DOMINION RADIO ASTROPHYSICAL OBSERVATORY

WHITE LAKE

BRITISH COLUMBIA

CANADA

Rookeries and Rattlesnakes
Division

SECRETS OF THE 10.03 MC/S SYSTEM

(Part II)

by

ALAN BRIDLE and RICK CHOQUETTE

JULY '66

"Now was the day departing, and the air
Imbrown'd with shadows, from their toils released
All animals on Earth, and I alone
Prepared myself the conflict to sustain .....

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SECRETS of the 10.03 Mc/s System

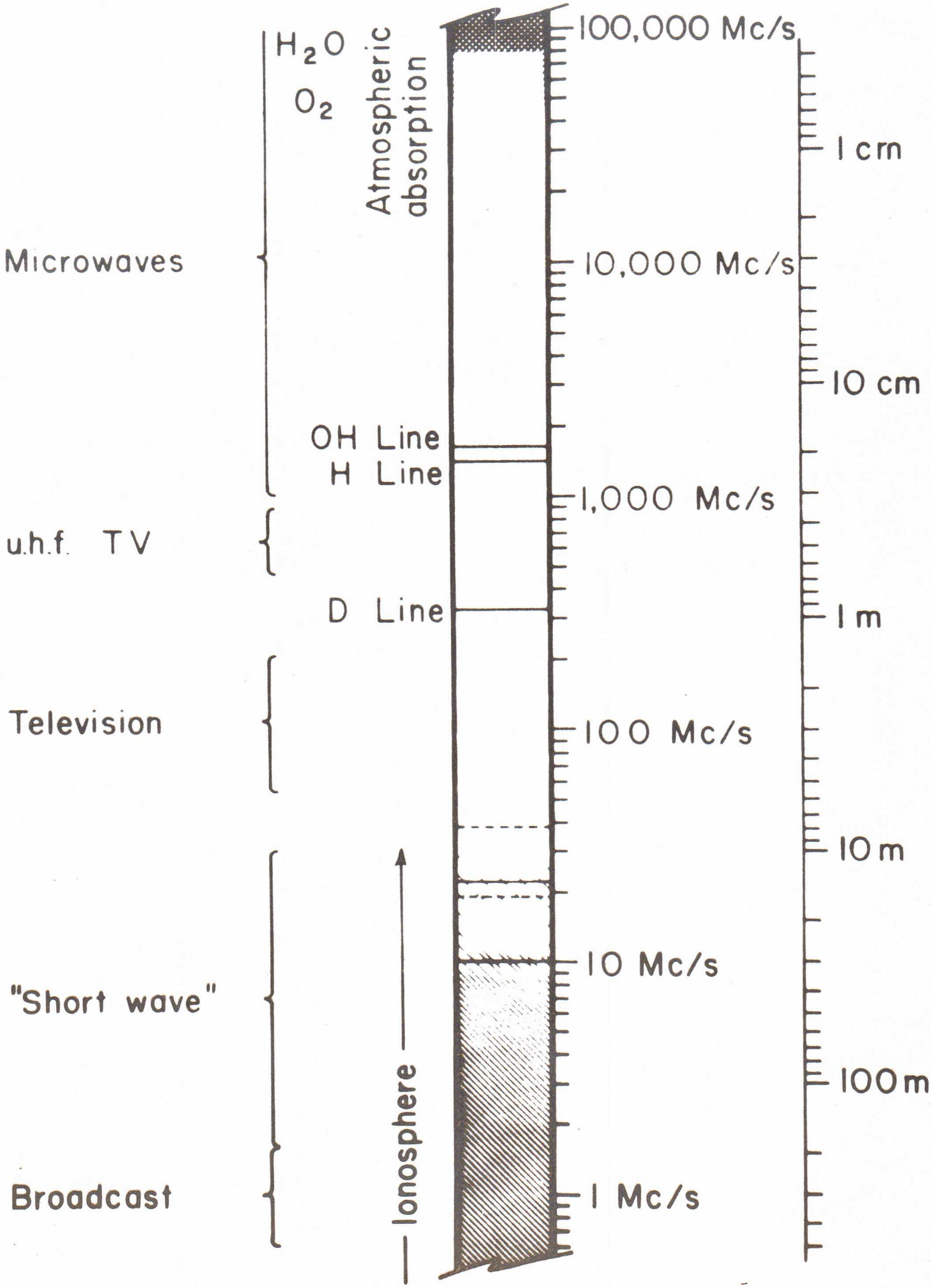
being

Part II of The Observer's Guide (to Dark Despair) :

CONTENTS

"A little glimpse of sky was seen above,
Yet by that little I beheld the stars ....

Dante



H_2O
O_2
Atmospheric absorption
Microwaves
OH Line
H Line
u.h.f. TV
D Line
Television
"Short wave"
Broadcast
Ionosphere
100,000 Mc/s
10,000 Mc/s
1,000 Mc/s
100 Mc/s
10 Mc/s
1 Mc/s
1 cm
10 cm
1 m
10 m
100m

§1. THE ANTENNA

a) The basic element

The basic "unit" or "building-block" of the antenna is an E-W row of 5 half-wave dipoles. The dipoles are parallel to the N-S direction, spaced 0.9 λ apart E-W, and are situated 0.125 λ above a reflecting screen. The dipoles in such a row are fed in phase from a balanced transmission line, onto which they are coupled at intervals of 1.0 λ through flexible twin lead. A balance-to-unbalance transformer is placed at the centre of each row to effect the conversion to coaxial cabling. The row is colloquially known as a "line of 5".

b) The E-W arm

The E-W arm consists of four long rows of dipoles spaced 0.5 λ apart in the N-S direction. Each of these rows consists of nine of the basic units, i.e. of 45 dipoles. The feeding system in each E-W row is of the "Christmas Tree" type. Each unit has a grading attenuator at the balance-to-unbalance transformer, and the units are then combined in three groups of three. 50 Ω coaxial cable is used throughout. The balance-to-unbalance transformers match the units to 50 Ω at the unbalanced side, and the outputs of the 3:1 junctions are re-matched to 50 Ω. A second 3:1 junction and impedance matching procedure brings the whole row of 45 dipoles into a single coaxial cable, which is taken to the phasing network at the crossover region.

The input to the phasing network, which is located at the refrigerator at the crossover, is therefore four coaxial cables at 50 Ω each. These four are combined in the E-W phasing device to produce eight beams centred on different declinations. Of these eight, two are very rarely used, being below the North Celestial Pole or very close to the horizon.

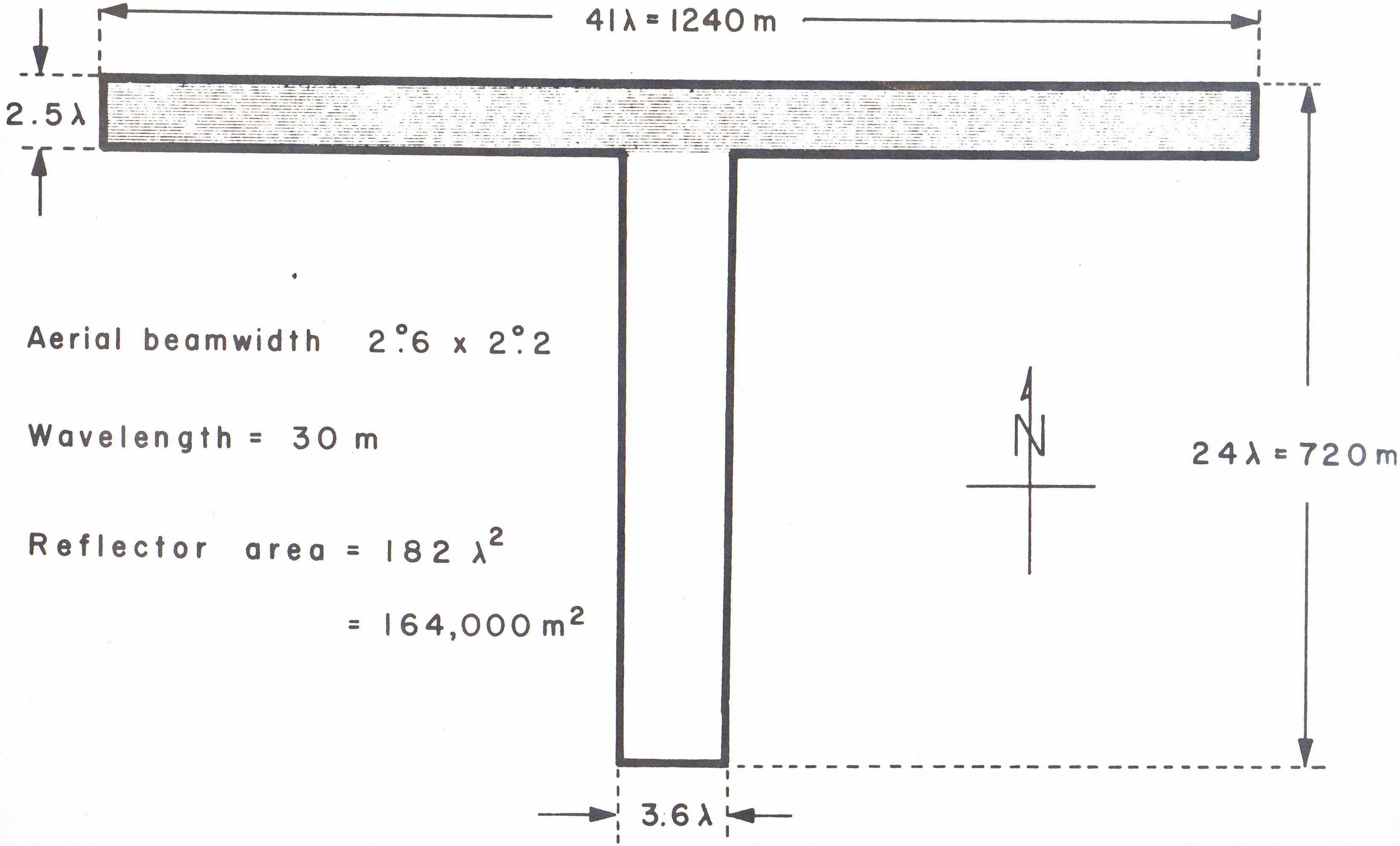
A coaxial relay bank activated from the control trailer is used to select the desired E-W beam, the signals then passing through a crystal filter whose centre frequency may also be selected from the control trailer, a valve preamplifier, and along a single long coaxial cable to the trailer.

At the trailer, the signal from the E-W arm passes through a 4:1 divider ; it can then be combined separately with four different N-S beams. It is usual to employ a set of N-S beams with that E-W beam giving the greatest forward gain in their direction.

c) The N-S arm

The N-S arm consists of forty-eight of the basic units spaced 0.5 λ apart

The 10.02 Mc/s radio telescope



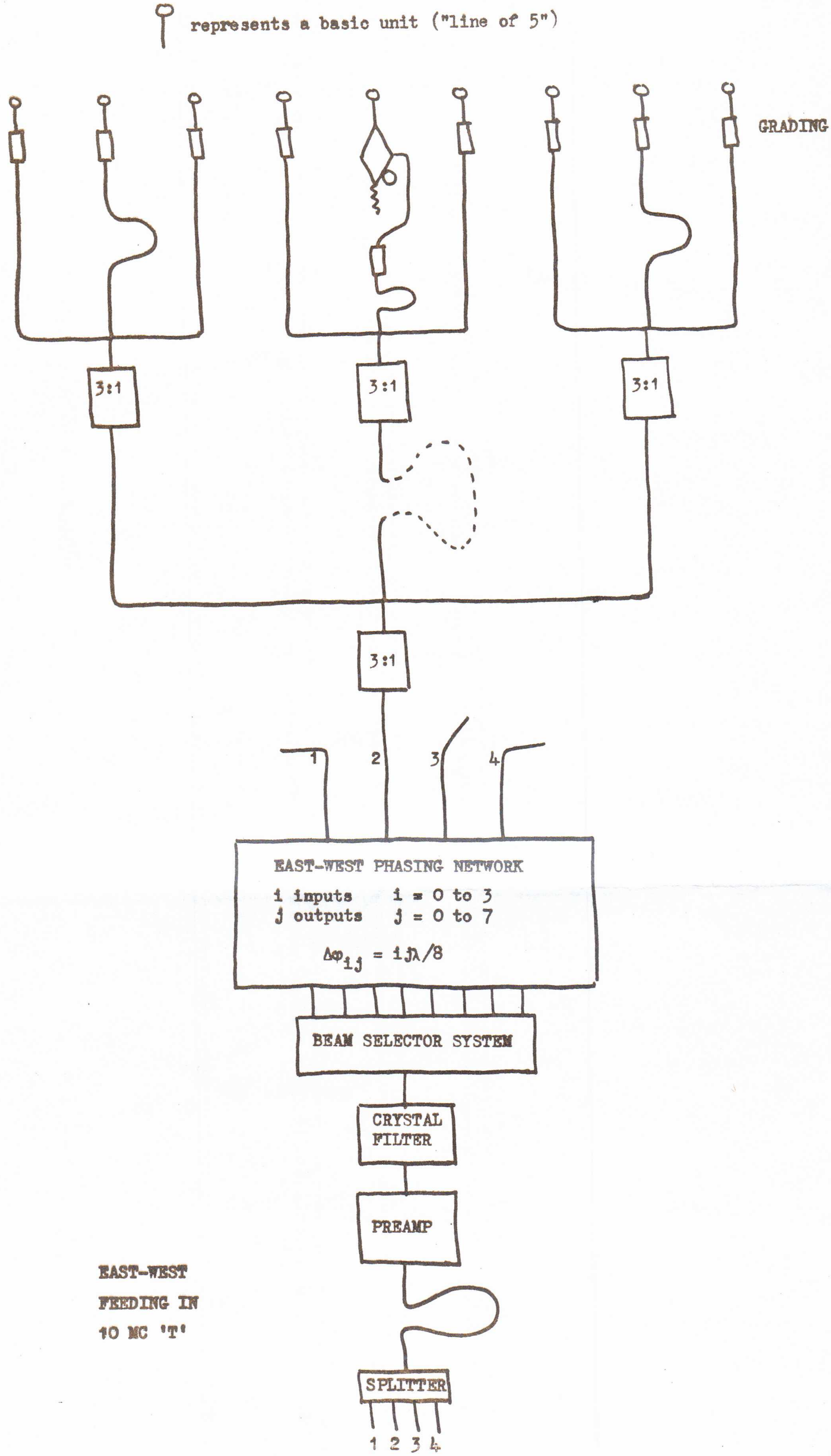
in the N-S direction. The arm runs to the south of the E-W arm, and the four most northerly units are shared with the E-W arm. To achieve this, the power from these units is split by a hybrid ring circuit at the balance-to-unbalance transformer so that identical in-phase powers are fed into the E-W and N-S feeder systems. The phase path through the hybrid ring circuit is compensated in the feeder arrangements of each of these units. Each unit is connected directly to a 50 Ω coaxial cable, and the forty-eight equal cables are taken to the control trailer separately. The grading attenuators for the N-S arm are located in the control trailer, at the input of the N-S phasing network.

The N-S phasing network combines the 48 inputs to produce 64 beams at different declinations. Of these, 13 are semi-redundant because they are directed below the North Celestial Pole. The N-S phasing network is colloquially known as "Rookery A". The 64 outputs are brought out on a panel in the control trailer, and are selected manually. Unused outputs are terminated in 50 Ω coaxial loads.

