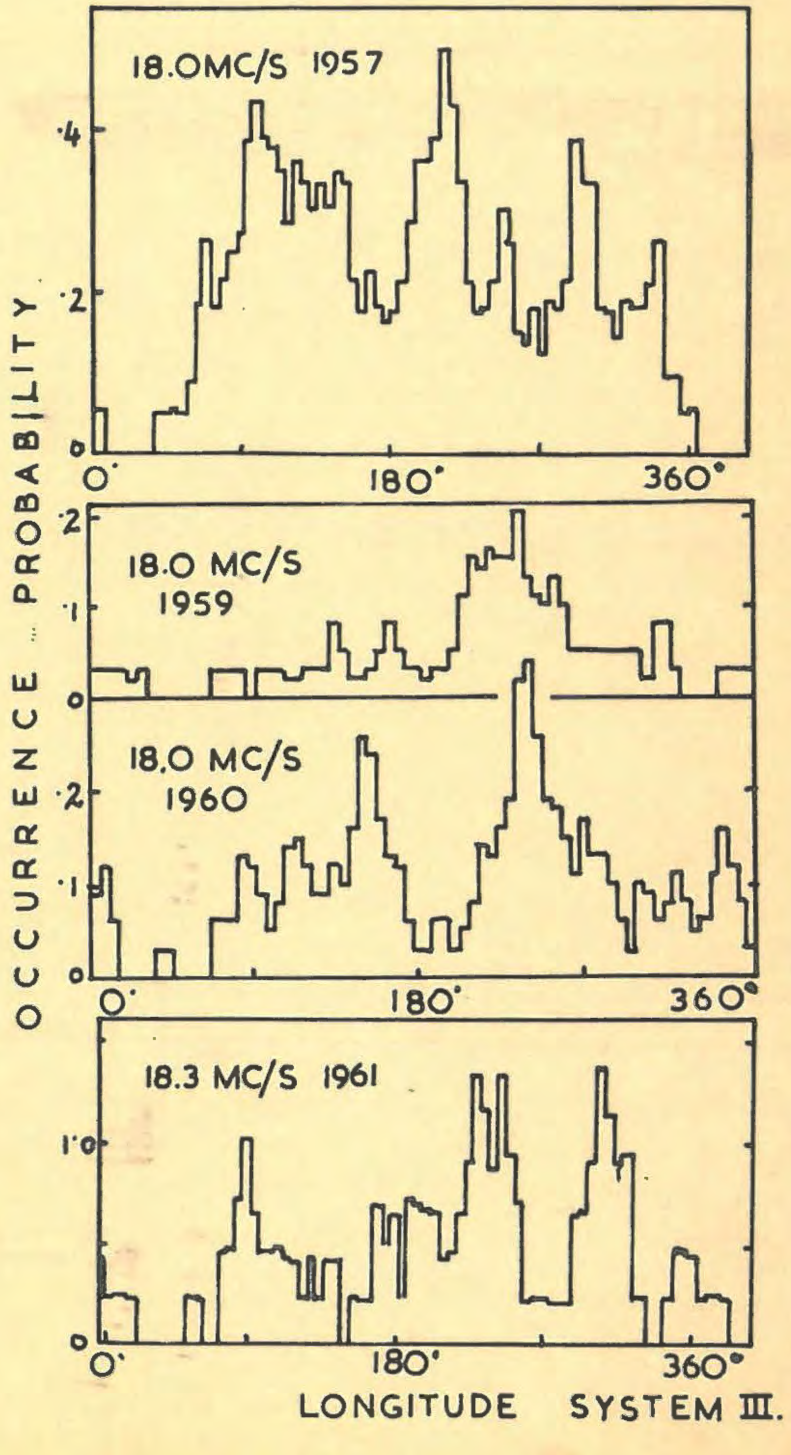


Fig. X. Histograms of Jupiter noise by previous observers.

impossible, because the sun also emits decametre radiation and it would be impossible to tell the two sources apart unless one had a very directional aerial, which we in fact did not have; our aerial had a beam width of about 80°.

The first time that the author was sure that signals were being received from Jupiter, was on the night of the 16th/17th July, 1962. From that date onwards signals were detected on most nights when conditions were suitable.

Listening to the signals they seemed to sound like waves of the sea breaking on a pebbly beach. i.e. a sort of "whoosing" sound. Recording indicated that the Jovian radiation appeared to consist of rapid bursts lasting a few seconds, interspersed sometimes by very much larger bursts, which themselves had a duration of the order of 1 second.

Since the aerial was of much too crude a design to allow the location of the sources to be definitely established, the signals were recognised by inspection. Fortunately we had the cooperation of an amateur radio astronomer from East London, Mr. M.C.Besch, who was able to provide us with data of his own observations.

This facilitated recognition, as one was able to pick out the Jovian signals from local interference. After a short while it was found fairly easy to distinguish between various kinds of recorded signals from their characteristics. The author estimates the power density of the decametre radiation from Jupiter received at Grahamstown to be of the order of $10^{-20}$ watts $m^{-2}$. $(cps)^{-1}$. This figure was arrived at by comparing the deflections produced by the Jovian bursts to the deflections produced by solar bursts as well as by the meridian passage of the Milky Way; for both these sources accurate estimations of the noise power received has been published by experimenters in those fields. (13.16, 36.) Since the measurements made during 1962 were meant only as preliminaries to larger scale investigations in the future, not too much emphasis was laid on exact measurements of the signal strength. The most accurate way of calibrating the strength of the incoming signal is to compare it to a known amount of white noise produced in a noise diode.

From September,1962 onwards there was rather a lot of interference mainly due to thunderstorms. Recordings made on 22 Mc/s were rendered useless after the 20 August due to appearance of interference which the Author was unable to locate or get rid of by altering the frequency of reception.

