

NATIONAL RADIO ASTRONOMY OBSERVATORY
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TRANSLATION OF

PLANS FOR RECEIVERS AT 3 FREQUENCIES, AND
EVENTUALLY AT 4 FREQUENCIES, FOR MEASUREMENTS OF SPECTRA

By

E. J. Blum

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PLANS FOR RECEIVERS AT 3 FREQUENCIES, AND EVENTUALLY AT 4 FREQUENCIES, FOR MEASUREMENTS OF SPECTRA

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I. Introduction

The attainable sensitivities of receivers, and the growing confusion concerning the radio spectra of sources, force us to attach prime importance to the problem of possible interference.

We consider only the frequencies in the radio astronomy range, and utilize wider passbands such that the whole of the protected band is used.

The central frequencies which should be used are 4995, 2695, 1413 and 610 MHz, with maximum bandwidths of 10, 10, 27 and 8 MHz, respectively.

In the case of parametric amplifiers, the eventual use of horns at the idler frequency (which constitute cold loads), should only be considered after a very careful study of the spectrum of possible interference at this frequency.

Finally, for these experiments the system normally provided for 2695 MHz should be used at 2295 MHz, with the same passband.

II. Surface Efficiency, and Receiver Temperatures at the Focus

The surface efficiency of the prototype part of the reflector has been estimated as 60 percent at 1420 MHz, 35 percent at 2300 MHz and 15 percent at 5000 MHz. These numbers are approximate, but may be considered to be a reasonable estimate.

For the surface temperature of the sun, we use only a fairly inaccurate measurement made by Delamoy. However, with a relatively simple focal system, we think that the solar radiation contribution prior to the focus may be assumed to be between 30 °K and 50 °K in the first phase, and between 10 °K and 20 °K with more elaborate focal antennas for all frequencies except 610 MHz, at which frequency the figure of 30 °K to 50 °K seems more likely.

The main high frequencies will be equipped with parametric amplifiers according to the following general outlines:

A degenerate amplifier is planned for 6 cm, for which the pump frequency will be 10 GHz. This pump will be common for the three other frequencies, and the idler wavelengths will be 3.2 cm, 3.5 cm and 3.9 cm respectively, so that standard 3 cm waveguide may be used.

Parametric Amplifier Noise

The calculation is based on two types of diode with different quality factors, the better diode not perhaps being necessary at 600 MHz.

F(MHz)	600	1420	2300	5000 [1]
Quality Factor	15 47	7 20	4 12.5	2 6
T _R	39° 13°	90° 30°	150° 50°	300° 100°

[1] We can envisage cooling the diode in liquid nitrogen at 5000 MHz. For the same quality factors, values of T_R will be 78° and 26°, respectively, at the cost of an important technical complexity (mechanical problems, more delicate tests...) and delays due to longer tests and adjustments (certainly not completed before December 1964).

Idler Load Noise

We can envisage a load at 300° or cooled in nitrogen or helium, or a sky horn.

Type	Noise Contribution			Advantages and Disadvantages
	600	1420	2300	
300° load	19°	50°	90°	Rather noisy
Load in N ₂	5°	13°	23°	
Sky horn	1°	3°	6°	Possible interference (9400, 8580 & 7700 MHz) with little protection.
Load in He (4 °K)		1°		Price: 60 million (?). Difficult maintenance problems.

We have given He cooling for reference. It seems more logical to use a maser here.

Total Noise -- Extreme Values

F(MHz)	600	1420	2300	5000
With normal diode and load at 300°	110°	200°	300°	350°
With best diode and a sky horn	65°	75°	90°	110°

The contribution of the sky horn at the principal frequency is negligible.