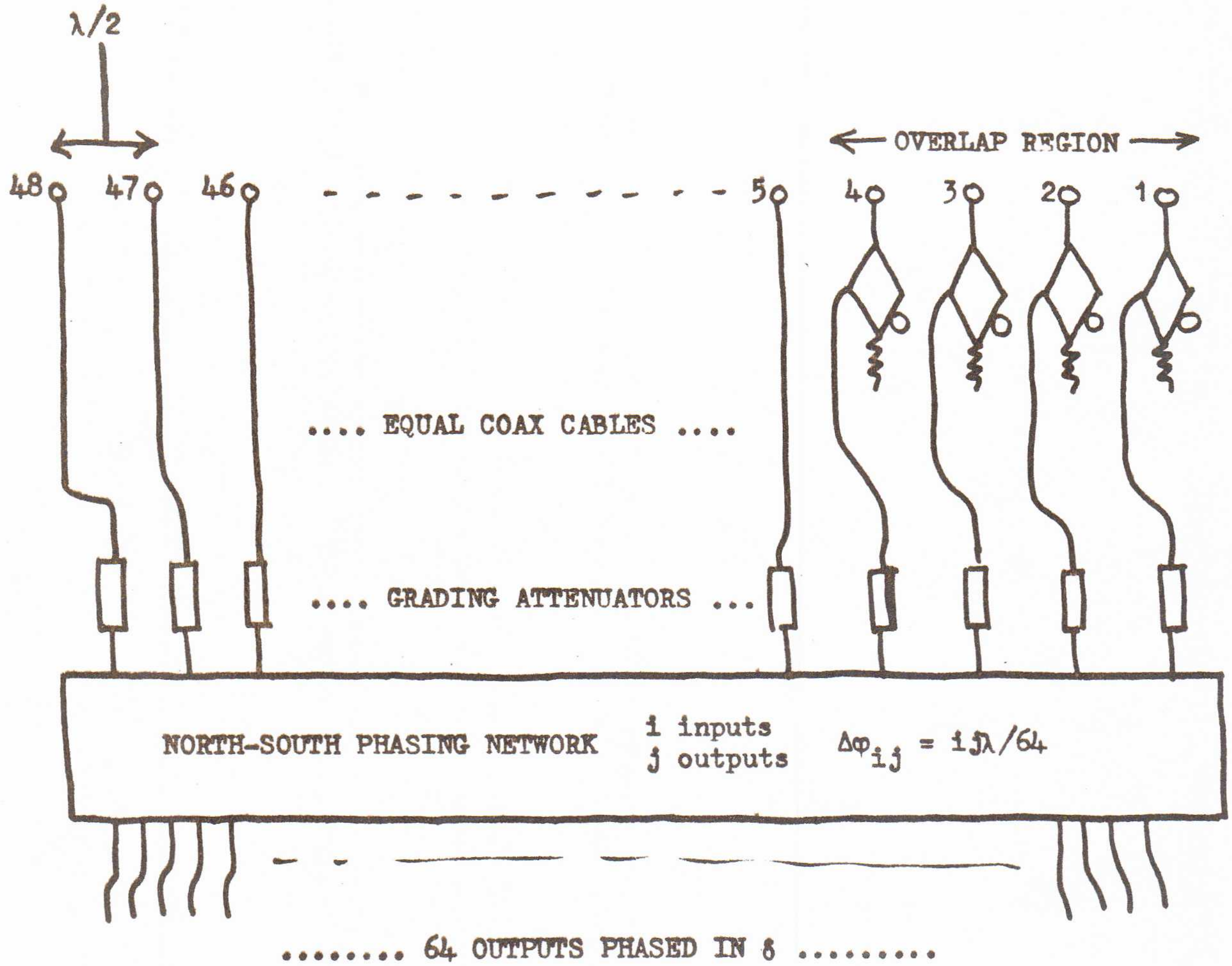
Schematic diagrams of the feeding arrangements described above are given on the next two pages.

d) <u>The relative phases of the two arms</u>

The relative phase of the N-S and E-W arms must be maintained as close to 0° as possible for all directions of the antenna beams in use, in order that the "DC" component of the antenna response be maintained with the correct amplitude for the synthesis of the aperture to which the T is equivalent. If the two phases were different by some phase angle φ, the DC component, which is derived by phase-switching the units in the "overlap" region of the two arms against themselves after splitting their power in the hybrid ring circuits, would be reduced by $\cos^2\varphi$ relative to its correct amplitude. To compensate for slight departures from $\varphi = 0$ which arise as the antenna beams at different declinations are used, or as crystal filters centred on different frequencies are switched in and out, small lengths of cable are inserted in the outputs of the N-S phasing device and of the 4:1 divider in the E-W cable, as required. It is essential to maintain $\varphi \approx 0$ for a correct representation of the sky in background work ; in radio source studies a significant departure from $\varphi = 0$ will cause a deterioration in the achieved signal-to-noise. This point will be discussed more fully in the sections on the theory of the antenna and on the practical operation of the instrument.


represents a basic unit ("line of 5")
GRADING
3:1
3:1
3:1
3:1
1
2
3
4
EAST-WEST PHASING NETWORK
i inputs i = 0 to 3
j outputs j = 0 to 7
Δφij = ijλ/8
BEAM SELECTOR SYSTEM
CRYSTAL FILTER
PREAMP
EAST-WEST
FEEDING IN
10 MC 'T'
SPLITTER
1 2 3 4

represents a basic unit ("line of 5")



NORTH-SOUTH ARM FEEDING IN 10 MC 'T'

e) The White Lake Dipole

The calibration of the absolute gain of the 'T' system can in principle be carried out by combining observations of any radio source made with the 'T' in its normal manner with observations of the same source made with the E-W and N-S arms phase-switched in turn against an aerial of known gain. The White Lake Dipole is an attempt at providing such a comparison standard, and consists of a single-wire half-wave dipole 0.125 λ above White Lake. A single coaxial cable comes from the dipole to the trailer, balance-to-unbalance conversion being carried out at the dipole. No attempt has been made to equalise phase paths between this dipole and the trailer, and the arms of the 'T' and the trailer respectively, with the result that a slightly more complicated observational technique is needed. This will be described later in the section on calibration of the antenna.

§2. THE RECEIVERS.

a) Total-power receiver

The Dicke-switch form of total-power receiver is used. In this system the radio-frequency power to be measured is presented to the receiver alternately with the power from a laboratory reference by a crystal diode switch driven with 300 c/s square-waves. The 300 c/s reference is also used to drive a synchronous detector at the audio stage output.

In practice the power to be measured is connected to one side of the RF chageover switch, and the other is terminated in a 50 Ω load. The receivers available for the main stages of RF amplification are communications receivers with input noise temperatures that are excessive for radio astronomy purposes, and so these are preceded by transistorised preamplifiers with acceptable noise figures. (The typical effective noise temperature for the transitorised preamplifiers is $T_{xs} \approx 300^{\circ}K$). IF conversion, amplification, and AF conversion are achieved in the communications receivers, and the audio signal passed to separate chassis for AF amplification, synchronous detection, and DC amplification and integration. AGC is normally applied throughout the total-power receivers, as the non-linear output response this introduces can be calibrated easily by replacing the antenna cable with a diode noise generator.

The DC output of the receivers is $\approx$ several volts and is suitable for driving a recording milliammeter of several kilohms impedance.

The transistorised preamplifiers will admit interfering signals which can beat against one another to synthesise a 10 Mc signal, and the total-power receivers must be used with a crystal filter network ahead of the Dicke switch, in the signal cable. Placing a crystal filter after the Dicke switch but before the preamplifier is only partially effective, as large interfering signals may still beat into the passband of the filter through the harmonic sidelobes of the reference 300 c/s square waveform.

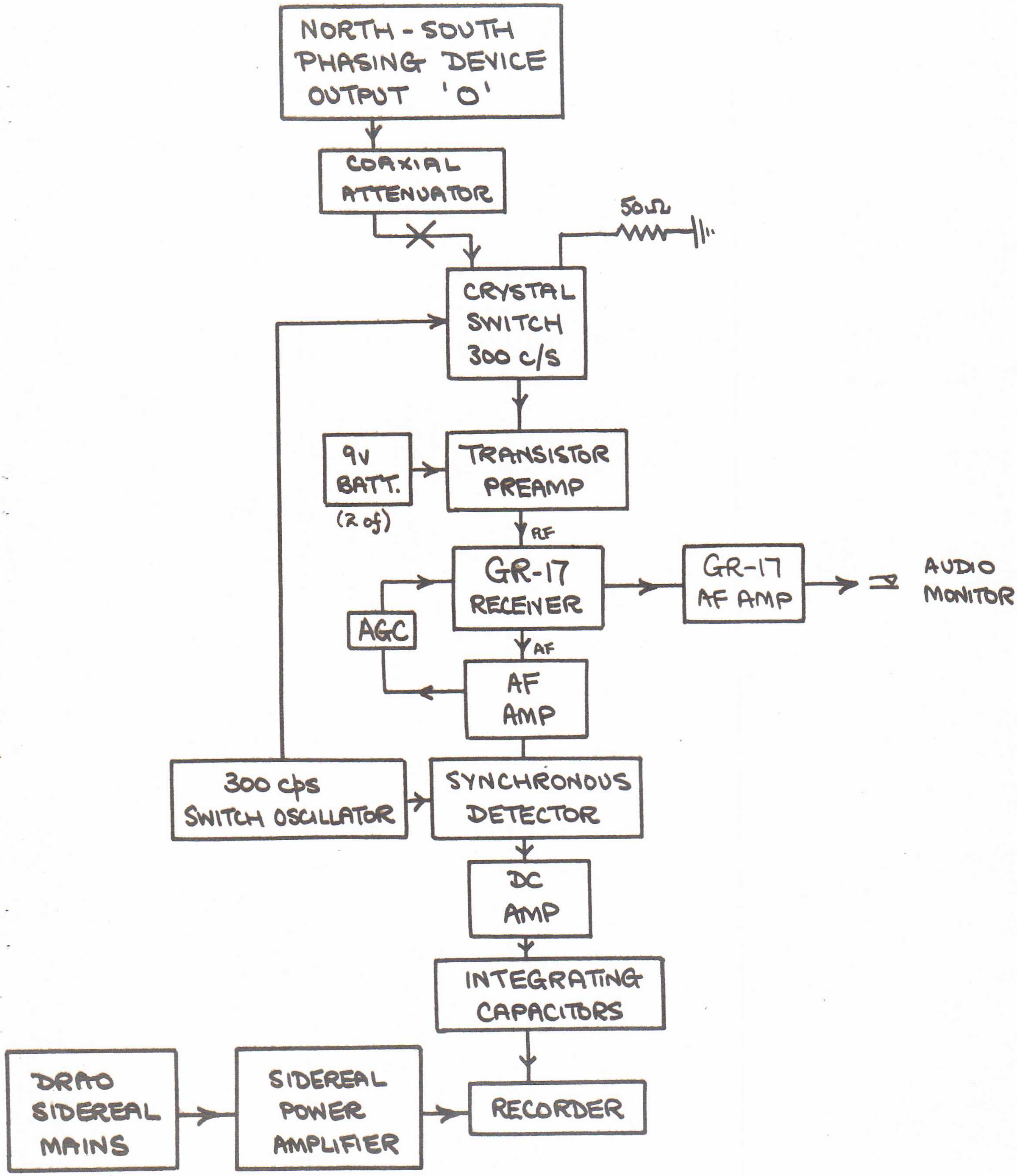
The total-power system is suitable for routine riometric observations, for which it is customary to use the N-S arm of the 'T' as an antenna, selecting the output of the N-S phasing device which produces a beam on the zenith (Output ‡0). It may also be employed for observations of sources with the E-W fan beam, by connecting it to one of the four outputs of the splitter in the E-W arm. In this case it is not necessary to add a crystal filter, as the E-W arm is filtered at the crossover (see §1b). It is also suitable for carrying out measurements of cable attenuations, losses in lumped circuits, gains of preamplifiers, noise generator calibrations, etc., for which purpose it forms a detector of great sensitivity.

A block diagram of the total-power receiver is given on the following page.

b) <u>180° - switching receiver (Phase-switch)</u>

In order to synthesise the desired aperture from the combination of signals detected by the two arms of the 'T', it is necessary to multiply the voltages appearing on these two antennae. It is shown in the theory of the receiver (§4) that this can be achieved by attaching the two arms to the inputs of a Ryle-type phase-switching receiver.

In the 10 Mc system, the output of the N-S arm is taken through a crystal filter to the 2:1 junction of such a receiver, and the output of the E-W arm is taken through an RF crystal diode switch driven by a 300 c/s square waveform whose two positions introduce path lengths of d and $d + \lambda/2$ in turn. The length d is arbitrary and is compensated for in the path inserted in the N-S arm. The switches introduce some 3dB loss, and must be inserted in the E-W arm side of the set to optimise signal-to-noise. The overall signal-to-noise performance of a phase-switched receiver is optimised when the signals presented to the switched and unswitched sides are equal (provided that both of these are well above set noise), and so it is arranged that extra attenuation is introduced into the E-W arm cable to balance



10 MC TOTAL POWER RX

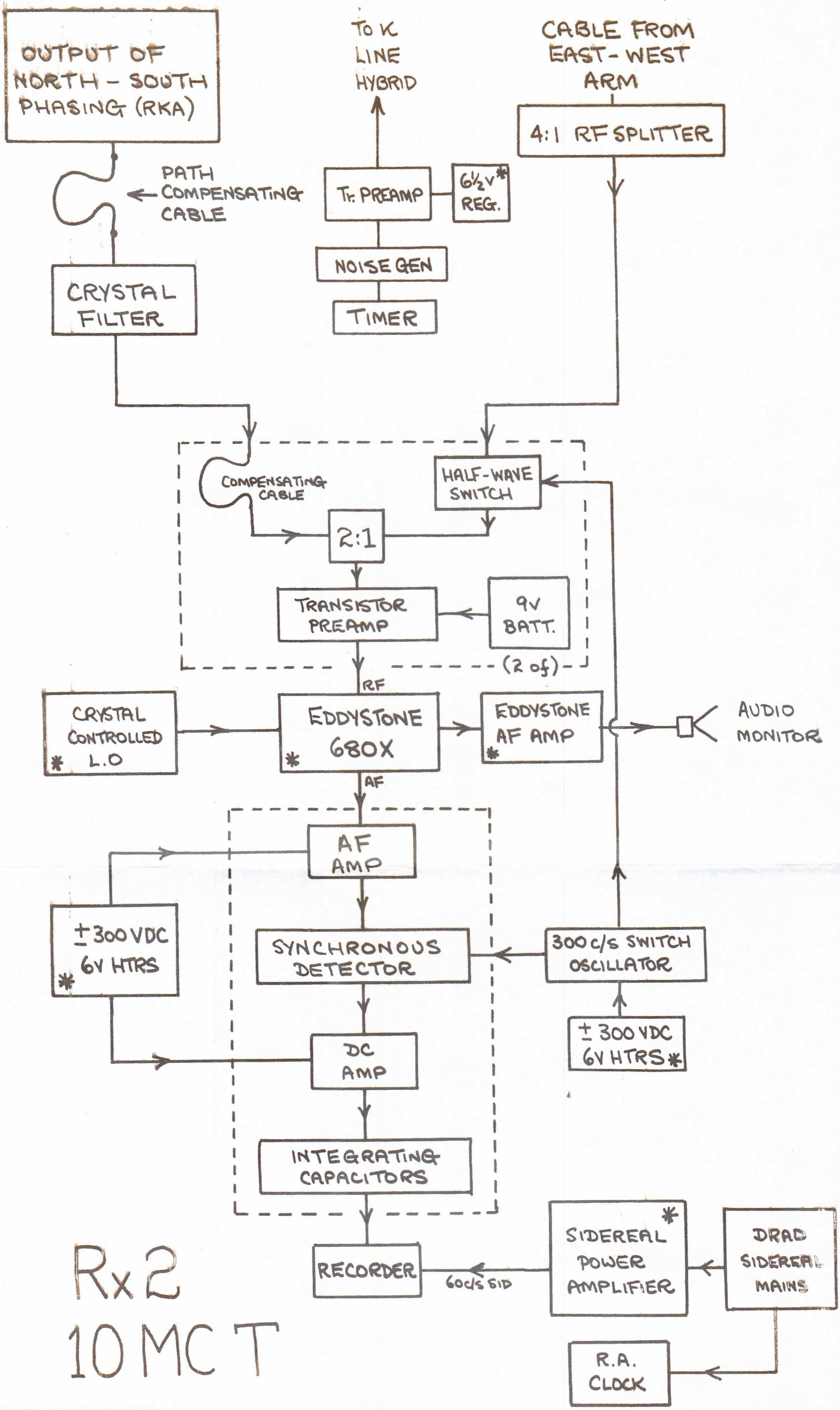
the loss in the N-S side. The effective loss in the E-W feeder system is much less than that in the N-S because of the presence of the preamplifier at the crossover (§1b). Under typical operating conditions some 12 - 14 dB must be inserted into the E-W arm output, and this is usually done immediately before the 4:1 splitter.