Most of the recordings were obtained before the beginning of September. Only during the beginning of October did reception conditions improve again. Unfortunately observations had to stop then as the paper supply had run out and none was available in the Republic. In addition Jupiter's meridian transit took place early in the evening. The times of necessary observation would have fallen before midnight, at which time one does not obtain very good results due to a greater likelihood of interference. Before September this interference generally had died down by about 8 o'clock. During September and October there were many occasions where interference would persist till very much later even after midnight. Generally it is fairly safe to say that the best time for radio astronomical observations is from midnight to about one hour before sunrise, when sunrise effects might interfere with recordings. Plate IV shows typical recordings made at both Observatories, Grahamstown and East London.

Plate IV. Typical Recordings; the top one was taken at East London, the lower three were taken at Grahamstown.

## TABLE I.

Range in Longitude of Central Meridian in System III coordinates of radio noise observations and events associated with the planet Jupiter observed at the Rhodes University Radioastronomical Research Station situated at Slaai Kraal near Grahamstown - CP. and at East London.

| Date | 18 Mc/s | | | | 22 Mc/s | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (SAT) | Observations | | Event | | Observation | | Event | | Remarks |
| 1962 Midnight | Began | Ended | Began | Ended | Began | Ended | Began | Ended | |
| July 17 | 171 | 53 | 203 | 230 | 171 | 53 | 203 | 230 | |
| 18 | 319 | 203 | 315 | 332 | | | NR | | |
| 19 | 117 | 5 | 314 | 329 | 117 | 5 | | | |
| 20 | 255 | 144 | | | 255 | 144 | | | |
| 21 | 45 | 294 | | | 45 | 294 | | | |
| 22 | 195 | 86 | | | | | NR | | |
| 23 | 340 | 236 | | | | | NR | | |
| 24 | 126 | 28 | 240 | 258 | | | NR | | EL |
| | | | 315 | 324 | | | NR | | |
| 25 | 276 | 178 | 314 | 9 | | | NR | | |
| 26 | 66 | 228 | 238 | 265 | 66 | 228 | | | EL |
| 27 | 213 | 119 | | | 213 | 119 | | | |
| 28 | 2 | 269 | 147 | 213 | 2 | 269 | 150 | 172 | |
| 29 | 149 | 97 | | | 149 | 97 | | | |
| 30 | 297 | 212 | 115 | 145 | 297 | 212 | | | EL(only) I/F-GN |
| 31 | 87 | 1 | 224 | 295 | 87 | 1 | 227 | 236 | EL(only) I/F-GN |
| Aug. 1 | 234 | 153 | 341 | 350 | | | NR | | |
| 2 | 22 | 303 | | | 22 | 303 | | | |
| 3 | 170 | 194 | 316 | 339 | | | NR | | EL |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 312 | 239 | 90 | 149 | 312 | 239 | 86 | 125 | |
| 5 | 107 | 36 | | | 107 | 36 | | | |
| 6 | 254 | 186 | 270 | 276 | | | | | |
| | | | 102 | 105 | | | | | EL(only)NR-GN |
| 7 | | | NR | | | | NR | | |
| 8 | 192 | 126 | 316 | 325 | 192 | 126 | 316 | 325 | |
| | | | 86 | 93 | | | | | |
| 9 | | | NR | | | | NR | | |
| 10 | 127 | 69 | 237 | 291 | 127 | 69 | 302 | 357 | |
| | | | 302 | 359 | | | | | |
| | | | 69 | 81 | | | | | |
| 11 | 276 | 219 | 90 | 155 | 276 | 219 | 109 | 237 | |
| 12 | 63 | 9 | 76 | 82 | 63 | 9 | | | |
| | | | 268 | 283 | | | | | |
| 13 | 211 | 161 | 133 | 152 | 211 | 161 | 133 | 152 | |
| 14 | 359 | 311 | 149 | 162 | 359 | 311 | 209 | 215 | |
| | | | 218 | 233 | | | | | |
| 15 | 147 | 101 | 243 | 258 | 147 | 101 | 246 | 264 | |
| | | | 304 | 329 | | | | | |
| | | | 356 | 2 | | | | | |
| 16 | 293 | 253 | 152 | 163 | | | NR | | EL(only)NR-GN |
| 17 | 83 | 46 | 222 | 284 | 83 | 46 | 301 | 305 | |
| | | | 316 | 341 | | | | | |
| 18 | 231 | 194 | 302 | 326 | 231 | 194 | 301 | 309 | |
| | | | 133 | 167 | | | | | EL(only) |
| 19 | 21 | 344 | 122 | 132 | | | | | |
| | | | 218 | 255 | | | | | EL |
| | | | 290 | 302 | | | | | EL |
| 20 | | | NR | | | | NR | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 21 | | | NR | | | |
| 22 | 133 | 77 | 265 | 304 | cf. Note 1. | EL |
| 23 | | | NR | | | |
| 24 | 54 | 19 | 216 | 262 | | EL |
| 25 | | | NR | | | |
| 26 | 356 | 319 | 106 | 133 | | EL |
| 27 | | | NR | | | |
| 28 | | | NR | | | |
| 29 | 88 | 52 | 312 | 319 | | |
| | | | 358 | 19 | | EL |
| 30 | 238 | 202 | | | | |
| 31 | 29 | 353 | 56 | 143 | | |
| | | | 232 | 262 | | |
| | | | 284 | 325 | | |
| Septl | 179 | 139 | | | | |
| 2 | 330 | 289 | 222 | 250 | | |
| | | | 264 | 282 | | |
| 3 | 150 | 77 | | | | |
| 4 | | | NR | | Period of strong thunderstorms. | |
| 5 | | | NR | | | |
| 6 | | | NR | | | |
| 7 | 4 | 311 | | | | |
| 8 | | | NR | | | |
| 9 | | | NR | | | |
| 10 | | | NR | | | |
| 11 | | | NR | | | |
| 12 | | | NR | | | |
| 13 | | | NR | | | |
| 14 | | | NR | | | |
| 15 | | | NR | | | |