After combination in a 2:1 matcher, the signals pass through a transistorised preamplifier and into a receiver which is essentially the same as for the total-power case. The communications receivers are presently Eddystone 680X or 940 models, and it has been found that their frequency stability is inadequate, especially if the ambient temperature is liable to fluctuate. Receivers ## 2, 3, and 4 are therefore provided with crystal-controlled local oscillator power. The crystal may be selected for operation at 10.01, 10.02, 10.03, 10.04, and 10.05 Mc, and the selector switch simultaneously selects the appropriate filter at the crossover for the E-W arm. The filters for the N-S arm must be changed manually in the control trailer.

AGC is not applied in the phase-switching receivers. The gain and zero level stability of the receivers is excellent under normal operating conditions, and the disadvantages of AGC far outweigh the advantages for phase-switched operation. In an AGC system, the gain is a non-linear function of the total power received, which means that there is a diurnal variation of receiver gain as the beam is scanned across the Galactic Plane. Furthermore, the stronger sources, such as Cas A, Cyg A, Vir A, Tau A, etc., will cause gain reduction as they enter the beam. This makes analysis of the records extremely tedious, and causes great inconvenience in calibrating source transits at low galactic latitudes or transits of or near bright sources (see first edition). An AGC-less system with frequent verification of the calibration has been found to be very satisfactory, and is now regarded as standard for phase-switched receivers.

A bank of capacitors totalling 200 μF is available for connexion to the built-in integrating circuits of the phase-switched receivers, to provide any integration time up to 20 minutes. At most declinations of the beam, an integration time greater than 5 minutes may not be used without loss of resolution, and an integration time of 80 seconds has been found very suitable for weak source observations under good conditions.

A block diagram of the phase-switched receiver is given on the following page.


OUTPUT OF NORTH - SOUTH PHASING (RKA)
PATH COMPENSATING CABLE
CRYSTAL FILTER
TO K LINE HYBRID
Tr. PREAMP
6½V * REG.
NOISE GEN
TIMER
CABLE FROM EAST-WEST ARM
4:1 RF SPLITTER
COMPENSATING CABLE
HALF-WAVE SWITCH
2:1
TRANSISTOR PREAMP
9V BATT.
(2 of)
RF
CRYSTAL CONTROLLED L.O *
EDDYSTONE 680X *
EDDYSTONE AF AMP *
AUDIO MONITOR
AF
AF AMP
±300 VDC 6V HTRS *
SYNCHRONOUS DETECTOR
300 c/s SWITCH OSCILLATOR
± 300 VDC 6V HTRS *
DC AMP
INTEGRATING CAPACITORS
RECORDER
60c/s SID
SIDEREAL POWER AMPLIFIER *
DRAD SIDEREAL MAINS
R.A. CLOCK

Rx 2
10 MCT

c) Conversion of 180°-switching receiver to total-power.

Only two Dicke-switch arrangements are available for the 10 Mc system, and it is sometimes necessary to convert a 180°-switching receiver to total-power operation. This is readily achieved by taking the two inputs of the receiver to the output ports of a 2:1 matcher, or to the symmetrical ports of a hybrid ring circuit, and connecting the signal to be measured to the input port of the matcher, or to one of the asymmetrical ports of the hybrid ring. This arrangement is then precisely equivalent to a Dicke-switch, except that the loss of the 2:1 or hybrid ring is introduced. This is of course calibrated out if the receiver is calibrated by replacing the power to be measured with a standard noise generator, and calibrating through the 2:1 or hybrid, and will not cause loss of signal-to-noise if the signal is well above receiver noise. If the signal is comparable with receiver noise before the 2:1 or hybrid is introduced, this system does cause reduction of signal-to-noise in the receiver output, and an actual Dicke-switch is to be preferred. For most applications at 10 Mc this is however unimportant.

d) Aerospace receiver.

A total-power receiver built into a single chassis and provided with an automatic built-in calibration cycle is now available for 10 Mc. This is intended to replace the receiver using the GR-17 communications receiver for the routine riometer observations, and a full description is given in the Aerospace instruction manual. This receiver is of course suitable for any of the applications described under §2a.

§3. RECORDING AND TIME-KEEPING.

a) Evershed system.

Four Evershed recording milliammeters are available for connexion to any receiver with DC ouput at a few volts and a few kilohms impedance. The clock mechanisms of these recorders are driven by 60 c/s_{SID} generated in the main observatory building and carried to the 10 Mc control trailer by land-line. This sidereal rate power is amplified to $\approx$ 120 volts at the 10 Mc trailer. The Evershed charts are run at 6 inches/sidereal hour, so that the printed scale reads the passage of sidereal time directly.

The Evershed recording system is a simple pen galvanometer, and so the scale is slightly non-linear across the paper. This non-linearity is taken out by printing a non-linear scale on the chart paper, and this scale <u>must</u> be used for the reduction of observations. The non-linearity across the chart amounts to $\approx$ 10 per cent.

b) <u>Esterline-Angus system</u>

One single-track E)A recorder is available for 10 Mc work. It is a multi-range servo recorder with a linear scale, and can be used with any receiver. It is usually also driven by the 120 volt sidereal rate power. Time-keeping on the chart may be achieved by connected one of the two side pens to a sidereal rate pulse generator which is normally kept with receiver #5.

c) <u>Philips multipoint system.</u>

This is a 12-channel sequentially printing wheel type recorder and it is intended that all 10 Mc observations be recorded on this eventually. Details from John Galt.

d) <u>Time-keeping.</u>

The N-S arm of the 'T' climbs a hill to the south, and the effective zenith of the array is at $\delta = 52^{\circ}\ 06'$. Throughout these notes "zenith" will be taken to mean "effective zenith" unless the contrary is explicitly stated.

The E-W arm is also built on a slope, and to compensate for this it is skewed. The effective meridian of the instrument is at H.A. $09^{m}\ 36^{s}$. "Meridian" will be taken to mean "effective meridian" henceforth.

No clock power is generated at the site. The frequency stability of power from either of the on-site diesel generators is atrocious, and recorders, clocks, etc. should only be connected to on-site-generated power in case of power failure at D.R.A.O. Sidereal power generated at D.R.A.O. is sent by land-line to the trailer, and is used without amplification to drive a numerical rotary clock. This clock is run $9^{m}.6$ fast relative to "true" sidereal time, and keeps the R.A. setting of the 10 Mc beam centre. It is independent of the sidereal rate power amplifier in the trailer and will keep going during diesel shut-down periods. A solar clock is also run on power from D.R.A.O. and is set to Pacific Standard Time. Recorder charts are normally synchronised to the R.A. clock. As the recorder drives are supplied through the sidereal rate power amplifier, these stop during diesel shut-down and must be re-synchronised after the diesel is re-started.

§4. INSTRUMENTAL PARAMETERS

In this section are assembled some numerical parameters of the system which are occasionally relevant.

a) Dipole elements

MEAN SELF-IMPEDANCE ABOVE SCREEN	(386 ± 8) + (6 ± 4)j ohms
END-FIRE MUTUAL COUPLING IN "T"	(137 ± 17) + (220 ± 80)j ohms
BROADSIDE MUTUAL COUPLING IN "T"	(-1 ± 1) + (40 ± 6)j ohms
FIRST DIAGONAL COUPLING IN "T"	(11 ± 22) + (22 ± 7)j ohms

b) Wander leads

MATCHED LOSS BETWEEN DIPOLE AND OPEN-WIRE LINE	0.17 dB (theoretical)

c) North-South Arm

LOSS IN COAX BETWEEN BALUN AND RKA	5.9 dB approx
AVERAGE LOSS IN GRADING ATTENUATORS	7.6 dB
AVERAGE LOSS IN ROOKERY "A"	4.5 dB
OUTPUT TEMPERATURE OF NOISE AT RKA	1500 - 3000 $^{\circ}$K typically

d) East-West Arm

LOSS BETWEEN BALUN AND FIRST 3:1	2.1 dB approx
AVEREAGE LOSS IN GRADING ATTENUATORS	7.1 dB
LOSS IN OUTER LONG CABLES	6.9 dB
INPUT NOISE TEMP OF VALVE PREAMP	400 $^{\circ}$K
APPROXIMATE GAIN OF VALVE PREAMP	30 dB
LOSS IN CABLE FROM CENTRE TO TRAILER	5.7 dB
EXCESS LOSS OF 4:1 SPLITTER	0.3 dB

e) Receivers

TYPICAL LOSS OF CRYSTAL FILTER	3 dB
TYPICAL LOSS OF 180° SWITCH	3 dB
INTPUT NOISE TEMP OF TRANSISTOR P/A	600 $^{\circ}$K
TYPICAL GAIN OF TRANSISTOR PREAMPS	30 dB
INTERMEDIATE FREQUENCY	445 kc

f) White Lake Dipole

LOSS OF LONG COAXIAL CABLE (1966.3)	12.7 dB
AVERAGE NOISE TEMP AT TRAILER	35,000 $^{\circ}$K

TABLE I T-ANTENNA GRADING

Element	Attenuator	Relative Voltage
N-S 1	hybrid + 6.0 db	.501
ARM 2	hybrid + 6.0 db	.501
3	hybrid + 6.0 db	.501
4	hybrid + 6.0 db	.501
5	3.09 db	.990
6	3.18	.979
7	3.28	.968
8	3.35	.961
9	3.46	.949
10	3.63	.930
11	3.72	.921
12	4.01	.890
13	4.17	.874
14	4.42	.849
15	4.66	.826
16	4.92	.802
17	5.25	.772
18	5.56	.745
19	5.86	.719
20	6.40	.676
21	6.71	.652
22	7.10	.624
23	7.50	.596
24	7.96	.565
25	8.51	.530
26	9.11	.495
27	9.66	.464

Element	Attenuator	Relative Voltage
N-S 28	10.24 db	.435
ARM 29	10.64	.415
30	11.54	.374
31	12.21	.346
32	13.04	.315
33	13.84	.287
34	14.97	.252
35	15.40	.240
36	15.92	.226
37	17.30	.193
38	18.24	.173
39	19.29	.153
40	20.14	.139
41	21.48	.119
42	22.67	.104
43	24.01	.089
44	25.62	.074
45	26.87	.064
46	27.88	.057
47	29.02	.050
48	29.39	.048
E-W 0	hybrid	1.000
ARM ± 1	4.0 db	.891
± 2	7.4	.602
± 3	14.1	.279
± 4	24.6	.083

§6. PHASING NETWORKS (THEORY)

a) Hybrid rings.

The phasing networks used in the 10 Mc system are all based on the hybrid ring network, which is shown diagrammatically on the next sheet. The four ports are connected by electrical paths of length $\lambda/4$ between ports A/C, A/B and C/D, and of length $3\lambda/4$ between ports B/D. When all ports are terminated in the design impedance, A is isolated from D but not from B or C, and C is isolated from B, but not from A or D. The hybrid rings used in the phasing of the 10 Mc antenna are not constructed in real cable, because of the great size of such a device when λ = 30 metres, but are made up from compact wide-band balance-to-unbalance transformers as illustrated on the next sheet. The turns ratios and impedance characteristics of these wide-band transformers are chosen to give the four-port behaviour of a hybrid with a design impedance of 50 Ω.

The property of the hybrid ring which is of especial significance for the phasing of the 10 Mc 'T' is that it permits the combination of two voltages in two different relative phases, so that the two resultants are isolated from one another. This property has been used in the 10 Mc system to provide simultaneously a large number of non-interacting feeder systems for both the North-South and East-West antennae.

Consider a voltage V_1 applied at B, and a voltage V_2 applied at C. The voltage at A is made up of V_1 seen through a $\lambda/4$ path, added to V_2 also seen through a $\lambda/4$ path, and is therefore effectively $(V_1 + V_2)$, multiplied by a constant factor. The voltage at D, on the other hand, is made up of V_1 seen through a $3\lambda/4$ path, added to V_2 seen through a $\lambda/4$ path, and is effectively $(V_2 - V_1)$, multiplied by a constant. If the four ports are all matched, the constant is $j/2^{\frac{1}{2}}$. Also, the "input" ports and the "output" ports are isolated, so that V_1 is isolated from V_2 and $k.(V_1 + V_2)$ is isolated from $k.(V_2 - V_1)$.

b) "Nests".

A "nest" is a group of four hybrid rings connected together to permit the combination of four different voltages in four different relative phases, with the same isolation properties as found with a hybrid ring.

The electrical paths between the four input and four output ports of a "nest" are shown diagrammatically on the next sheet but one.

The connexions between the ports of a "nest", considering only the excess path lengths over the shortest path between ports, are also shown. A "nest" could be built directly in this way, but the mechanical construction would be cumbersome compared with one based on hybrid ring networks. In the hybrid ring nest, no junction of higher order than a T is required.

It has been found convenient to describe the path lengths between input and output ports of a nest in matrix terms. If the four input voltages are denoted by V_n (n = 0 to 3), and the four output voltages by V_m (m = 0 to 3), then we have

$$V_m = \Sigma N_{mn} V_n \qquad \text{over all } n$$

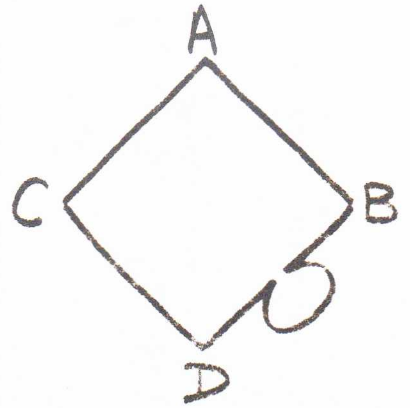
where the terms N_{mn} represent the losses and relative phase paths between the inputs n and the outputs m. To the first order, the losses will be neglected, so that the N_{mn} will be simply the factors $\exp(j\varphi_{mn})$ which describe the phase paths. The above equation expresses the rule for multiplication of a vector V_n by a matrix N_{mn} to derive a vector V_m, so that the terms N_{mn} may usefully be written as a matrix, which for a "nest" turns out to be

$$N = \tfrac{1}{2}\cdot\begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{pmatrix}$$

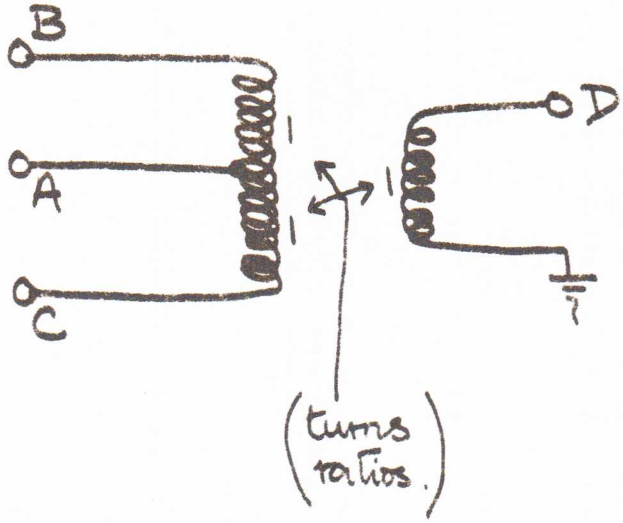
Consider the case where $V_n = 1$ for all n (equal in-phase voltages at all four input ports). Then we find $V_m = 2$ for m = 0, $V_m = 0$ for all other m. All the applied power emerges from a single output port, output '0'.

Suppose we apply voltages V_n = 1, j, -1, and -j, for n = 0,1,2,3. Then we find that $V_m = 0$ for m = 0,1,2, and $V_m = 2$ for m = 3. In the case where V_n = 1. -j, -1, j, only V_m for m = 1 is non-zero, and in the case where V_n = 1, -1, 1, -1, only V_m for m = 2 is non-zero. We find therefore that the effect of the nest on these four different input combinations is to bring all the power out at one port in each case, a different port for each combination. Now consider the situation where each V_n is the voltage induced by radiation arriving at an antenna. If the antennae are identical and individually directed at the zenith, m = 0 corresponds to the phasing of the four antennae to look at the zenith, m = 1 and m = 3 to phasing of the four antennae to zenith angles of + 30° and - 30°, and m = 2 to zenith angles of + 90° and - 90° (two horizontal beams). We have considered the antennae to be spaced $\lambda/2$ apart in this.

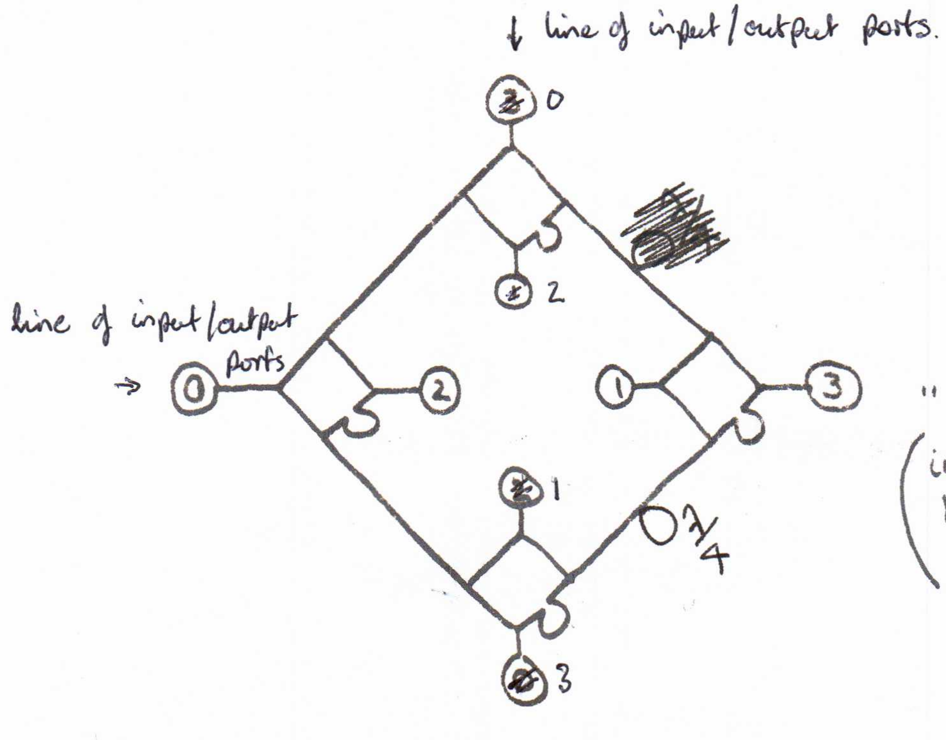
This is in essence the system which is used for the declination phasing of the East-West arm, where the four antennae $\lambda/2$ apart are the four East-West rows. In practice it is possible to switch in additional paths of lengths 0, $\lambda/8$, $\lambda/4$, and $3\lambda/8$ across the arm to provide beams directed to



HYBRID RING



WIDE-BAND TRANSFORMER HYBRID



"NEST" (in terms of hybrid rings.)

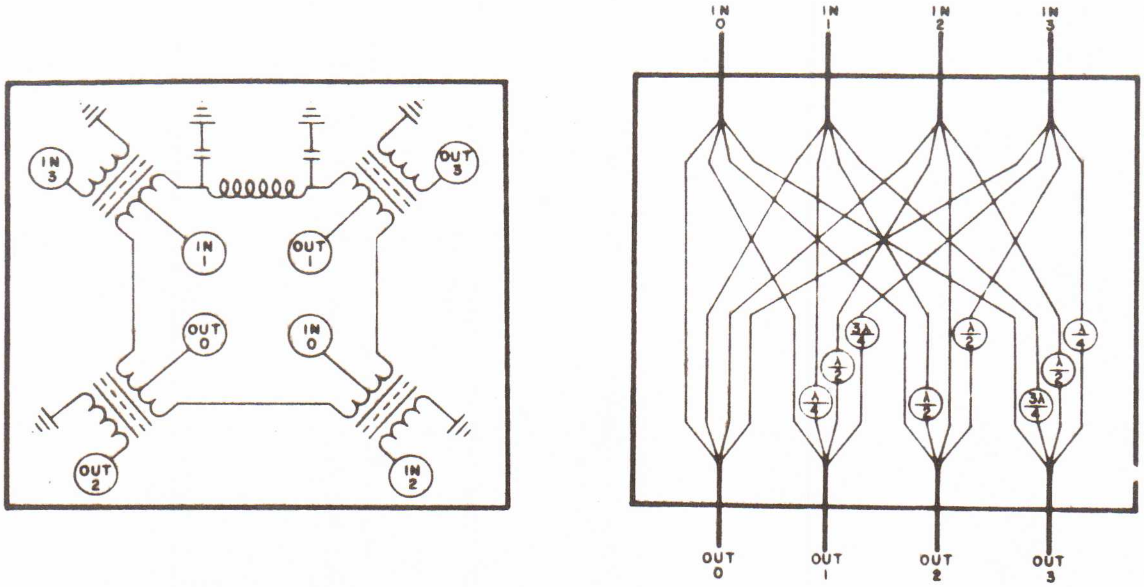


FIG. 9 NEST OF HYBRIDS

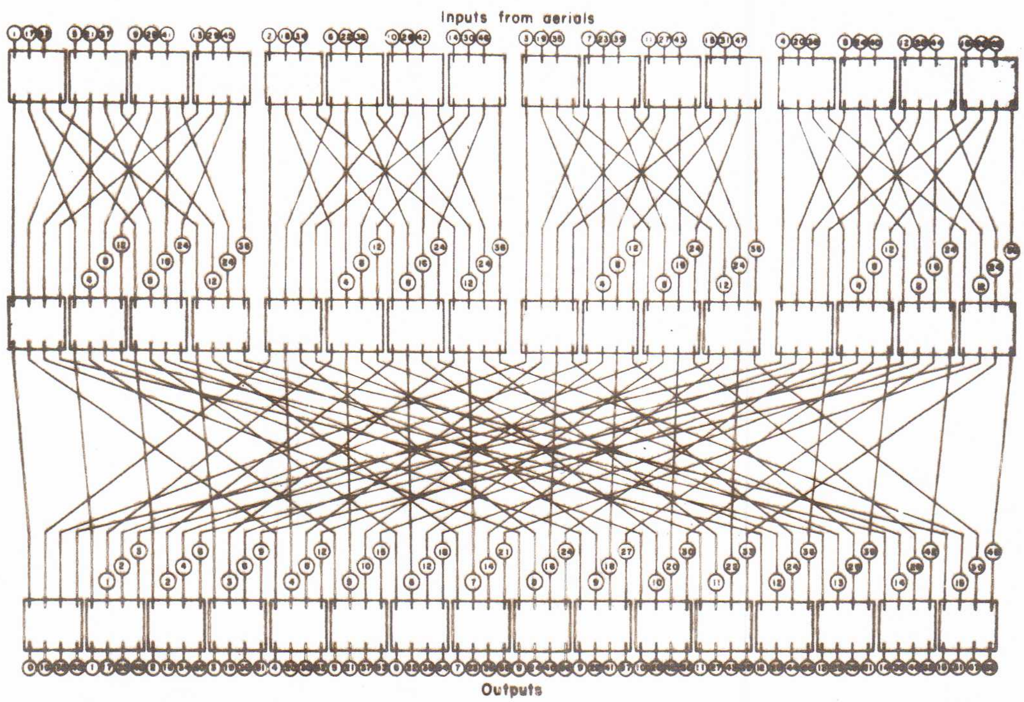


FIG. 10 THE ROOKERY

intermediate zenith angles. These beams provide extra forward gain in the directions of half the North-South phasing positions of the North-South arm than would be the case if a single nest were used.

c) "Rookeries"

A rookery is an extension of the nest concept in all directions, to produce 2^p phasings from $2^p - q$ antennas. A rookery with q = 0 will be called a "perfect rookery". The case p = 1 is a hybrid ring, p = 2 a nest. An example of p = 3 was used originally to phase the East-West arm in declination, but as there are only 4 independent East-West rows, this rookery had q = 4. Four of the eight input ports were replaced with dummy loads. It can readily be seen that this procedure approximates to correct phasing of the four antennae, but introduces "sidelobe" responses. At half the junctions in the rookery, the precise cancellation and addition of phases of coherent signals that is required for exact rookery operation does not take place, because some components of the coherent power are missing. Consider the case of a nest. Its response to (1, 1, 1, 1) is (4, 0, 0, 0), but its response to (1, 1, 0, 0) is (2, 1+j, 0, 1-j), in which we have thrown normalisation to the winds. A perfect rookery generates no sidelobe responses, and as q increases from zero, sidelobes increase, approaching the 3 dB level as q becomes close to 2^{p-1}. In a practical rookery for radio astronomy applications q should be kept less than 2^{p-2}.

"The rookery", or the North-South phasing device in the 10.03 Mc/s instrument, is a rookery with p = 6 and q = 16. Its sidelobe responses are typically 30 to 40 dB down more than 4° from the principal response, when it is correctly adjusted for loss and phase. In practice this level of performance is achieved unless gross errors are present, and this may be used as a test for errors in setting up.

Rookeries maintain all the properties of isolation of the antennae and of the output ports which are true for nests and hybrid rings. A typical "Christmas-tree" feeder system reflects all power incident on the antenna which does not have the phase graduation demanded by the feeder system phasing. A rookery accepts all the power incident upon the antenna and distributes it to isolated receiver ports without loss in the ideal case. The isolation properties are not affected by grading of the antenna, and it can be shown that the unbalance of powers at junctions in a rookery produced when the inputs are voltage graded corresponds to the amount of beam broadening expected from the grading. The isolation property reduced mutual interactions between the antenna array elements through the feeder system, and mutual couplings in a rookery-fed antenna should be close to those expected from geometry.

§6 OBSERVING PROCEDURES - PENCIL BEAM SYSTEM

a) Introduction.

Two distinct types of observing procedure have been applied in the 10.03 Mc/s project to date. These may be called "survey" and "multisource" procedures. Some general remarks apply to both systems; these are associated with the phase balancing of the two arms and the use of the pencil beam calibrator chassis.

b) Phase adjustment.

As indicated in section §1d, the relative phases of the two arms of the antenna must be maintained close to 0°. This relative phase depends upon the transfer phase of the preamplifier used at the crossover in the East-West arm feeding arrangement, on the path lengths through the cable feeder systems in both arms (which are a function of frequency) and on the crystal filter networks used. This last is a function of receiving channel as well as a function of frequency.

The phase adjustment must be performed every time the phasing of the antenna is changed, and because of the dependence on the path lengths through the crystal filters and the cables, whenever the frequency of observation is changed and whenever the receiver channel used for a given phasing is changed.

In practice the phase compensation required for a given antenna phasing, observing frequency, and receiver channel has been found to vary only very slowly with time. The principal cause of variation is thought to be the unequal expansion and contraction of the long coaxial cables feeding the North-South arm and the crossover region, also possibly the long term variation in transfer phase of the croosover preamplifier. It is possible to determine the phase compensation required for a given antenna phasing, observing frequency, and receiver channel approximately once a month, and to use tabulated values of the compensating cables when changing from one condition of the antenna and receivers to another. The tabulation of the compensating cables is made especially easy because a simple relationship exists between adjacent antenna phasings for a given observing frequency and receiver, within the same East-West beam.

The phase compensation is performed by inserting a small length of cable at either the output of the North-South phasing network or the RF splitter in the East-West arm feeder, as required for compensation. The cables for this purpose are provided in quanta of $\approx \lambda/64$ (48 cm. in fact), and are colloquially known as "PCBs" (Phasing Cable Bits). If at a given frequency and with a given frequency of observation, the n'th beam from the head of column of output ports of the North-South phasing device requires x PCB's for the phasing correction, the n-1 th such beam requires x+1 PCB's. Here a PCB length is counted positive if inserted in the North-South side. For example, if it is known that at 10.02 Mc/s, receiver §3 requires 2 PCB's for phase compensation in beam 9, inserted at the North-South side, then in beam 12 the phase compensation will be 1 PCB inserted at the East-West side.

The correct PCB for a given phasing of the antenna may be determined by sending a high-level noise signal to the crossover region of the antenna through the cable connecting the trailer to the hybrid in the K line of the East-West arm. Approximately 20,000,000°K of noise temperature may be generated at the trailer by drawing 10 mA on the "5.6K" noise generator and putting this into the pencil beam calibrator, whose preamplifier commonly has 30 dB of gain. When this is done, a large deflexion appears on the outputs of all receivers, in the "negative" sense for the phase-switched systems. The receiver gains may be reduced to bring this deflexion on-scale on the pen recorders, and the deflexion then maximised by the insertion of different PCB's on a trial-and-error basis. At very little extra complication, an extra $\lambda/4$ may be inserted in the East-West arm cable before the RF splitter, and the deflexion minimised. This provides a more sensitive phase adjustment. The PCB required to maximise the deflexion produced by the inserted noise signal is that which optimises the phase adjustment of the antenna (in the $\lambda/4$ - less method). A short receiver time-constant can be used during this procedure, and it has been found that a PCB determination for all phasings of the antenna at a given frequency for a given receiver can be made in a few minutes. Note that a CW signal is not suitable for this adjustment because of the differential phase characteristics of the crystal filter networks within their passband. The use of a noise signal assures the best mean phase adjustment possible with a given set of cables and filters.

The PCB determination should be performed approximately once a month, or whenever signal-to-noise seems low on the records.

c) <u>Pencil-beam calibrator</u>.

The pencil-beam calibrator consists of a transistorised preamplifier with ≈ 30 dB gain at 10.03 Mc/s, operated from a highly stable DC supply, and whose output is normally connected to a long cable leading into the asymmetrical port of the cable hybrid at the crossover in the K line of the East-West arm. All pencil-beam observations are usually calibrated by passing a noise signal of known r.m.s. level through this preamplifier and thereby producing a standard (negative) step on the phase-switched record. The step is negative because of the extra $\lambda/2$ path length introduced in one side of the feeder system as seen by the noise generator, in the asymmetrical arm of the cable hybrid. The height of the step can be adjusted as necessary by varying the stabilised plate current drawn by the noise generator, but it also depends on the gain of the preamp in the pencil beam calibrator. The gain of this preamp must therefore be monitored frequently. It has been found that with the existing circuitry it is sufficient to determine the gain once every week. The gain measurement has been performed by passing noise power directly into a total-power receiver, and then through the pencil-beam calibrator preamp in series with an accurately known attenuator which introduces a loss very nearly equal to that of the amplifier. The switched attenuator box built into the calibrator front panel has been used for this purpose. If several stepped noise levels are displayed on the pen-recorder of the total-power receiver under the two conditions, an accurate reduction of the preamplifier gain can be made by a regression procedure.

Note that the gain of the crossover preamplifier does not need to be measured because the calibration signal is introduced ahead of it in the East-West feeder system. The loss of the long cable connecting the K line hybrid to the trailer should be measured occasionally to correct for long-term variations which may affect the calibration height, but such variations have not been found to date.

d) <u>Loss equalisation.</u>

The noise which appears on the output of the pencil-beam system is galactic noise. At all points in the system the "signal" noise fluctuations exceed those generated by the receivers or by the feeder system, by no less than a factor of four. Under these conditions it is easy to demonstrate that optimum signal-to-noise is achieved on the correlated output when the noise inputs from the two arms of the antenna are approximately equal. Because a preamplifier has been introduced in the East-West feeder system, the noise output of the RF splitter is considerably higher than that of the North-South phasing device over most regions of the sky. To compensate for this, a coaxial attenuator is inserted into the East-West line immediately ahead of the splitter. The value of this attenuator ($\approx$ 10 dB for normal preamplifier gain at the crossover) may be determined by connecting a total-power receiver to output ports of the North-South phasing and of the splitter in turn (the 3dB loss of the typical phase-switch in the East-West side of the receivers cancels the 3 dB loss of the typical crystal filter in the North-South side) and adjusting the attenuator value for equal deflexions in the two connexions when a high-level noise signal is applied to the K line hybrid, as in PCB determination. The value of this attenuator is not critical to within a dB, as the total power received by each of the two arms of the antenna is anyway modulated by the orientation of the Galaxy in the reception pattern. Gross variations in the gain of the preamp at the crossover (which have not been observed) would need to be corrected for by adjustment of this attenuator, and this adjustment should be checked very occasionally. If the preamplifier at the crossover is changed, the equalising attenuator must of course be re-determined.

It is part of the normal operating procedure of the instrument to make these adjustments and general calibrations as frequently as necessary, whatever the form of operation in use, and it will be assumed below that these are carried out, in particular that the antenna is always correctly adjusted for equality of phase path from the two arms, at the time of any observation.

e) Survey observing procedure.