| | | | | |
|---|---|---|---|---|
| 16 | 293 | 200 | | |
| 17 | 178 | 312 | | |
| 18 | | | NR | |
| 19 | 198 | 72 | 253 | 277 |
| 20 | 11 | 287 | | |
| 21 | 312 | 220 | 204 | 223 |
| 22 | | | NR | |
| 23 | 257 | 152 | | |
| 24 | | | NR | |
| 25 | 195 | 93 | 302 | 3 |
| 26 | | | NR | |
| 27 | 137 | 30 | | |
| 28 | 322 | 178 | | |
| 29 | 77 | 323 | | |
| 30 | 317 | 109 | | |
| Oct. 1 | | | NR | |
| 2 | 205 | 50 | | |
| 3 | | | NR | |
| 4 | 150 | 347 | 236<br>283 | 248<br>304 |
| 5 | 260 | 133 | 332<br>77 | 342<br>125 |
| 6 | 123 | 280 | | |
| 7 | 255 | 68 | 291 | 303 |
| 8 | | | NR | |
| 9 | 294 | 153 | 103 | 167 |
| 10 | | | NR | |
| 11 | | | NR | |
| 12 | | | NR | |
| 13 | | | NR | |
| 14 | | | NR | |
| 15 | | | NR | |
| 16 | END OF OBSERVATIONS. | | | |

NR = No Record. This was either due to the apparatus not functioning properly or due to interference, mostly thunderstorms.

EL = Recording from East London similar to the one obtained at Grahamstown.

I/F = Interference.

GN = Grahamstown.

<u>NOTE:</u> 1) Although the 22 Mc/s equipment was operating until the end of the observing period, no usable recordings were obtained after the 20th of August. During most of the following period some unidentified interference was recorded which had a very large bandspread, but did not reach down to 18 Mc/s. It was tried on quite a few occassions to shift the frequency of observations, but it was of no use, the interference reappeared on each new frequency. It is thought, that it might have something to do with the proximity to the 250 V power line. Before any further observations are taken at the site, it is advisable to shift the pole and lay an underground cable for the last 100 metres.

2) It is indicated in the remarks column, whenever recordings obtained by Mr. Bosch were used. The 24th of July was the first occasion on which signals were recieved at both stations. No recordings were obtained in East London during September due to very bad interference. Mr. Bosch was unable to take observations before midnight, for non-scientific reasons; therefore when conditions did improve again he was unable to observe at the right time.

# CHAPTER V.

## 5.1 A POSSIBLE MECHANISM OF PRODUCTION OF DACAMETRE NOISE.

Before we go into details of the Author's model, let us first have a closer look at some of the mechanisms that were proposed by various people to explain the Jovian decametre radiation.

Shain first proposed a theory to explain the phenomena in 1955. (12.) He suggested that the outbursts might be ordinary "static" due to lightning like discharges in the Jovian atmosphere. His theory was short lived. The narrow bandwidth and relatively long duration of the Jovian pulses were not at all like terrestrial static. Calculations also indicated that the peak radio frequency energy emitted by Jupiter amounted to about 10 kilowatts per cycle per second of bandwidth, which exceeds by several orders of magnitude the radiation due to terrestrial lightning strokes (17.). Smith (40.) discounted the lightning hypothesis as early as 1955. He suggested instead that the radio bursts might be created by turbulence between atmospheric belts at different latitudes. Field revived this idea in 1960 (34.) when he pointed out that the electrical discharges could result from e.m.f's, induced by Jupiter's magnetic field, discharging through the atmosphere.

Zhelezniakov (41.) was the first one to suggest plasma oscillation as the cause of the radiation. A highly ionized medium can be set into oscillation under favourable conditions, when it will emit radio waves. Zhelezniakov based much of his numerical calculation on the assumption that most of the radiation was composed of pulses of duration of the order of milliseconds. He felt that his theory could not account for the longer pulses. Gardner and Shain (16.) and Gallet (14.) made the suggestion that the plasma oscillations could be set off by shock waves ascending from volcanic eruptions on the surface of Jupiter.

Kraus (17.) made the suggestion that the outbursts might be triggered by solar particles. Warwick (24.) found some experimental evidence which supported Kraus's suggestion in the form of a strong positive correlation between Jupiter's decametre emission and solar decametre emission. Jupiter emission followed solar emission with a time delay of one or two days.

Drake and Hvatum (42.) proposed that Jupiter may be surrounded by vast belts of trapped solar particles, analogous to the famous Van Allen belts. Field (33., 35.) has derived quantitative theories of such belts. According to his ideas the microwaves are either "cyclotron" or "synchrotron" radiation from electrons trapped in the planet's magnetic field. He also suggested that the decametre radiation might be cyclotron radiation from protons; synchrotron radiation from protons is extremely unlikely because of the high energy required to accelerate the protons to such high volocities that relativistic effects have to be taken into account.

The Author thinks it very unlikely that the observed decametre radiation is of cyclotron type. The cyclotron frequency is given by $f = eH/2 \Pi m$, where m is the mass of the particle. It is obvious that the frequency is, therefore, inversely proportional to the mass of the particle. A wavelength of 30 cm, being a mean value of the observed decimetre radiation, is equivalent to a frequency of 1000 Mc/s, and therefore we would expect to observe about a two thousandth of this, i.e. 500 kc/s, which in itself is unobservable on the Earth's surface due to reflections in the ionosphere, although it might be possible to observe it from a rocket. The observed peak of radiation is around 18 Mc/s.

We shall now develop our own model:

The Sun appears to emit clouds and streams of gas, with speeds of the order between 500 km/sec. and 1500 km/sec. (43.). This gas is a neutral plasma supposed to consist of equal numbers of protons and electrons. It has been suggested that these protons cause the aurora and a direct proof of the entry of protons into the terrestrial atmosphere has been obtained by Gärtlein (44.). He observed an asymetrical broadening of the H-alpha line ( $\lambda$ = 6562A) in the aurora, extending more towards the violet than towards the red. During a moderate aurora the shift may correspond to a mean velocity of 675 km/sec. with a maximum of 1350 km/sec. Meinel (45.)

even reported a velocity of up to 3200 km/sec. during intense auroral displays.

Field (33.) suggested that this "Solar Wind" is the source of energy for the decimetre radiation from Jupiter, by the trapping of electrons in the postulated magnetic field of the planet.

It might be possible that the protons in the solar wind are the cause of the decametre radiation. The velocity of the solar wind is determined mainly by that of the protons; the electrons must travel at the same rate, since the plasma is supposed to be neutral.

It is intended to show here that the kinetic energy of the protons is sufficient to account for the energy required for the emission of the decametre radio noise.

For our calculation we shall use the value of the solar wind density given by Parker (46.), who estimates it to be 5 - 50 protons $/cm^3$; let us suppose it is 50 protons/$cm^3$ at the distance of the Earth from the Sun. If we assume an inverse square relationship we would expect a density of 2 protons/$cm^3$ at the distance of Jupiter from the Sun. Furthermore, assuming that the total "catchment" area is equal to the area of Jupiter's visible disc and that the protons travel with a average velocity of 1500 km/sec, the total number of protons arriving at Jupiter would be of the order of $5 \times 10^{28}$ per second.

The power density of the decametre radiation received on Earth is about $10^{-20}$ watts. $m^{-2}.(cps)^{-1}$, according to my own estimate (of section 4.2), which closely agrees with the accepted value. At opposition Jupiter is about $6.2 \times 10^{11}$m distant. Assuming a total bandwidth of 1 Mc/s for a certain radio burst (7.), the total radiated power from Jupiter must be $4\ \Pi\ (6.2 \times 10^{11})^2.10^6.10^{-20}$ which is approximately $10^{11}$ watts. If all the power is provided by the kinetic energy of the protons and we substitute the appropriate values for the mass of the proton, the velocity (1500 km/sec) and the energy required ($10^{11}$ joules/sec) into the equation $KE = \frac{1}{2}Nmv^2$( where N = total number of protons and the other symbols have their usual meanings) and solve for N, we find that $10^{26}$ protons/sec would be required.

That means that enough energy would be available to produce the electromagnetic waves, if only 0.2% of the total energy brought to Jupiter by the protons of the solar wind was converted into electromagnetic radiation. If we should use Chapman's value (43.) of the density of the solar wind at the distance of the Earth, which he estimates as 1000 protons/$cm^3$, the available energy would be increased by a factor of twenty.

From here onwards the Author's model is very speculative, but it seems desirable to pursue it a little further. It has been shown above that enough energy is available. Any model trying to explain the Jovian decametre radiation would have to account for the following:

a) A general mechanism of production.
b) The pulses of duration of the order of a second.
c) The right handed polarization.
d) The pulses of the order of milliseconds.
e) The observed inverse relationship between Jovian decametre radiation and the sunspot cycle.

## THE MODEL.

It is proposed that the radiation is caused by a process of sudden dumping of protons collected in the Jovian magnetic fields; these protons are brought to Jupiter by the Solar winds; the dumping takes place into three magnetic anomalies situated on Jupiter's northern hemisphere; the process of radiation is analogous to the Čerenkov effect.

### a) A general mechanism of production.

The protons on being dumped into a magnetic anomaly must impinge on the Jovian atmosphere and will cause the radiation to be given off. The Čerenkov radiation is an electromagnetic shock wave phenomenon, the optical analogue of the well known "supersonic bang". Looked at from an atomic point of view it is a particular type of energy loss in very soft collisions. This electromagnetic radiation is emitted whenever a charged particle passes through a medium in which the group velocity of electromagnetic radiation is less than the particle velocity. If "n" is the group refractive index we have the essential criterion, which must be satisfied for a shock wave to be produced, is that the particle velocity must exceed c/n, i.e. the particle runs away from the slower portions of its own electromagnetic field. The group velocity of electromagnetic waves may even fall to zero for certain electron concentrations, direction of propagation and frequency in an ionosphere; when this happens we get reflection of electromagnetic radiation. Since Jupiter's ionosphere must be electromagnetically anisotropic on account of the postulated magnetic field, the theory of emission of Čerenkov type of radiation caused by protons may be rather involved and no attempt will be made here to solve the problem quantitatively. Nevertheless let us take a closer look at the problem in a qualitative way.

Suppose a proton impinges on the Jovian atmosphere, which is electromagnetically anisotropic, and emits electromagnetic radiation. The "optic axis" of the medium will be aligned at some angle to the direction of motion of the proton. The two extreme cases, i.e.

along and perpendicular to the direction of motion are shown in Fig. XI. We shall get two wave fronts, one due to the ordinary the other due to the extraordinary component, each being propagated at a different velocity, dependant on the refractive index of the medium. The process could best be compared to the process of double refraction in crystal optics. Čerenkov radiation is given off in a direction perpendicular to the surface of a cone, as shown in Fig. XI. The cone angle will depend entirely on the velocity of the particle and the appropriate refractive index of the medium.

### b) The pulses of duration of the order of a second.

The varying conditions in the Jovian atmosphere and ionosphere for the ordinary and the extraordinary wavefront, will cause these to be propagated at different velocities. They would arrive at the terrestrial receiving station in and out of phase with each other. This would cause an effect similar to the fading of signals from distant radio stations.