When the instrument is used for survey observations, determination of three quantities is essential, i) the zero level of the receiver, ii) the gain of the receiver, and iii) the prevailing condition of the ionosphere. The automatic calibration timer for the pencil-beam system provides facilities for regular determination of the receiver characteristics. Both one-hourly and two-hourly cycles are provided, each cycle consisting of a) reversal of the phase of the phase-sensitive detector relative to the 180° switch, providing a measurement of the zero level of the receiver, b) the injection of a preset noise signal through the pencil-beam calibrator, providing a measurement of the gain, and c) restoration of the normal phase of the switch and detector until the next cycle. In practice a restricted form of calibration has been found sufficient, which is to be preferred because it occupies less of the observing time of the instrument with calibration procedures. The zero level of the receivers may be determined by replacing both antenna cables with 50 ohm terminations and recording the output of the system. It is found that the zero stability of the phase-switching receivers is extremely good, and it is sufficient to check the zero levels in this way at the beginning and end of a survey run.It is extremely important to note that the level thus obtained does not correspond to the receiver output for zero correlated noise temperature received by the two antennae. The discrepancy arises because the pencil beam calibrator continuously injects a small amount of noise into the K line. The correction to the receiver zero level for the contribution of the pencil beam calibrator must be verified daily as it is liable to slow variations. This correction is found by replacing the pencil beam calibrator with a 50 ohm termination at the trailer end of the long cable to the K line while observing a region of the sky in which there is little variation of sky brightness.

Gain calibration may be carried out using the calibration timer with the phase-reversing microswitches disconnected, so that a preset negative step is applied once every cycle of the timer. The two-hourly cycle has been found to be sufficient, and at the beginning of a survey run the cycle should be adjusted with the knurled knob on the front panel of the timer chassis to ensure that the calibration periods will not interrupt expected source transits. The simplified form of calibration cycle has been used for almost all observations during 1965/66. The present (Eddystone + Cambridge phase-switch set) receivers are linear at least up to the brightness of Cass A and so a single calibration step suffices for gain calibration. Linearity may anyway be verified during the setting up of a run by introducing a stepped calibration with the timer over-ridden with the cut-out switch on the front panel.

The determination of ionospheric conditions is made by observing transits of easily detectable bright sources. Survey runs must be organised so that a bright source transits every few hours to serve as a scintillation and refraction indicator. Deep and fast scintillation are easy to detect on the bright sources, giving rise to "spiky" transits and mis-shapen traces. If the scintillation depth exceeds about 40 per cent, weak source observations become extremely unreliable and should be discarded. The detection of slow scintillation is more difficult. Strong source transits must be carefully examined for evidence of scintillation quasi-periods of the order of the time taken for a source transit in the beam. Gross errors may arise in the apparent fluxes of records obtained under such conditions.

Refraction may be regarded as taking two independent forms, although this is not strictly correct. East-West refraction is usually only apparent near sunrise and sunset ($\pm$ 90 minutes), and may displace source transit times by as much as 10 - 15 minutes, although 5 minutes is more common. Instances have however been found of refractions of up to 5 minutes of time close to 0^h P.S.T. These anomalous refractions must be watched for on the records. North-South refraction has two components, a virtually "steady" component of 31 $\sec^2\varphi$ minutes of arc southwards at angle φ from true zenith, arising from the gradient of electron density in the ionosphere with latitude, superimposed upon which there is a random component which may become as large as $\pm$ 90 minutes of arc. North-South refraction may only be determined by observing bright sources in adjacent phasings of the antenna and comparing the amplitudes in the two channels.

Determination of the ionospheric conditions is essential if observations taken with the instrument are to be useful, and it must be considered part of the setting-up procedure to ensure that sufficient bright sources are included in the run to enable this to be done.

Gain settings and optimum calibration heights, etc., are a function of the galactic parameters of the survey region, and the flux densities of sources expected to transit, etc., and can only be set up after a little experience has been obtained with the instrument. With the existing equipment, an audio gain of x3, with second detector current of 50 microamps has been most useful for survey runs, with a noise calibration of 2 or 3 mA of 50 ohm diode noise applied through a pencil-beam calibrator gain of 32.5 dB .

In setting up the zero level of the recorders, it is well to remember that the calibration steps in the coldest regions of the sky may produce deflexions well below the output deflexion of the system with 50 ohm terminations in both sides.

A short programme of setting-up for survey operations may be summarised as follows:

1. SELECT ANTENNA PHASINGS FOR SURVEY TO INCLUDE TRANSITS OF BRIGHT SOURCES APPROXIMATELY EVERY TWO HOURS, WITH ESPECIAL IMPORTANCE NEAR SUNRISE OR SUNSET.
2. CONNECT RECEIVER CHANNELS INTO THESE PHASINGS WITH CORRECT PHASE COMPENSATION BETWEEN THE ARMS OF THE ANTENNA.
3. CHECK LOSS EQUALISATION BETWEEN THE ARMS AND GAIN OF PENCIL BEAM CALIBRATOR PREAMP IF NECESSARY.
4. SELECT RECEIVER GAIN AND TIME CONSTANT WITH REFERNCE TO POSITION IN THE GALAXY OF THE SURVEY, EXPECTED TRANSITS OF BRIGHT SOURCES, AND INTERFERENCE CONDITIONS.
5. TERMINATE INPUT PORTS OF RECEIVERS WITH 50 OHM LOADS AND SET ZERO LEVEL OF RECEIVER OUTPUTS APPROXIMATELY 20 PER CENT FULL SCALE ON THE PEN RECORDER.
6. CONNECT RECEIVERS TO ANTENNA AND ESTABLISH SKY BRIGHTNESS LEVEL FOR A FEW MINUTES. WHEN THIS HAS BEEN DONE, DISCONNECT PENCIL BEAM CALIBRATOR FROM K LINE CABLE AND REPLACE WITH 50 OHM TERMINATION. RECORD NEW LEVEL FOR A FEW MINUTES. THIS MUST BE DONE WHILE OBSERVING A REGION OF SKY IN WHICH THE BRIGHTNESS IS NOT RAPIDLY CHANGING. WHEN THE STEP IS WELL-DETERMINED, RECONNECT PENCIL BEAM CALIBRATOR TO K LINE CABLE.
7. ADJUST TIMER CYCLE SETTING TO SPACE CALIBRATION STEPS BETWEEN EXPECTED SOURCE TRANSITS. WITH "LOAD" PORT OF TIMER CHASSIS TERMINATED IN 50 OHMS (DIODE NOISE GENERATOR DISCONNECTED FROM PENCIL BEAM CALIBRATOR) SET UP DESIRED CALIBRATION LEVEL ON MILLIAMMETER WITH OVER-RIDE SWITCH THROWN. SET SWITCH TO AUTOMATIC POSITION AND RECONNECT NOISE GENERATOR TO LOAD PORT.
8. SURVEY OBSERVATIONS ARE UNDER WAY. DATE CHART AND LABEL CHANNELS, ETC.
9. AT END OF RUN, CHECK STABILITY OF CALIBRATION HEIGHT BY THROWING OVER-RIDE SWITCH WITH NOISE GENERATOR DISCONNECTED FROM LOAD PORT ON TIMER, AND REPEAT STEPS 5 AND 6. NOTE MEAN CALIBRATION HEIGHT ON RECORD, OR INDICATE DRIFT IF ANY.
10. CHECK IONOSPHERIC CONDITIONS AND APPLY FEEDBACK TO NEXT SURVEY !

f) <u>Multisource observing procedure</u>.

This is basically the same as that for survey operation except that a) the zero level is not usually determined or kept on scale, and b) the automatic timer cycle is not employed. The object of multisource operation is to utilise periods of exceptionally favourable ionospheric conditions for observation of as many transits of discrete sources as possible. Multisource observations will usually employ a higher gain setting of the receivers and consist of a set of drift curves at declinations chosen to provide a number of transits of interesting sources at similar times. The runs will provide a determination of the level of background radiation before the transit of the earliest source and after the transit of the latest source sufficient to define the levels against which the sources are observed, but no more. The zero level is not of interest as multisource runs are usually too short to be of value for the galactic survey. A calibration is applied to all receivers immediately before or immediately after the run, or both if it is a particularly extended run. The receivers will of course be connected to the antenna phasings appropriate for the run with the correct phase compensation while the calibration is carried out. The calibration is initiated by using the over-ride switch on the calibration timer, whose timing motors are switched off. The height of the calibration is selected to correspond to the mean deflexion on the record to be produced by the source transits expected. Receiver gain should generally be set as high as possible, taking into consideration the time-constant in use.

Multisource observations, as with survey observations, should be arranged to contain the occasional bright source which may be used to monitor scintillation and refraction. Attempted observations of weak sources without knowledge of prevailing scintillation and refraction conditions are of little value.

A scheme for multisource observations may be summarised as follows:

1. DECIDE TO PERFORM MULTISOURCE OBSERVATIONS FROM KNOWLEDGE OF TREND OF SCINTILLATION CONDITIONS, ETC.
2. SELECT IN ADVANCE GROUPS OF SOURCES FOR OBSERVATION, CHOSEN TO INCLUDE SCINTILLATION AND REFRACTION INDICATORS, AND PROGRAMME CALIBRATION TIMES.
3. PHASE ANTENNA FOR FIRST SET OF OBSERVATIONS AND MAKE PCB COMPENSATIONS, ETC. CHECK PENCIL BEAM CALIBRATOR GAIN, LOSS EQUALISATION, IF NECESSARY.
4. REFER TO BACKGROUND MAP (178 MC/S TURTLE and BALDWIN WILL DO) TO ESTABLISH APPROXIMATE TREND OF CHANGES IN SKY BRIGHTNESS DURING THE RUN, SELECT HIGHEST GAIN POSSIBLE FOR GIVEN NOISE ON RECORD AND EXPECTED BACKGROUND VARIATION, AND ADJUST RECORDER ZERO SET LEVERS TO POSITION RECORDER CHANNELS APPROPRIATELY.
5. APPLY CALIBRATION THROUGH PENCIL BEAM CALIBRATOR, AVOIDING CALIBRATION ON RAPIDLY VARYING SKY BACKGROUND.

6. SWITCH OFF CALIBRATION TIMER AND NOISE DIODE POWER SUPPLY.

The success of multisource observing depends mostly on choosing the correct occasion for applying it, and on careful advance programming of the observations. Selection of the calibration time is of especial importance, as only one calibration is applied to a multisource run in general. Calibrations must avoid rapidly changing background levels, otherwise the reduction of the record will be reduced in accuracy. This is extremely problematical near the galactic plane or the region of the galactic spur, and needs very careful consideration and execution. Calibration should also be applied <u>before</u> source transits near sunrise and sunset, because of the well-known phenomena of enhanced sunrise and sunset interference. This is especially important near sunrise, and it is vital to obtain a secure precalibration if a source transit is to be successfully observed near this time. Watch the colour of Apex - if it's orange - calibrate !

g) <u>Timing of observations.</u>

The timing of observations at the 10.03 Mc/s site is determined by that at D.R.A.O. Any failure in the D.R.A.O. timekeeping also affects that at the trailer, and power failures. etc. must be corrected for. It is advisable to check the timing before observations begin every day.

1. INSPECT CHARTS FOR EVIDENCE OF RECORDER TIME FAILURE. THIS WILL APPEAR IF DIESEL HAS SHUT DOWN OR IF TROUBLE DEVELOPS WITH RECORDER DRIVES.

2. IF IN DAYTIME, RAISE D.R.A.O. ON INTERCOM AND ASK FOR TIME CHECK ON SIDEREAL AND P.S.T. RATES FROM CONTROL ROOM. THIS CAN BE GIVEN OVER THE TELEPHONE BETWEEN CONTROL ROOM AND TRAILER, IF DIAL TONE IS REMOVED BY DIALLING DIGIT 4.

3. IF AT NIGHT, RAISE D,R,A.O. BY TELEPHONE. TO DO THIS, DIAL 497-5321 AND <u>IMMEDIATELY</u> REPLACE RECEIVER. WHEN BELL RINGS, WAIT UNTIL D.R.A.O. ANSWER AND THEN LIFT RECEIVER. BEMUSED ASTRONOMER WILL NOW BE ON OTHER LINE. D.R.A.O. RECEIVER CAN BE REPLACED WHILE PERSON AT OTHER END GOES TO CONTROL ROOM TELEPHONE.

4. SET RIGHT ASCENSION CLOCK 9 MINUTES AND 36 SECONDS AHEAD OF D.R.A.O. SIDEREAL CLOCK.

5. SET RECORDER TIME TO RIGHT ASCENSION CLOCK.

§7 REDUCTION OF RECORDS

This is a notoriously personal part of any set of observations and the purpose of this section is merely to make some general indications of how reductions have been done in the past. In the case of the riometer observations there is a strong argument for continuity of method.

a) Riometer

The charts should be labelled with the "sidereal date" at each 0^h of right ascension. Calibration cycles should be scaled off and plotted to give determinations of the receiver law, and adjacent calibrations compared for receiver drifts. If the drift between calibrations is less than $\approx$ 3 or 4 per cent per day, which it should be in normal operation, the mean calibration may be used for the reduction of the intervening data. If the drift is excessive, the variation should be assumed linear, and only those hours for which the interpolated calibration would differ by less than 5 per cent from one or other of the actual calibrations should be reduced.

The record is read every hour on the hour. The deflexion on the chart is recorded as accurately as possible on the duplicated sheets of riometer scalings for that month, at each hour. If there is low-level interference present on the record but the "true" level may be estimated to within a few per cent, the record is scaled but the entry is made on the sheets in red instead of black. Hours which are lost due to heavy interference are marked with an X, and hours lost through equipment failure, diesel shut-down, use of the total-power channel for another purpose, etc., are marked "OFF". If an absorption event is noticeable on the record the level may be recorded with the superfix 'A', for later comparison with 22 Mc/s riometer data.

The calibration is then used to produce a second sheet marked "riometer level". This perhaps slightly pedantic method of reduction is preferred because it provides a means of checking the analysis at a later date, in that both the measured chart deflexion and the assumed calibration curve are to hand.

Future generations of 10 Mc/s riometer operators may or may not wish to use the 1965/66 estimates of unabsorbed level. If no important changes have been made to the antenna, the feeder system, beam '0' of the North-South phasing, or to the noise diode generator, the 1965/66 unabsorbed level should still be relevant. It is thought to be fairly well defined between right ascensions 22^h and 17^h (be prepared however for future communications from A.H.B.).

Mrs. Baird has prepared tables for converting un-meter-corrected riometer levels into true absorption factors at the zenith assuming the correctness of the 1965/66 unabsorbed level estimates.

The correction of the milliammeter in noise diode power supply §1 has been made relative to the portable gold-plated superstandard PVB 300 and should be accurate to ± 0.5 per cent r.m.s. The milliammeter is found to be non-linear near the bottom of the range, and also not to have a true/apparent slope of unity. The calibration curve is given elsewhere in this volume. It is not known whether or not this calibration is a function of time.

For hysterical reasons, the calendar plots of riometer level made during 1965/66 are expressed in apparent milliamps of diode noise current. If direct comparison between future riometer levels and those obtained in 1965/66 is sought this bizarre procedure should still be followed.

Once an unabsorbed level has been assumed, determined, or borrowed from earlier observations, the absorption factors (defined as the factor by which the observed riometer level must be multiplied to yield the unabsorbed level) may be found for any hour for which riometer data exists. For those hours which are lost due to interference or equipment outage, mean information has been substituted on the premise that mean absorption data is better than none. The mean used has been derived from the calendar plots by fitting a line through these at all dates, placing lower weight on levels suspected of containing low-level interference. The mean derived in this way is effectively a running mean over the nearest three or four days' observations. No evidence has been found that the mean levels are internally inconsistent, and this procedure is possibly the only one which enables missing data to be approximated.

The absorption factors derived in this manner apply to the zenith only, as the fan beam of the riometer is narrow in declination. This has some advantages over the absorption factor that might be derived from a broader beam which averages over the sky however, and permits the absorption at any desired angle from the zenith to be found if a model of the ionosphere is assumed. At night the absorption should be mainly F-layer absorption and the correction for zenith angle has been made assuming a layer of constant thickness and density at a height of 350 km. above the antenna. The correction is then a geometrical correction for absorbing path length. Typical night-time absorption factors in the Penticton winter at 10.03 Mc/s are $\approx$ 1.05 to 1.10, and the correction to high zenith angles is sensibly independent of the exact model assumed for the ionosphere, down to $\approx 40^{\circ}$ zenith angle. Daytime absorption factors are more typically $\approx$ 1.50 to 2.00, and this is no longer true. Further, daytime absorption arises substantially in the D region of the ionosphere, which is somewhat lower than the F region. No definite procedure for the treatment of daytime absorption has yet been established. Fragmentary calculations on night-time zenith angle corrections have been donated to John Galt by A.H.B.

b) Pencil Beam - Source Transit.