Another process could also be possible. It might be similar to a mechanism proposed by Winckler, Bhavsar and Anderson (47.). They have proposed this process to explain the large number of energetic X-rays produced at large altitudes. The radiation was given off mainly in bursts of very high intensity and lasting only about 0.1 seconds. They were occurring with periods of 0.8 seconds

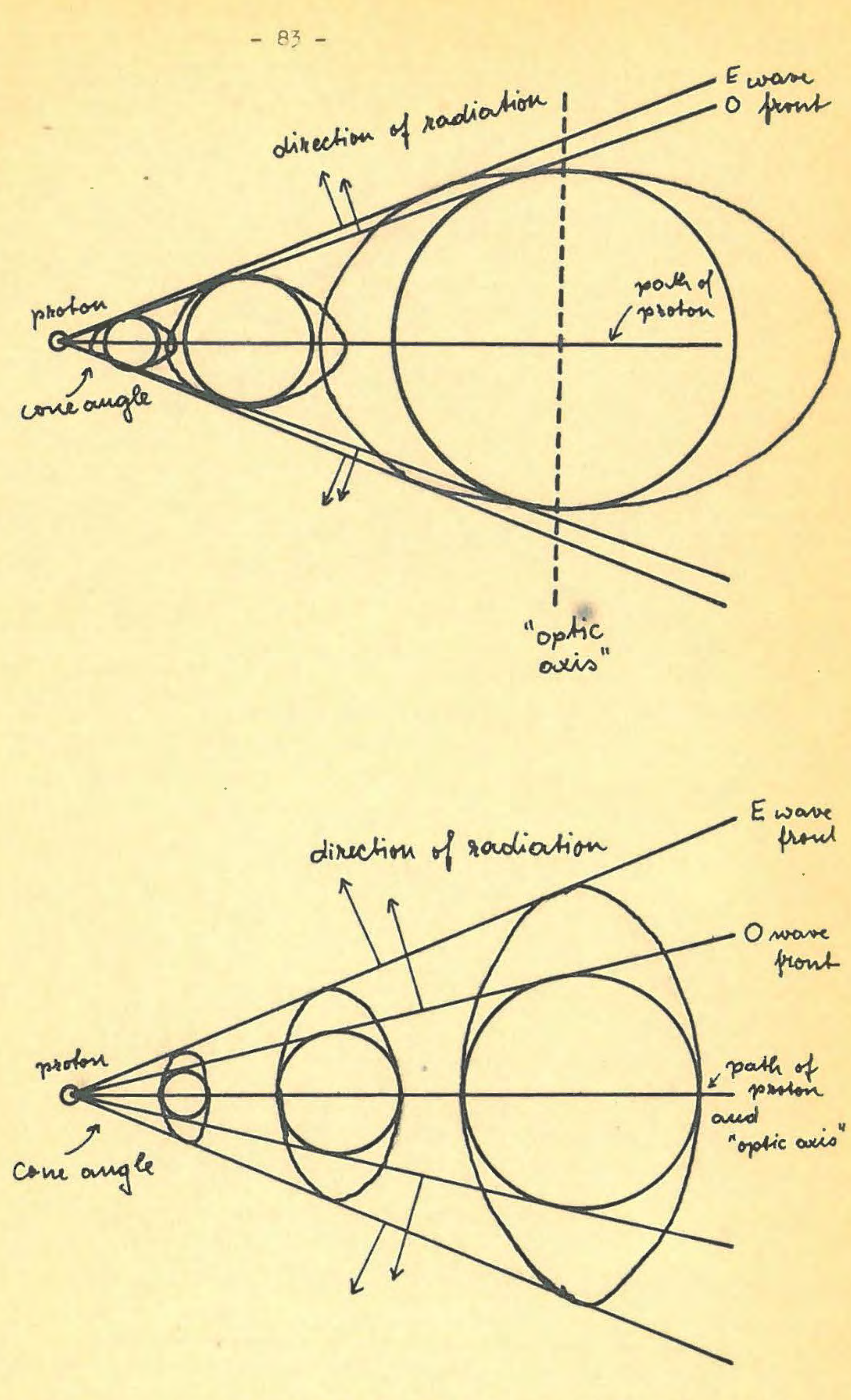


Fig. XI. The two extreme cases in which the optic axis is an anisotropic medium can be aligned.

and multiples thereof. They proposed that some kind of unspecified impulse accelerates and bunches a group of electrons in the geomagnetic field. The bunch of electrons moves to the atmosphere and the electrons in the loss cone escape, producing one very sharp X-ray burst. The electrons that were not in the loss cone remain trapped and may oscillate as a bunch, with a characteristic bounce period of 0.8 seconds along a line of magnetic flux, backwards and forwards from the north to the south pole, radiating every time some electrons reach the loss cone.

In the case of the Jovian emission the radiation could be produced by protons bouncing back and forth between Jupiter's north and south pole and radiating everytime some protons are dumped in a magnetic anomaly.

### c) The right handed elliptical polarization.

The proton when it is in a magnetic field gyrates around a line of magnetic flux. If during this gyration electromagnetic radiation is given off, it will be found to be elliptically polarized. From the fact that most of the radiation received is right handed polarized the most likely conclusion that can be drawn is that the sources of radiation are located on one magnetic hemisphere only.

### d) Pulses of the order of a milli second.

If a proton on gyrating around a line of magnetic flux gives off electromagnetic radiation analogous to Čerenkov radiation, it will be found that the radiation is modulated with twice the gyrofrequency since the cone of emission sweeps past the observer and he will observe radiation whenever he "looks" normally onto the surface of the cone. That Jupiter's decametre radiation has a hyperfine structure has been shown conclusively by Douglas and Smith (30.), who have found rapidly varying signals of duration of the order of a few hundredths of a second. Kraus (31.) also found signals of the order of ten milliseconds. The gyrofrequency of a particle is given by $f = eB/2 \Pi m$. With the aid of this formula, it might be possible to find the value of the Jovian magnetic field. Up to now two values have been obtained. One by Field (33.) who postulated a value of 1.2 webers. $m^{-2}$ in trying to explain the decimetre radiation. He used as a model cyclotron emission by electrons. This value is very high, to say the least. If Jupiter really had such a strong magnetic field, spectroscopical observations would have had to show some sort of splitting in the spectral lines; but nothing of that sort has as yet been found. Barrow (27.) found a "much more reasonable" value of 6.4 x $10^{-3}$ Webers. $m^{-2}$. He assumed that the decametre radiation was at the gyrofrequency of the electrons. Since we, in this thesis, have proposed that protons are the cause of the decametre radiation we cannot use any of these values for any of our calculations. If one assumes our model to be correct, and protons gyrating around a magnetic line of flux cause the hyperfine component of the decametre, we can arrive at a value for the Jovian magnetic field. Let us use the value given by Kraus, i.e. one pulse lasts ten milliseconds. The frequency, therefore, is 100 cps., which would be twice the gyrofrequency. The equation $f = eB/2\,\Pi\, m$ can be rearranged to $B = 2\,\Pi\, mf/e$; substituting we get $2\,\Pi\,.1836(9.1 \times 10^{-31})\,.50/(1.6 \times 10^{-19}) = 3 \times 10^{-6}$ Webers. $m^{-2}$; this is about 1% of the strength of the Earth magnetic field.

### e) The observed inverse relationship between the Jovian decametre radiation and the sunspot cycle.

Up to now it has always been assumed that the observed minimum of radiation during 1959 as reported by Carr et al. (29.) has some relationship with the sunspot cycle. No one, as yet, has mentioned the fact that the period of revolution of Jupiter is just about the same as the period of the sunspot cycle. During 1959 Jupiter's south pole was at its maximum "visibility" as observed from Earth. Therefore if the magnetic anomalies responsible for the emission of decametre noise are on the far side of Jupiter and located fairly close to the pole on the northern hemisphere, the electromagnetic radiation would have to travel a larger distance in the Jovian atmosphere and be subject to more absorption during that period.

This would explain the minimum. Figure XII shows a diagram of the probability of occurrence versus the time in years for the three main sources that have been observed during the past few years. Also on the same drawing is a graph of the angle of tilt of Jupiter's axis towards the Earth. From this it is immediately obvious that the minimum of probability of occurrence occurred at the time when Jupiter's north pole was at its minimum visibility from Earth.

Working on this hypothesis and the fact that the observed polarization was right handed in the radio sense i.e. clockwise if we look in the direction of propagation, the vector relationship between the force acting on the particle, the magnetic field and the particle velocity i.e. $\vec{F} = \vec{v} \times \vec{B}$ gives us an indication as to the magnetic polarity of Jupiter. Observed from Earth the proton would gyrate in an anti-clockwise direction and the force on it would be towards the centre of the "circle of gyration". This means that the line of magnetic flux would have to come out of the north pole and go through that circle of gyration. Jupiter's geographical north pole would therefore also be a magnetic north pole; unlike the Earth whose geographical north pole is in actual fact a magnetic south pole.