The method of reduction of a source transit is the same for "survey" and for "multisource" observations. It consists of fitting the known polar diagram of the antenna to the record of the transit, adjusting both amplitude of the deflexion and transit time to obtain optimum fit. In the presence of scintillation with depths not exceeding about 50 per cent, the criterion for fitting the polar diagram is that equal areas of the record shall lie above and below the fitted curve, When scintillation becomes extreme, some of the radiation from the source is scattered outside the beam and this criterion will no longer be valid.

The method used by A.H.B. for fitting the polar diagram is as follows :

1. OBTAIN POSITIONS OF HALF-POWER POINTS AND ZEROES OF EAST-WEST POLAR DIAGRAM IN MINUTES BEFORE AND AFTER MAXIMUM. MARK THESE ON THE RECORD, CENTREING ON APPARENT TIME OF MAXIMUM DEFLEXION.
2. MARK LIGHTLY ON THE RECORD IN PENCIL THE MEAN LEVEL AT THE TIMES OF POLAR DIAGRAM ZEROES, AND SKETCH IN BEST ESTIMATE OF BACKGROUND LEVEL UNDER THE SOURCE, TAKING INTO ACCOUNT TRENDS OF PRECEDING AND FOLLOWING BACKGROUND.
3. MAKE THE BEST FIT TO THE RECORD AT THE TIMES OF MAXIMUM- AND HALF-MAXIMUM DEFLEXION, GIVING ALL THREE TIMES EQUAL WEIGHT. SKETCH IN SMOOTH CURVE TO SHOW POLAR DIAGRAM.
4. IF FIT LOOKS ASYMMETRICAL, DISPLACE THE TIME OF MAXIMUM DEFLEXION AND TRY AGAIN, STARTING FROM STEP 2.
5. REPEAT ADJUSTMENT OF TRANSIT TIME AND OF MAXIMUM DEFLEXION TO OBTAIN EQUAL AREA FIT.
6. RECORD:
   A) SIDEREAL DATE
   B) AMPLITUDE OF PEAK DEFLEXION AS A RATIO TO OFF-SOURCE NOISE
   C) BEAM NUMBER OF TRANSIT
   D) SCINTILLATION DEPTH
   E) AMPLITUDE OF PEAK DEFLEXION IN DIODE MA, SCALED FROM NEAREST RECEIVER CALIBRATION, OR MEAN OF PRECEDING AND FOLLOWING CALIBRATIONS, AS APPROPRIATE.
   F) PENCIL BEAM CALIBRATOR GAIN AT TIME OF OBSERVATION.
   G) RIOMETER ABSORPTION CORRECTION AT TIME OF OBSERVATION.

The observed amplitude of the deflexion is corrected to a standard gain of the pencil beam calibrator, and to 0 dB of ionsopheric absorption. It is then divided by the gain of the antenna in the direction of the source, allowing for North-South refraction, and converted to a flux through the calibration known for each phasing of the antenna in terms of flux units per diode milliamp.

c) New Sources - N.P.C. list

The 1965/66 observations have produced a number of sources not identifiable with any in catalogues prepared at higher frequencies. The search for these on survey records is an important part of the analysis, and any run showing small scintillation depth should be carefully scrutinised for uncatalogued sources. Transparent overlays showing the polar diagram of the antenna at different declinations, on the time-scale of the recorder chart drive, are a very useful accessory when making a source search. The determination of refraction is of course extremely important when a "new" source is found, and possible refraction effects should be considered when attempting to make an identification in the 4C catalogue. New sources should be searched for in 4C, in the Parkes catalogue, the NRAO catalogue, the 38 Mc/s (Cambridge) catalogue, and also in Abell's catalogue of rich clusters of galaxies. If both survey and multisource observations are being made, it is important to include new sources in the multisource programme, and much can be gained by inspecting every survey run of suitable quality for new sources and immediately including these in the multisource observing. As only about one night in four is suitable for observations of extremely weak sources, the keeping of a curiosity list enables best use to be made of the observing time on the instrument.

d) Pencil beam - Background and Extended Sources.

Sources whose transits appear broader than the antenna beam need special treatment. Observations of peak deflexions in adjacent phasings of the antenna allow North-South angular diameters to be derived, and most of the the extended sources observed with the instrument may be assumed to have Gaussian profiles in each co-ordinate. The procedure for deriving fluxes is similar to that for point sources except that the integrated flux under the transit curve is required. This may readily be normalised to the calibration curve for point sources if a Gaussian profile is assumed for the source, and all that is necessary is to determine the half-width of the transit profile (or the declination profile) and the peak deflexion, to make an adequate correction. In the case of a source such as M31, or of an absorption feature such as the Rosette Nebula, the feature may be treated as a background feature and converted into brightness temperature contours in the reduction. The distinction between a point source type of analysis in which the flux scale is used directly and an extended source analysis is largely one of convenience only.

The procedure for analysis of the galactic background surveys is extremely straightforward. The record is scaled every semi-half power beam width, including calibration steps. Each calibration step is subtracted from the interpolated background at the time of calibration (a linear interpolation suffices for nearly all circumstances) and a mean calibration is derived for the run. The calibration heights are inspected for systematic drift, and if such is found, the record deflexions are reduced with reference to the closest calibration.

run showing small scintillation depth should be carefully scrutinised for uncatalogued sources. Transparent overlays showing the polar diagram of the antenna at different declinations, on the time-scale of the recorder chart drive, are a useful accessory when making a source search. The determination of refraction is extremely important when a "new" source is suspected, and refraction effects must be considered when attempting to find an identification for a source. The catalogues which have been used for finding sources are 4C, the Parkes catalogue for declinations 0° to $+20^{\circ}$, the N.R.A.O. catalogue, and the 38 Mc/s (Cambridge) catalogue. A significantly high identification rate has also been found in Abell's catalogue of rich clusters of galaxies.

e) Pencil beam - extended sources.

Sources whose transits are broader than the East-West polar diagram, or which appear broadened in declination from observations of transits in adjacent phasings of the antenna, should be catalogued separately from discrete (un-broadened) sources. The flux scale established for point sources may be applied to broad sources if a correction is made for the effects of beam broadening. The peak deflexion of a source may be corrected to an integrated deflexion if it is assumed that the source shows a Gaussian profile (which need not be circularly symmetric) using observations of apparent half-width in the two principal planes only. The relation $\theta_a^2 = \theta_b^2 + \theta_s^2$ where $\theta_{a,b,s}$ are the angular half-widths of the apparent deflexion, the beam, and the source, may be used to derive the correction, making the assumption that all profiles are Gaussian. The ratio of θ_a to θ_b corrects the flux density, and θ_s is the angular diameter of the source. For sources whose angular diameters exceed about $1^{\circ}.5$, θ_a is quite easily measurable, and θ_s can be derived from the experimental data. For sources whose angular diameters are less than this, θ_a is harder to measure and it may be necessary to assume a value for θ_s in order to correct the flux density.

f) Background records.

Pencil-beam background records are scaled every semi-half-power beamwidth, including calibration steps. Each calibration step is subtracted from the interpolated background at the time of calibration (a linear interpolation suffices in most cases) and the step heights are inspected throughout the run. If there is sign of systematic drift of the receiver gain, which is unusual, record deflexions are reduced with reference to the nearest calibration. If not, the mean calibration is derived by averaging all the individual steps. The mean deviation is also derived, multiplied by 5/4, and divided by the square root of (N-1), where N is the total number of calibration steps scaled. Any calibrations differing by more than twice the resultant number from the mean calibration height are discarded and the procedure repeated.

The deflexion of the recorder when the receiver is terminated in 50 ohm loads at each side is subtracted from all deflexions, and the correction for the pencil beam calibrator is added. Each number is then scaled by the mean calibration height. This provides a scaling of the output of the system in diode milliamps at each semi-half-power beamwidth position. In the absence of ionospheric absorption and pencil beam calibrator drift, these numbers will repeat. Correction for absorption, calibrator gain, etc. then proceeds as for point source observations.

The deflexion is proportional to the square root of the correlated product of the two antenna temperatures. The relation of this quantity to the sky brightness temperature is not very simple, and an empirical scale may be set up by observing the region of sky near the area of minimum brightness temperature, and extrapolating the A.H.B. scaled aerials (Cambridge) experiments to derive the scale. Alternatively, the scale may be established from the known antenna parameters, losses, etc. The conversion is a function of declination because the beamshape changes as the antenna is phased to low declinations. It is also a function of declination in much the same way as the absolute gain of the antenna for source observations.

9) Interferometer reductions.

No particular procedure has been established for the reduction of either three-element or two-element interferometer records, which have so far only amounted to a fraction of a per cent of total reductions.

§8 STORAGE AND NOTATION OF RECORDS FROM PHASE II OBSERVATIONS

All records from Phase II observations are stored in cardboard boxes displaying at one end the numbers of the two channels on the record, and the "solar" dates on which the record starts and ends. "Ticks" appearing on the boxes merely denote completion of various stages of analysis, and do not refer to observing conditions, etc. Any complete charts bearing no usable information are labelled "Nothing on this chart". No charts from Phase II have been discarded.

a) Dating of records

Records are usually dated with conventional dates stamped onto channels 1 and 3 with a rubber date stamp. For the purpose of reference however a system has been used which has become known as "sidereal date". In this system a day is considered to commence when 0^h of R.A. is on the meridian of the instrument, and the day is numbered as the solar date on which the 0^h transit occurs. These "sidereal dates" will be written against 0^h markers on the charts. On those charts edited by W.B., the midnight time is also indicated by a line and the two "solar" dates, preceding and following the line. All tabulationsof source observations, survey runs, riometer levels, etc. in Phase II literature use the "sidereal" dating system.

b) Index of source transits

This file was prepared by W.B. and lists source transits by beam number, channel number, and sidereal date during the period of optimum observing from late December 1965 until late March 1966. Observations falling outside this period are not listed. As some observations of sources were made outside this period, the index is therefore incomplete. It will be especially incomplete for ttransits of sources at R.A.'s between 17^h and 23^h. In the index a tick indicates that a bump appears on the records at the time of source transit, or at a time plausibly different from the true transit time allowing for E-W refraction, and a cross indicates no apparent deflexion at transit. Indication is made of the presence of interference or of a transit being obliterated by a cycle of the automatic calibration system.

Each run in a given beam number is tabulated in a column headed with the dates and times of starting and ending. For every beam number a "finding list" was prepared indicating expected transits, and these lists are attached on loose slips which may be overlaid on the appropriate pages of the index. In each column the times of sunrise and sunset are indicated, referred to the R.A. on the meridian at these times.

It should be borne in mind that the assessment of source detection was done by "unskilled labour". It is sometimes over-optimistic !

§9 OBSERVATIONS TO DATE

This section will give a brief account of the observations which have been made in the period October 1965 - July 1966, and will suggest a number of promising lines of future work with the 10.03 Mc/s instrument.

a) Riometer.

Riometer records are complete from October onwards except for a number of diesel generator outages. Loss of information due to interference became very severe from April 1966 onwards, but there is sufficient data to enable mean absorption to be determined over most of the observing period with tolerable accuracy. No attempt has yet been made to analyse the "difficult" times between 17^h R.A. and 22^h R.A. for the unabsorbed level. These hours transit in summer night-time and the unabsorbed level is probably not seen at any time. It is most noticeable that the maximum level seen for these hours is very poorly defined, whereas the maximum level for almost all other hours is well-defined. Identity between the maximum observed level, less average noise, and the unabsorbed level has been assumed in 10.03 Mc/s riometer reductions to date. The general results for pre-dawn absorption at 10.03 Mc/s using this criterion are not inconsistent with those of the 22 Mc/s riometer, although it is presently too early for detailed comparisons.

Virtually all point source observations have been obtained at night-time, and the typical absorption correction at the zenith which has been applied is of order 1.05 to 1.10. In this case the correction for zenith angle is not very sensitive to the model assumed for the tionosphere.

In May 1966 a second riometer channel was begun, using the North-South arm beam '17' in the total-power mode. The purpose of this channel is to monitor the zenith correction in daytime and night-time, relative to beam '0', and thus to check the correction which has been made for night-time observations and to help in the derivation of a correction for daytime records.

Also in May 1966, the total power observations were transferred to receivers using crystal-controlled local oscillators, to protect against the large temperature changes which take place in the trailer in summertime. The ambient temperature can rise to well over 90° in summer daytime within the trailer, whereas in winter it is rarely above 70°. The gain stability of the receivers with crystal oscillators against temperature variation is extremely good.

b) Absolute Fluxes of Cass A and Cygnus A

The small 10.05 Mc/s interferometer at the D.R.A.O. was used for observations of Cass and Cygnus during November 1965. These observations were taken with the two elements phase-switched against one another ; AGC was not applied in the recievers, which werenot observed to show appreciable gain change between daily calibrations. The receiver was calibrated by injecting noise power from the Aerospace "A" generator after splitting in an ANZAC wide-band hybrid whose loss was known. The temperature scale of the Aerospace noise generator at 10 Mc/s should be good to 0.1 dB.

Scintillation-free fringes were frequently obtained for Cass A, and on a lesser number of occasions for Cygnus A. The observations were taken with the two arrays phased to the zenith ; Cygnus fringes were more frequently obliterated by sunset interference than were Cass fringes. Four transits of Cygnus were good enough to be scaled however, and so were eleven transits of Cass. The acceptance criterion was quite stringent - complete absence of interference and scintillation depths of less than twenty-five per cent were required.

Observations were corrected for ionospheric absorption using the corrections derived from the 10.03 Mc/s riometer. The corrections to the flux of Cygnus are somewhat uncertain due to the difficulty of estimating the unabsorbed level on the riometer output for 20^h R.A. After correction for the ionosphere, the deflexions at transit for each source were averaged. The standard deviation of the mean was derived in each case, and transits showing deviations greater than twice the standard deviation were rejected. This criterion eliminated four transits of Cass and none of Cygnus. The Cass transits then repeated to within 2 per cent, and those of Cygnus to within 20 per cent. The uncertainty in the flux of Cygnus is therefore made up primarily from the non-repetition of the records.

Correction was made for the confusion of the two sources, using their measured positions at 178 Mc/s.

Cable losses were carefully measured by taking a noise generator out to the arrays and injecting noise into the long cables bringing the signal to the observatory. Losses in the baluns and in the short cables from the dipoles to the junction boxes were measured by bringing all four such cables into the laboratory and measuring their losses in pairs with the balanced sides of the baluns joined.

An attempt to measure the mutual coupling between the dipoles showed that this effect was small enough to be neglected for the present purpose.

The gain of the antenna was evaluated from theory. It was assumed that the dipoles have the radiation patterns of ideal half-waves, and also that the reflecting screen was perfect. From the measurements on reflecting screens performed by A.H.B. and also by Bryan Andrew at Cambridge, the power loss in the screens used here should be less than 1 per cent. The assumption that the screens are effectively infinite may be dubious, but a) the ground itself will be a tolerably good reflector at 10 Mc/s ($\lesssim$ 6 - 8 per cent power loss), and b) the largest currents in the ground screen will flow immediately under the dipoles. The effect of the finiteness of the screen on the beamshape of the antenna is probably very slight, and altogether it seems probable that the errors introduced by the screen are small compared with those due to wrongly corrected ionospheric absorption, which must be estimated as high as 5 per cent.

The gain of the array subject to these assumptions was computed on the MATS computer in Ottawa, programme ALBRIDLE written by Carman Costain. The computation is based on the general expression for the radiation pattern of each array in altazimuth co-ordinates, derived independently by A.H.B. and C.H.C., to be :

$$G(\alpha,\varphi) = \frac{2\cos^2(\frac{1}{2}\pi\cos\varphi\cos\alpha)\,\sin^2(\pi\sin\alpha/4)\,\cos^2(\frac{1}{2}\pi\cos\alpha\sin\varphi)}{(1-\cos^2\varphi\cos^2\alpha)} \times 6.029$$

This expression was integrated in $\frac{1}{2}^{\circ}$ strips to obtain the gain of the array. The same programme was used to compute the gain of a half-wave dipole in free space, and achieved the accepted result within $\frac{1}{2}$ per cent.

The derived fluxes for Cass A and Cyg A were 28,000 $\pm$ 2800 f.u. and 13,400 $\pm$ 3400 f.u. respectively.

c) Point Sources.

166 point sources were observed in the "survey" and "multisource" programmes together. Approximately 75 per cent of the usable transits came from multisource observations. The results of this programme have been distributed around the observatory in the form of two tables of fluxes, Table 1 being observations which have been subjected to the test of repetition, and Table 2 being those which have only been made on one occasion and which are therefore fundamentally insecure.

The method of reducing the records is described under "Reduction of Records". The calibration was determined by extrapolation of the spectra of 3C 33, 3C 192, 3C 244.1, 3C 300, 3C 310, 3C 348, 3C 353, 3C 452 to 10.03 Mc/s, and fitting the observations to the predicted fluxes for these sources, as well as to the measured fluxes of Cass A and Cyg A. The fit was done for both the gain near the zenith and for the variation of gain with zenith angle.

The calibration sources were selected as sources of low brightness temperature, as far as possible elliptical galaxies with no indication of core-halo radio structure. No sources identified with stellar objects were admitted, and only sources with well-defined spectra at the higher frequencies were considered. A further requirement was good quality of the observations at 10.03 Mc/s and freedom from confusion at this frequency. The sources 3C 98 and 3C 20 would have served as calibration sources but for this last requirement. 3C 33 has close positional agreement with an Abell cluster, but no suggested core-halo structure. It is a well-known double source with two components centred on an elliptical galaxy, and its inclusion in the list is thought to be justifiable. There is no evidence that the source exhibits a steep low-frequency spectrum in common with many other sources near or in Abell clusters.

The salient features of the resulting list of flux densities are as follows

a) all sources with flat spectra at 10 Mc/s lie at low galactic latitudes, or are identified with sources having small angular diameters,

b) quasars have no general low-frequency behaviour of their spectra. Several quasars having low-frequency cutoffs not hitherto documented were observed, 3C 216 and 3C 380 showing decreasing fluxes below 20 Mc/s.

c) all but one of those sources having excessive fluxes at 10 Mc/s may be identified with clusters of galaxies, or sources in clusters of galaxies. The exception is a blue stellar object, and the observational material for it is very confused. It is quite likely that the excess flux for this source is spurious. The 22 Mc/s and 10 Mc/s D.R.A.O. data seem to be in disagreement with that at 26.3 and 38 Mc/s.

d) many of the sources with low frequency excesses show broadening at 22 Mc/s and/or small scintillation depths relative to other nearby sources at 22 Mc/s and 10 Mc/s.

e) a significantly high proportion (1 in 2) of sources not previously catalogued but observed at 10.03 Mc/s may be identified with Abell clusters, the coincidence rate for random source positions being 1 in 5.

f) The distribution of spectral indices at 10 Mc/s is much broader than that at 178 Mc/s, but is centred on a similar mean spectral index of ≈ 0.8.

g) the distribution of spectral indices for sources in Abell clusters is significantly different from that of all other sources, being centred on a mean index of $\approx 1.3 - 1.2$.

h) a correlation may exist between the likelihood that a source shows a low-frequency excess and its higher-frequency spectral index. No source with a high frequency ($\sim$ 200 Mc/s) index greater than 0.75 has been observed to have a low-frequency excess, and no source in an Abell cluster with spectral index less than 0.7 does not show a low-frequency excess. The behaviour of LF-excess sources above 400 Mc/s is not certain. At least one, the Coma Cluster, shows an extremely steep spectrum above 400 Mc/s, the index again rising to $\approx$ 1.7 .

The agreement between source fluxes from Phase II observations and those from Chris Purton's observations (Phase I) is very good. The mean ratio C.R.P./A.H.B. is 1.00 $\pm$ 0.25 for the eighteen sources in common. The C.R.P. fluxes have been obtained from an antenna calibration based on pure thought, (losses in the antenna, geometry and mutual coupling for theoretical dipoles), and was obtained by integrating up the antenna beam. The flux scale is also in agreement with a number of unpublished fluxes at 10.03 Mc/s read over the telephone to A.H.B. by Tom Clarke (NBS, Boulder) at 6 a.m. one fine morning.

The source is list is probably complete between 0^h and 16^h of right ascension, declinations greater than 10° and less than or equal to 60°, down to $\approx$ 150 f.u. The derived logg(N) - log (S) relation for sources at galactic latitudes greater than 20° within these limits has a slope of -1.9, and shows clearly incompleteness below 130 f.u. Outside the r.a. and declination limits mentioned above, the survey runs are incomplete and the coverage of sources is almost random. Very few sources have been observed below declination 0°, where the zenith angle dependence of the antenna gain becomes strong, and the gain is falling very rapidly, being down by $\approx$ x 50 at the declination of Hydra A ($\approx -12^\circ$).

No observations of anyssort were made at declinations greater than $+75^\circ$ in Phase II work.

Immediate suggestions for future work are the re-observation of all sources in the A.H.B. list with weight factors less than 5, especially the N.P.C. sources and those in Table 2. Good sky coverage with survey runs may enable many more N.P.C. sources to be found with certainty, and it will be of great interest to try to identify these with Abell clusters. It should be possible to complete the survey to 100 f.u. over much of the sky and thereby obtain a much larger statistical sample for study at 10 Mc/s. Observations of sources at high zenith angles with the White Lake Dipole interferometer would be of value in checking the various assumptions made about zenith angle dependence of the antenna gain.

Table 7.1

FLUX DENSITIES OF SOURCES NEAR THE ZENITH

$(Z \leqslant 15^{\circ})$

OBSERVED R.A.	DEC	SOURCE	10 MHZ FLUX	EXPECTED FLUX	NOTES	WEIGHT
$00^{h}\ 24^{m}$	$63^{\circ}.9$	3C 10	360 ± 85	1200	steep bgrd slope	4
00 41	51.9	*3C 20	220 ± 40	250	conf. by 3C 22	35
00 49	51.0	*3C 22	155 ± 20	125	conf. by 3C 20	4
01 10	49.3	*3C 35	175 ± 30	175		8
01 34	37.8	3C 46	75 ± 35	100		9
02 21	42.9	*3C 66	740 ± 170	350		169
02 22	39.9	*3C 65	195 ± 30	165		21
02 35	59.1	3C 69	UL 200	220	1 record S = 180	
02 48	39.4	4C 39.10	140 ± 45	100	[illegible]	15
03 17	41.4	*3C 84	2000 ± 380	1800	includes 3C 83.1	861
03 25	55.2	*3C 86	230 ± 50	215	bgrd hump	21
04 06	42.9	*3C 103	210 ± 60	230	steep bgrd slope	25
04 16	37.9	*3C 111	480 ± 60	540		150
04 47	45.0	*3C 129	300 ± 55	260	includes 3C 129.1	18
04 59	46.5	* HB 9	690 ± 120	800	integrated flux	40
05 02	38.1	*3C 134	670 ± 100	1100	bgrd hump	22
06 07	48.1	*3C 153	275 ± 50	90		4
07 42	38.0	3C 186	125 ± 45	120		25
07 46	56.0	*4C 56.16	190 ± 35	220		10
08 11	48.3	*3C 196	460 ± 140	?	bgrd confusion ?	127
08 20	43.1	*3C 199	160 ± 30	?		4

Table 7.1 continued

OBSERVED R.A.		DEC	SOURCE	10 MHZ FLUX	EXPECTED FLUX	NOTES	WEIGHT
08^h	39^m	$58\overset{\circ}{.}0 \pm 0\overset{\circ}{.}9$	*	190 ± 60			12
09	07	$43\overset{\circ}{.}0$	3C 216	UL 70	160		
09	19	45.8	* 3C 219	390 ± 110	340		167
10	10	46.6	3C 239	UL 70	160		
10	15	39.5	4C 39.29/30	145 ± 35	100		36
10	31	58.6	*3C 244.1	200 ± 45	200		48
10	57	43.2	3C 247	110 ± 25	<40		12
11	13	40.8	* 3C 254	190 ± 40	165		113
12	49	57.2	[illegible]	130 ± 35	[illegible]	3C 277.1 ?	8
12	55	47.5	* 3C 280	190 ± 50	160	conf source foll	34
12	57	$38\overset{\circ}{.}1 \pm 1\overset{\circ}{.}0$	*	155 ± 40		4C 38.34/37.35 ?	10
13	05	46.7	* [illegible]	160 ± 65		Abell 1682 ?	18
13	37	39.0	* 3C 288	190 ± 70	145		184
14	01	52.3	4C 52.29	100 ± 30	80	conf by 3C 295	18
14	10	52.1	3C 295	65 ± 35	<60	conf by 4C 52.29	9
14	15	$49\overset{\circ}{.}0 \pm 0\overset{\circ}{.}9$		125 ± 45			4
14	25	37.9	*4C 38.39	230 ± 60	340		110
14	56	47.9	* NRAO 462	180 ± 40	(130)		3
15	22	$43\overset{\circ}{.}6 \pm 0\overset{\circ}{.}9$	*	155 ± 50			6
15	23	54.6	3C 319	140 ± 35	150		21
15	35	56.0	3C 322	130 ± 20	100		8
nothing visible DUBSIS 16	03	44.3	*4C 44.27	150 ± 25	100		10
16	09	66.1	* 3C 330	160 ± 65	220		11

Table 7.1 continued

OBSERVED R.A.	DEC	SOURCE	10 MHZ FLUX	EXPECTED FLUX	NOTES	WEIGHT
$16^h\ 28^m$	$44^\circ.3$	* 3C 337	215 ± 55	70		11
16 28	39.6	* 3C 338	410 ± 75	540		130
17 24	51.0	3C 356	130 ± 30	160		12
18 07	48.5	4C 48.45	170 ± 40			6
18 29	48.7	3C 380	190 ± 35	600		8
18 43	45.6	3C 388	300 ± 90	200		3
19 58	40.6	3C 405	13500 ± 3500	-	interferometer	
21 17	60.7	3C 430	265 ± 70	300		6
21 54	37.8	3C 438	150 ± 20	390		6
22 44	39.5	3C 452	450 ± 90	500	bgrd complicated	24
23 22	58.6	3C 461	28000 ± 2800	-	interferometer	

Table 7.4

FLUX DENSITIES OF SOURCES AWAY FROM THE ZENITH
(Z 15°)

OBSERVED R.A.		DEC	SOURCE	10 MHZ FLUX	EXPECTED FLUX	NOTES	WEIGHT
00^h	19^m	$15^{\circ}.5$	3C 9	180 ± 65	200		10
00	39	33.0	3C 19	UL 80	90		
00	52	68.1	3C 27	200 ± 55	180		6
01	06	32.2	* 3C 31	175 ± 40	110		20
01	07	13.2	3C 33	435 ± 55	400		21
01	34	30.1	M33 4C 29.03	105 ± 40	90	appear as one	9
01	35	20.8	* 3C 47	320 ± 60	450		44
01	55	28.7	* 3C 55	170 ± 60	190		8
02	30	34.6	* 3C 68.1	160 ± 20	140		24
02	32	31.3	* 3C 68.2	210 ± 50	230		3
02	56	05.9	3C 75	375 ± 100	230		4
03	08	17.0	3C 79	265 ± 55	230		3
03	33	-01.2	3C 89	460 ± 180	420		8
03	57	10.3	3C 98	260 ± 45	310		12
03	57	14.5	4C 14.10	225 ± 50	110	P 0356+14	18
04	12	11.3	3C 109	220 ± 45	230		4
04	12	14.2	4C 14.11	60 ± 30	75	(P 0411+14, confused (with	8
04	20	14.5	4C 14.12	350 ± 75	130	(P 0418+14/P 0419+14	8
04	35	29.6	* 3C 123	1000 ± 210	1150		70
05	01	25.2	* 3C 133	165 ± 40	140		4
05	31	22.0	* 3C 144	4650 ± 1700	3500		10
06	11	26.4	3C 154	125 ± 50	220		4

Table 7.4 continued

OBSERVED R.A.	DEC	SOURCE	10 MHZ FLUX	EXPECTED FLUX	NOTES	WEIGHT
$06^h\ 15^m$	$22^{\circ}.7$	* 3C 157	470 ± 100	450	S/L of 3C 144 ?	29
06 20	14.5	3C 158	190 ± 50	210	complex bgrd	18
06 43	21.4	3C 166	145 ± 30	210		13
07 00	25.3	* 3C 172	155 ± 35	150	S/L of 3C 144 ?	18
07 11	11.8	3C 175	210 ± 65	290		4
07 24	12.5	4C 12.29 4C 12.30	280 ± 80	(300)	P 0722/0725+12	10
07 26	24.7	*4C 24.15	285 ± 45	(600)		68
07 35	$22^{\circ}.8 \pm 1^{\circ}.0$ *		180 ± 45			5
07 43	01.9	3C 187	UL 180	200		
08 00	14.4	3C 190	195 ± 40	160		28
08 03	10.7	3C 191	250 ± 60	200		31
08 03	24.3	* 3C 192	190 ± 40	200		55
08 20	06.1	3C 198	230 ± 50	240		2
08 24	29.4	* 3C 200	160 ± 55	150		4
08 31	11.6	4C 11.28	195 ± 70	130	P 0830+11	69
08 43	$29^{\circ}.6 \pm 0^{\circ}.2$ *		190 ± 40		4C 29.31 ?	12
08 55	$11^{\circ}.0 \pm 0^{\circ}.3$		415 ± 110			10
09 03	16.9	3C 215	175 ± 45	150		4
09 05	18.4	4C 18.28	235 ± 70		P 0907+18	48
09 16	-11.8	3C 218	5000 ± 1250	5200		24
09 20	31.6	4C 31.33	130 ± 25	50		6
09 23	14.9	4C 14.31	205 ± 65	170	P 0922+14	35
09 36	24.7	4C 24.20	80 ± 20	90		15

Table 7.4 continued

OBSERVED R.A.	DEC	SOURCE	10 MHZ FLUX	EXPECTED FLUX	NOTES	WEIGHT
$09^h\ 38^m$	36°.1	3C 223	100 ± 30	110		4
09 40	13.9	3C 225	140 ± 45	120	conf by 3C 228	6
09 46	07.6	3C 227	590 ± 100	480		24
09 48	14.4	3C 228	190 ± 35	200	conf by 3C 225	18
10 00	29.0	* 3C 234	390 ± 80	380		82
10 008	06.7	3C 237 3C 238	200 ± 45	180		18
10 41	12.3	3C 245	165 ± 40	120		144
10 54	18°.6±1°.1		280 ± 60			10
11 04	11.3	4C 11.38	250 ± 60	(240)	P 1101+11	2
11 07	25.2	* 3C 250	390 ± 95	390		12
11 42	22.3	*3C 263.1	150 ± 60	130		20
11 43	19.8	3C 264	795 ± 170	270		183
11 44	31.8	3C 265	UL 175	260		
11 59	73.3	3C 268.1	210 ± 60	160		4
12 19	33.9	3C 270.1	130 ± 50	100		5
12 29	12.6	3C 274	8800 ± 1600	9000		910
12 57	28.3	* COMA C	470 ± 90	?	Coma cluster, conf	279
13 09	27.6	3C 284	120 ± 25	140	conf by Coma C	12
13 30	30.7	3C 286	85 ± 25	50		15
13 51	31.6	* 3C 293	210 ± 60	(110)		48
14 21	19.8	3C 300	290 ± 60	240		6
15 03	26.1	* 3C 310	680 ± 125	630		175
15 11	31°.3±0°.3		135 ± 35			4

Table 7.4 continued

OBSERVED R.A.	DEC	SOURCE	10 MHZ FLUX	EXPECTED FLUX	NOTES	WEIGHT
15^h 30^m	$24^\circ.2$	* 3C 321	230 ± 70	190		15
16 01	02.0	3C 327 3C 327.1	1660 ± 550	800		21
16 19	17.5	3C 334	UL 130	160		
16 49	05.0	3C 348	5390 ± 840	5500		186
17 19	-01.0	3C 353	2790 ± 300	2000		24
20 13	23.5	3C 409	660 ± 170	890		7
20 47	$29^\circ.5 \pm 0^\circ.5$	Cygnus Loop	1250 ± 400	1300	integrated flux	30
21 22	25.0	3C 433	85 ± 30	560		2
23 36	26.9	3C 465	525 ± 85	410		6