Only further research along these lines will show

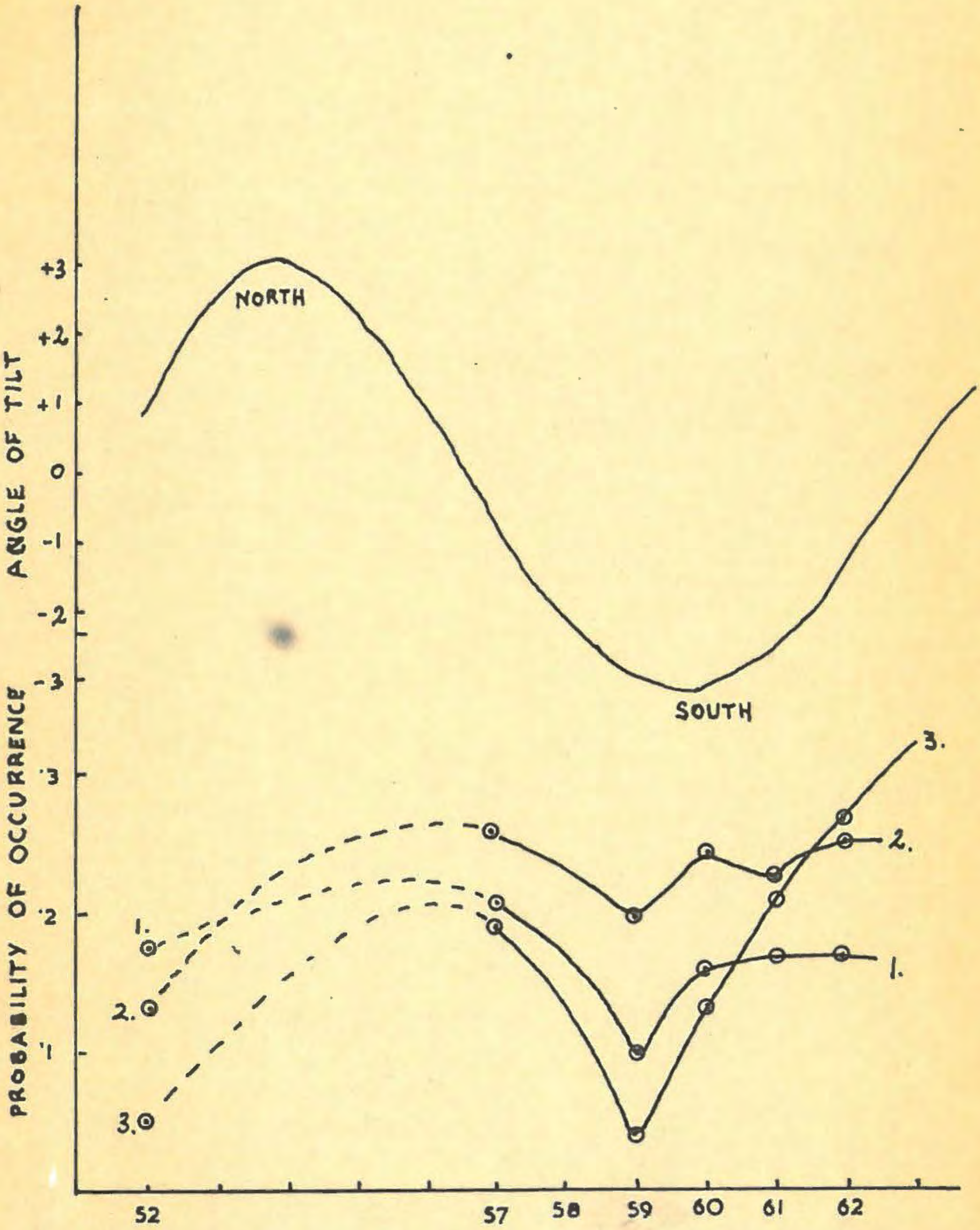


Fig XII. Probability of occurrence versus the time in years for the three main sources that have been observed during the past few years. TOP: Angle of tilt of Jupiter's axis vs. since Positive sign means North pole is visible. Negative sign means South pole is visible.

if the model is successful. So far it seems to have fitted all the data that was available to the Author, but any new fact that might be discovered could disprove it or might **prove it.**

Who knows!

## 5.2 CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH.

It is difficult to compare results from different observers. But all the same a certain amount of correlation does exist between various results. With this investigation a start has been made to open up a new branch of research at Rhodes University. I believe that observations should be continued on a much larger scale at this institution. Grahamstown would be ideally placed to form the necessary link between existing observatories in America and in Australia. Cooperation between the research stations on these two continents and our Physics department could lead to observations being made of Jupiter throughout each apparition. Many a scientist working on the problem of Jovian radioemission has bemoaned the fact that such facilities do not exist and stressed the necessity of continuous observation, as this might provide important data about the phenomena.

It might be that the Author has opened up a new way of looking at the problem of Jupiter's decametre radiation. The idea of a radiation analogous to Čerenkov radiation, seems promising. The quantitative aspect of the possible rate of radiation of energy by that process needs to be investigated. The Author plans to derive a theory based on such a process for the Jovian decametre radiation. Following such lines of thought, it might be fruitful for a group equipped for such a project to investigate the possible emission of Čerenkov radiation proper. With a sufficiently high amplifying device it might be possible to detect light intensity variation, by letting the light from Jupiter be collected by a telescope and all but a small zone be blotted out by screens. The remaining light intensity should then be investigated for variation. In such a way variations from small areas might be detected and compared with radioastronomical data. This might help to find a solution to the very interesting problem of the radio emission by the planet. The variations as such, if they are of Čerenkov origin, will certainly not be observable if the whole disc of Jupiter is observed, as Carr et al. (29.) tried to do.

Another interesting problem, that might be worth while investigating was put forward by Briggs (48.). He suggested that some relationship might exist between the intensity of radio emission by the planet and the colour intensity of various surface features, mainly the Great Red Spot. It was suggested by Briggs that the colour could be explained by assuming a synthesis of complex organic compounds. These could be produced from the Jovian gases of the atmosphere if some source of the high energy was available.

The following process could be possible, as envisaged by the Author:

The protons that arrive at Jupiter could, on being dumped, ionize the Jovian atmosphere. The dumping would also affect the magnetic field and the strength would vary. Such a change would set up an electric field. When the potential is high enough a discharge could take place, which could provide the energy for the chemical process. How far this process is applicable is doubtful, since such changes do occur in the Earth atmosphere due to dumping from the van Allen belts and there are, as far as the Author is aware, no considerable electric field changes.

Radio Moscow reported recently, that reflection measurements of radio waves bounced off Jupiter carried out by Russian radio-astronomers indicated, a van Allen belt type of radiation shell around the planet. A closer study of possible similarities between the terrestrial and the Jovian belts might be very fruitful.

The most urgent need at the moment seems to be polarization measurements at fixed frequencies over a fairly large range of frequencies. Comparison of the states and changes of states of polarization might give some indication as to the process that causes this radiation. Swept frequency investigations should be carried out at the same time to show how the Jovian bursts build up and how they are distributed.

The needs of astrophysical observations in the Republic may not be obvious, but South Africa is ideally placed to form a link between existing radio observatories and Grahamstown in particular is suited, because terrestrial interference is reduced to a minimum due to the absence of large industrial undertakings in the vicinity.

## ADDENDUM

PUBLICATIONS RELEVANT TO JUPITER RESEARCH (too late for inclusion in the main part of the thesis).

In the September issue of Nature L.Landovitz and Leona Marshall discuss the possibility of stimulated electron spin-flip transitions as the source of the 18 Mc/s radiation on Jupiter. They suggest that the radio emission is a maser-like phenomenon. The decametre emission is caused by electrons making spin-flip transitions in the perturbed magnetic field of Jupiter. The solar particles are supposed to impinge on the Jovian magnetic field and stimulate perturbations which in turn cause very sudden changes in it in the time of the Lamor precession frequency. The incidence of a cloud of solar particles subjects an electron population in a static magnetic field to an oscillating magnetic perturbation causing the electron population to emit radiation at the Lamor frequency characteristic of the static field.

## GLOSSARY OF ASTRONOMICAL TERMS.

APPARITION: The interval between successive conjunctions of a planet with the Sun during which the planet is favourably placed for observations.

CONJUNCTION: The configuration of Earth, Sun and Planet, when the three lie most nearly in a straight line with the Earth at one extremity. If the planet is between the Sun and the Earth, the planet is said to be in inferior conjunction; if beyond the Sun, in superior conjunction. Only superior conjunction of Jupiter can occur, since it is always farther away from the sun than the Earth and can therefore not come between the Sun and the Earth. Any two celestial objects are said to be in conjunction when, as seen from the Earth their right ascensions, measured on the ecliptic, are identical.

ECLIPTIC: The plane of the Earth's orbit around the Sun; also the apparent path among the stars followed accurately by the Sun and approximately by the planets.

OPPOSITION: The configuration of Earth, Sun and Planet, when the three lie most nearly in a straight line with the Earth in the middle. When a planet is in opposition, the Earth, as seen from the planet, would be in inferior conjunction with the Sun. Only Planets whose orbits are exterior to that of the Earth can therefore come to opposition and be viewed on the meridian at midnight.

| | |
|---|---|
| SIDEREAL PERIOD: | Time taken for one rotation, as seen from the Sun. |
| SYNODIC PERIOD: | Time between two similar conjunctions of a planet. |

## NUMERICAL QUANTITIES ASSOCIATED WITH JUPITER AND ITS ORBIT.

DIAMETER: 142,700 km (equ) 133,200 km (polar)

Earth = 1 11.2 10.4

MASS: $1.9 \times 10^{30}$ grams

DENSITY: 1.34 gms/cc or 24 % of earth's density

SURFACE GRAVITY: 2.64g (at equator) 2.67g (at poles)

INCLINATION OF EQUATOR TO PLANE OF ORBIT: 3°.07

MEAN DISTANCE FROM SUN: $7.78 \times 10^{8}$ km or 5.2028 (Earth=1)

SIDEREAL PERIOD OF REVOLUTION IN TROPICAL YEARS: 11.8622

MEAN SYNODIC PERIOD IN DAYS: 398.88

ECCENTRICITY OF ORBIT: 0.04843

INCLINATION OF ORBIT TO ECLIPTIC: 1°18′20″

## REFERENCES.

1. Herrmann, Astronomie, eine moderne Sternkunde (C.Bertelsmann,1960)
2. Payne-Gaposchkin, Introduction to Astronomy (Methuen, 1961)
3, Peek, The Planet Jupiter (Faber & Faber, 1958)
4. Graham-Smith, Radioastronomy (Penguin, 1960)
5. Burke and Franklin, J.Geophys. Res. 60. 213 (1955)
6. McClain and Sloamaker, in Paris Symposium on Radio Astronomy, (Stanford Press, 1959).
7. Smith, Science, 134. 587 (1961)
8. Ellis, Nature, 194. 667 (1962)
9. Kraus, URSI 12th General Assembly 1957, Boulder, Colorado, U.S.A. publication 581 of the Nat. Acad. Sciences-Nat. Res. Council, (1958)
10. Mills and Little, Aust. J.Phys. 6. 272 (1953)
11. Ryle, Proc. R.Soc. 211. 351 (1952)
12. Shain, Aust. J.Phys. 9. 61 (1956)
13. Franklin and Burke, J.Geophys. Res., 63. 807 (1958)
14. Gallet, USA Nat. Acad. Sci-Nat. Res. Council Publ. 581. 143 (1958)
15. Gallet, Planets and Satellites (ed. Kuiper) (Chicago Univ. Press, 1961)
16. Gardner and Shain, Aust. J.Phys., 11. 55 (1958)
17. Kraus, Proc. I.R.E., 46. 266 (1958)
18. Carr, Smith, Pepple & Barrow, Astropys. J., 127. 274 (1958)
19. The Astronomical Ephemeris (yearbook) (H.M.S.O.)

20. Explanatory Supplement to the Ephemeris, (H.M.S.O., 1961)

21. Smith and Carr, Astrophys. J. 130. 641 (1959)

22. Smith, Carr, Bollhagen, Chatterton and Six, Nature, 187. 568 (1960)

23. Booker, Proc. I.R.E., 46. 298 (1958)

24. Warwick, Science, 132. 1250 (1960)

25. Carr, Smith and Bollhagen, Phys. Rev. Letters (USA), 5. 418 (1960)

26. Barrow, J.Brit. Aston. Assoc., 69. 211 (1959)

27. Barrow, Nature, 188. 924 (1960)

28. Appleton, J.Inst. Elect. Eng., 71. 642 (1932)

29. Carr, Smith, Bollhagen, Six and Chatterton, Astrophys. J., 134. 105 (1961)

30. Douglas and Smith, Nature, 192. 741 (1961)

31. Kraus, Aston. J. 61. 182 (1956)

32. Gallet, Inst. Rad. Eng. Trans. on Antennas and Propagation, 327. (1957)

33. Field, J.Geophys. Res., 64. 1169 (1959)

34. Field, J.Geophys. Res., 65. 1661 (1960)

35. Field, J.Geophys-Res., 66. 1395 (1961)

36. Barrow and Carr, J.B.A.A. 68. 63 (1958)

37. Schelkunoff and Friis, Antennas Theory and Practice (Wiley, 1952)

38. Philips Handbook, (Philips)

39. Elmore and Sands, Electronics, (McGraw-Hill, 1949)

40. Smith, Observatory, 75. 252 (1955)

41. Zhelezniakov, Soviet Astron.-A.J., 2. 206 (1958)

42. Drake and Hvatum, Aston.J., 64. 329 (1959)

43. Chapman, J.At. & Terr. Phys., 15. 43 (1959)

44. Gärtlein, Nature, 167. 277 (1951)

45. Meinel, Astrophys. J., 113. 50 (1951)

46. Parker, J.Res. Nat. Bur. Stand. (USA), 65. (D/6), 537 (1961)

47. Winckler, Bhsavsar and Anderson, J.Geophys. Res., 67. 3717 (1962)

48. Briggs, Observatory, 80. 159 (1960)