Appendix 8A

CRL Flux Densities at 22.25 MHz for Sources Observed at 10 MHz

SOURCE	FLUX DENSITY	ERROR	NOTES
3C 9	85	30 per cent	
3C 10	6500	25	
3C 19	65	15	
3C 20	130	15	
3C 22			
3C 27	150	20	
3C 31	95	20	does not broaden response
3C 33	280	20	
3C 35	45	30	
3C 46	70	30	
3C 47	225	20	
3C 55			
3C 65	85	30	
3C 66	3000	30	broadens antenna response
3C 68.1	60	20	
3C 69	95	20	
3C 75	125	25	
3C 79	120	25	
3C 84	840	20	includes 3C 83.1
3C 86	125	30	on background "hump"
3C 89	155	20	
3C 98	240	30	
3C 103	130	35	
3C 109	130	30	
4C 14.11	30	50	
3C 111	270	20	
3C 123	860	30	
3C 129			includes 3C 129.1
3C 133	75	20	

Appendix 8A continued

SOURCE	FLUX DENSITY	ERROR	NOTES
3C 134	440	20 per cent	
3C 144	2900	20	
3C 153	80	20	peak flux density, broadened
3C 154	120	30	
3C 157	520	25	
3C 158	110	25	
3C 166	120	30	no background confusion
3C 172	60	25	
3C 175	135	20	
4C 12.29/30	110	25	peak flux density, broadened
3C 186	55	30	
3C 187	110	30	
3C 190	75	20	
3C 191	80	20	
3C 192	130	20	
3C 196	180	30	on background "hump"
3C 198	165	30	
3C 216	85	20	
3C 218	1800	20	
3C 219	165	25	
3C 223	50	30	
3C 225	95	20	partly conf by 3C 228
3C 227	220	30	
3C 228	100	20	partly conf by 3C 225
3C 234	225	25	
3C 237/238	80	30	confused
3C 239	55	30	
3C 245	50	30	
3C 247	40	20	
3C 250	105	30	
3C 254	90	25	confused by Cas A S/L
3C 264	225	20	

Appendix 8A continued

SOURCE	FLUX DENSITY	ERROR	NOTES
3C 265	60	30 per cent	
3C 268.1	80	30	
3C 274	4800	20	
3C 280	100	20	
Coma-C	230	25	excludes 3C 277.3, broad
$13^h\ 06^m,\ 46\overset{\circ}{.}8$	100	20	
3C 286	65	30	
3C 288	70	30	
3C 293	60	30	
4C 52.29	30	50	confused by 3C 295
3C 295	120	30	confused by 4C 52.29
3C 300	120	30	
4C 38.39			on background hump
3C 310	295	20	
3C 321	110	30	
3C 334	70	20	
3C 337	65	30	
3C 338	275	20	
3C 348	2500	20	
3C 353	1150	20	
3C 380	235	25	
3C 388	80	20	
3C 405	26000	20	Cygnus A
3C 409	450	25	
3C 433	170	20	
3C 438	200	20	
3C 452	290	20	
3C 461	47000		Cassiopeia A
3C 465	195	20	

Table 7.2

VALUES OF R(10) AND OTHER DATA FOR SOURCES NEAR THE ZENITH

SOURCE	R(10)	OPTICAL OBJECT	m_V	IDENTIFICATION QUALITY	b^{II}
3C 10	0.30	SNR		1	+ 01°
3C 20	0.88	?			- 11
3C 22	1.24	?			- 12
3C 35	1.00	G(D3)	14.5	3	- 13
3C 46	0.75	G	19.5	3	- 24
3C 66	2.11	G(ED2)d cl	12.3	1	- 17
3C 65	1.18	?			- 20
3C 69	0.9	?			- 01
4C 39.10	1.40	?			- 17
3C 84	0.97	G(ED2) cl	12.0	1	- 13
3C 86	1.07	?			- 01
3C 103	0.91	?			- 07
3C 111	0.89	?			- 09
3C 129	1.00	(G)	19.0	3	00
HB 9	0.86	SNR		1	+ 03
3C 134	0.61	?			- 02
3C 153	3.06	G cl	18.0	2	+ 13
3C 186	1.04	Qsr	17.8	1	+ 26
4C 56.16	0.86	G			+ 31
3C 205	1.35	Qsr	17.8	2	+ 37
3C 216	0.43	Qsr	18.3	1	+ 43
3C 219	1.15	G(cD5)	17.5	1	+ 45
3C 239	0.44	Qsr	17.5	3	+ 53
4C 39.29/30	1.45	?			+ 56
3C 244.1	1.00	G cl	19.0	2	+ 51
3C 247	2.75	Qsr	18.4	1	+ 62
3C 254	1.15	Qsr	17.5	1	+ 66
3C 277.1	0.81	Qsr	18.0	1	+ 60

d) Extended sources.

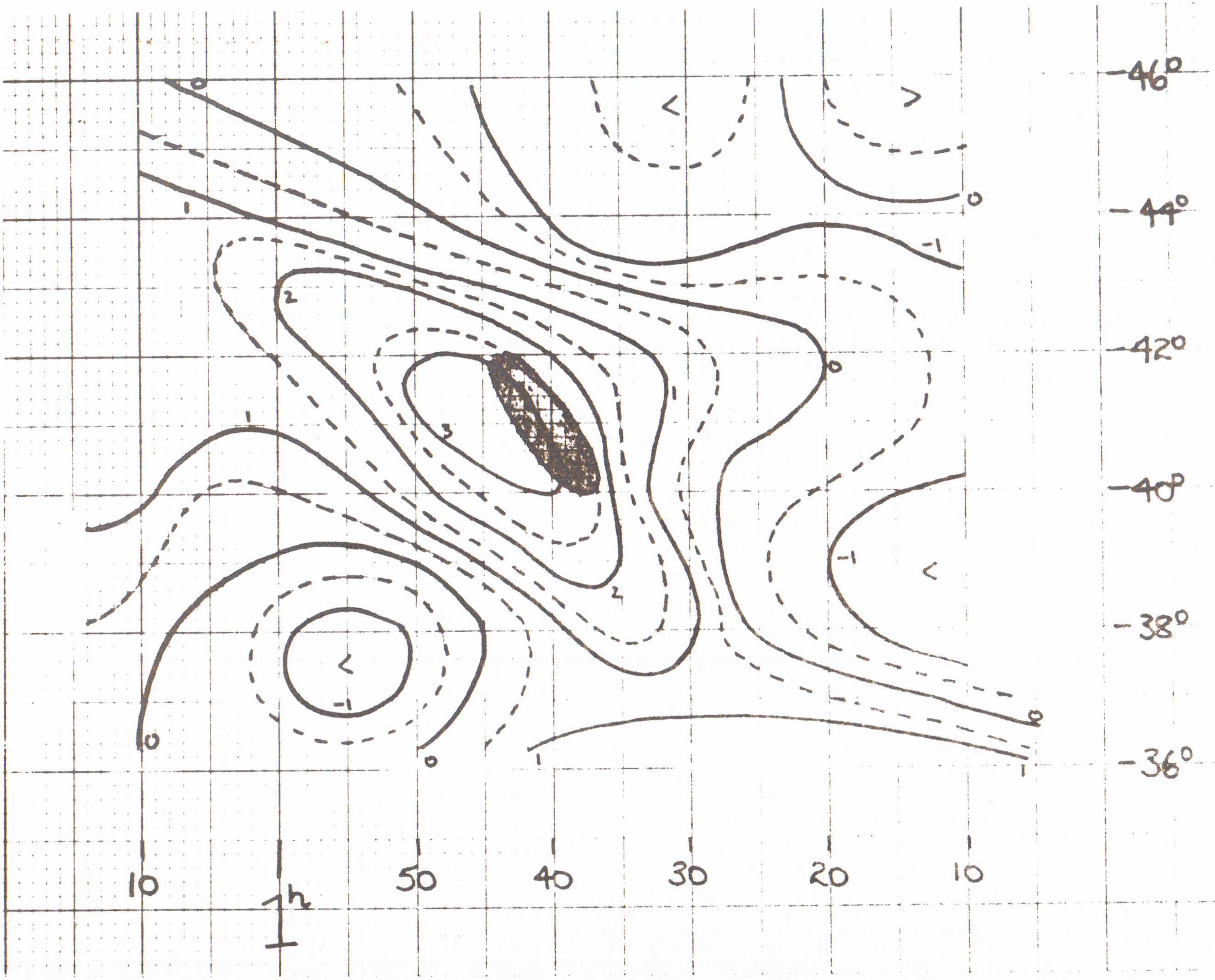
Of the roughly half a dozen extended emission sources observed by A.H.W., only M31 and HB9 have been analysed at the time of writing. M31 was carefully observed over a period of a fortnight in early December, 1966. The signal-to-noise on a given transit was about 2 or 3 to 1, and some three or four transits have been added numerically at each declination to achieve a better ratio. After correction for ionospheric absorption and numerical integration, the drift curves in beams 4, 5, 6, 7, 8, and 9 were combined between r.a. 0010 and 0110 to produce the contour map on the next sheet. The unit here is arbitrary, and the zero level chosen at the mean background level. As on all maps of this region, there is considerable background confusion, at least ± 1 of the arbitrary units, and it is not surprising that the $+1\frac{1}{2}$ contour is the first to enclose the source completely. The shape of the source is in fairly good agreement with higher-frequency maps, a small source to the south of the galaxy and lying on the major axis projected being confused with the main source at 10.03 Mc/s. The asymmetry of the 10 Mc/s contours about the optical nebula is undoubtedly real. At this time of year refraction is in the wrong sense to account for it, and also point sources transiting before and after the nebula were carefully checked when the asymmetry became apparent from individual drift curves. At present two possibilities arise to account for the assymmetry a) it is produced by the lumpiness of the background and b) it represents "halo"-type emission (or a nearby confused source) of relatively steep spectrum. A certain asymmetry relative to the 38 Mc/s contours of Baldwin and Kenderdine may arise from the low resolution of the 10 Mc/s map.

The reductions of HB9 show an angular diameter of $1\overset{\circ}{.}9 \pm 0\overset{\circ}{.}4$, which is in agreement with the 178 Mc/s diameter of $1\overset{\circ}{.}8 \pm 0\overset{\circ}{.}4$.

e) Background survey.

Very little of the processing of the background survey in the Phase II work has been carried out. Preliminary inspection of those drift curves scaled in detail shows strong resemblance to the 178 Mc/s map of Turtle and Baldwin, except for a) deep absorption near the galactic equator towards the region of the centre of the galaxy, and in the positions of most of the bright optical HII regions, b) a deep trough near the region of minimum brightness, rather than a gentle valley as at 178 Mc/s, and c) some indication of a double ridge to the "leading edge" of the North Gala ctic spur. The survey from Phase II has good coverage of the sky between declinations +15 and +60, but is patchy elsewhere. The Rosette Nebula and W.3/4 regions were studied specially in Phase II.

REGION OF M31 AT 10.03 MC 1966.0 CO-ORDINATES HPBW $2^{\circ}.3$ in δ
$2^{\circ}.6$ in α

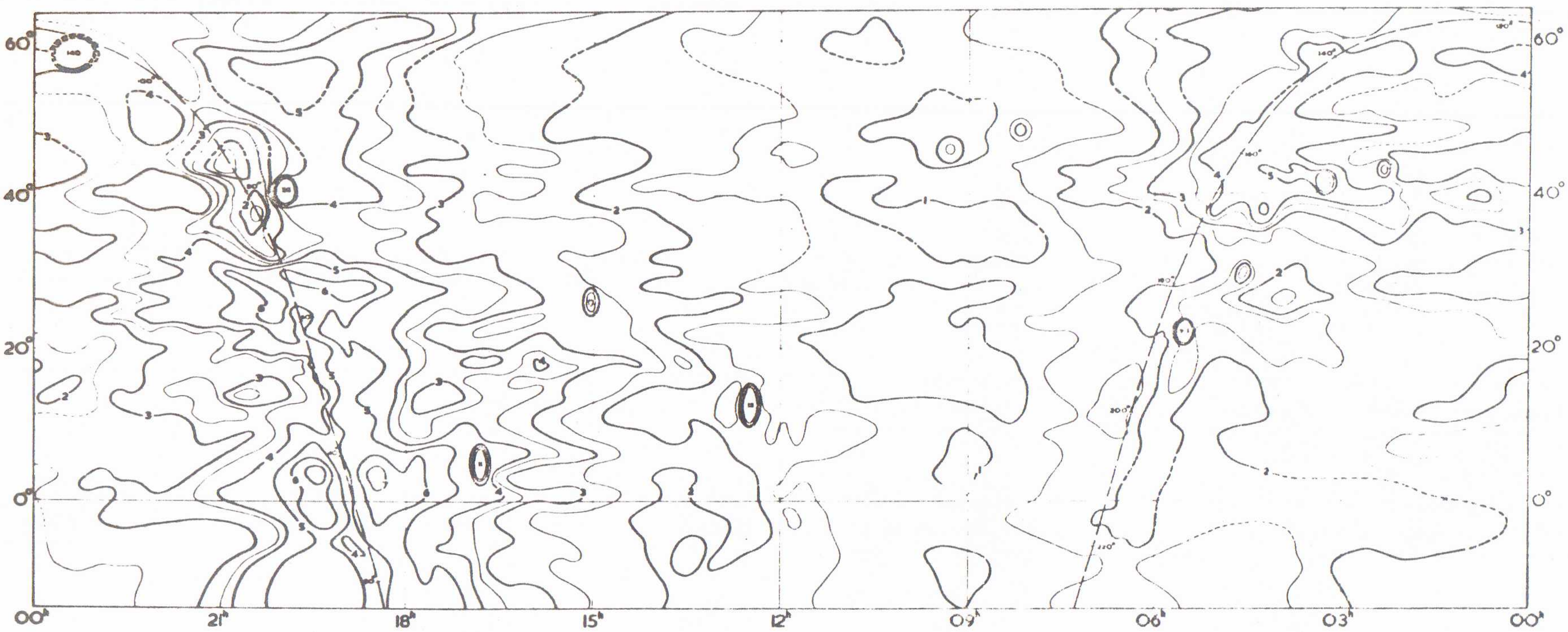


The part of the galactic plane towards the galactic centre was specially studied by Chris P. in the Phase I observations, but it is probably true to say that any region of the sky close to the plane of the galaxy will profit from further study (this ain't easy though because of the awkward transit times of much of the galactic equator). The region around Taurus is missing from the A.H.B. maps because Jupiter was injecting bursts typically 3 x Cass on 95 per cent of nights. This region should be clearer for study in the forthcoming months. Detection of interplanetary scintillation on Taurus A would be an experiment that could be attempted in 1966/67 but which was ruined by Jupiter in 1965/66. It has been suspected also that 3C 157 (IC 443) shows deep scintillation on occassions. This may mean a) the Penticton ionosphere has ways and means of its own, or b) IC 443 contains fine structure. This observation is uncertain from Phase II because of the proximity of Jupiter for the entire period in which observations could be obtained.

The map produced by Chris Purton is appended to the next sheet. Very considerably more detail than this is present on the Phase II drift curves, and it seems certain that a considerable amount of finer structure can be investigated with the system as it now is.

f) <u>Jupiter</u>.

The two salient features about this accursed planet are that it ruins all observations at its R.A. on 95 per cent of nights and that the existing data on it at 10 Mc/s are in need of extensive analysis. The programme of simultaneous observations of Jupiter undertaken in collaboration with the NBS group at Boulder, Colorado seems to have yielded very low burst correlation, in agreement with the results of Southern hemisphere workers. The observing time was chosen to cover a range of Io angles and source presentations, however, and turned out to cover the entire range of ionospheric conditions also. Detailed analysis of the existing data would likely yield some results. In particular, A.H.B. believes that the correlation may vary from night to night. Also, does Jupiter ever produce a clean polar diagram (steady emission) at 10 Mc/s ? Some 22 Mc/s observations suggest that it does, also some 10.05 Mc/s interferometer transits, although on these the time-constant used for the observations is too long for certainty.


60°
40°
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