III. Observation Procedure and Integration Time

The solution envisaged up to the present consists of having a single carriage for the primary antennas at the three highest frequencies, and a second carriage for the primary antenna at 610 MHz (grouped eventually with a CNET antenna at 900 MHz). The width of the focal region in the direction of right ascension is

50 or 16 cm at 5000 MHz

120 or 45 cm at 1420 MHz

The first figure in each case corresponds to a focal system using the first diffraction ring, the second figure to the classical system. In the first case we also have a slight improvement in resolving power. The energy distribution is:

0.5	2.2	0.5
2.2	81	2.2
0.5	2.2	0.5

	Width (m)*	Efficiency	10 dB lobe-width	First secondary lobe
Central region + first diffraction ring (perfect focal system)	2.5	85%	0.93	13 dB
Classical horn at focus	0.72	60%	1.4	23 dB

* The meaning of this column seems to be inferred in the text, but the numbers given were rounded in the original table (compared with the text). I have taken the liberty of making table agree with text. -- N. J. K.

This gives the efficiency of an otherwise perfect antenna. The figures are valid for 610 and 1420 MHz. For 2300 and 5000 MHz, it seems reasonable to reduce the efficiencies by a factor of $\frac{35}{60}$ and $\frac{15}{60}$ respectively (compare with section II).

The width of the antennas for the three-frequency carriage varies from 2.50 m to 72 cm, depending on the system adopted. We have assumed that the width of the focal region at 2300 MHz is intermediate (between the 1420 MHz and the 5000 MHz widths), and that the same system is adopted for all three frequencies.

It is difficult to compare the effectiveness of these systems, because it depends strongly on the measuring procedure used. If the carriage is set in a series of fixed positions, and if a point source signal arrives in successive positions for the three horns, then the system with the highest efficiency is the worst, since the measuring time for the same antenna temperature increased in the ratio $\frac{2.50}{0.72}$, i. e., more than $\frac{85}{60}$.

On the other hand, for an extended source (with the image at the focus covering 20 times the focal region, for example), the effectiveness of measurements at fixed positions becomes good.

In the case of a weak source, we may have to use a long integration time at 5000 MHz, and only a few minutes at 1420 MHz. Then there is no reason to use all frequencies in rapid succession. We can make a slow scan at 5000 MHz using several passages of the source, one slow scan at 2300 MHz, and a measurement of ten minutes

or so at 1420 MHz -- perhaps at the end of the other measurements. Even for sources with a flat spectrum, the necessary integrating times are in the ratio 4:1 to obtain the same antenna temperatures at 5000 and 1420 MHz, and this should be augmented by a further factor 2, if we remember that, at the highest frequency, aberrations permit only 15° of the field to be utilized. Nothing that we shall consider here allows us to find a better receiver grouping, or an optimum measuring procedure.

We cannot pass to the construction without deciding both the method of observation and the disposition of the receivers.

The preceding description shows that the system chosen is closely related to the observation programs themselves: it is essential to detail these programs before attempting to build receiver systems. When the relative integration times at the four frequencies and the ultimate sensitivity have been fixed, we will see the situation more clearly; but we must first decide on the measuring range and the level of the secondary lobes. For this proposal we must now have two figures for each receiver: the minimum integration time (determined by the speed of passage of a point source compounded with the eventual movement of the focal system) and the maximum integration time fixed by the attainable sensitivity.

Provisionally we will take as minimum $\frac{1}{10}$ of the passage time for a point source through the focal system assumed fixed, or $\tau = 0.4$ sec at 5000 MHz, and the maximum time will be $N \times 0.4$ sec.

IV. Principles of the Receivers Envisaged

The small cross polarization of the radiotelescope permits measurements of the correct polarization, but with a technique quite different from the usual.

We cannot rotate the focal system, since there is no circular symmetry, and we consider placing at the focus two adjacent antennas accepting, respectively, vertical and horizontal polarization. Obviously interpretation of the results requires a knowledge of the total polarization characteristics of the instrument, and as the main reflector beam is not able to move far from the meridian it will not be possible to determine the contribution from the sun. It is probable that measurements will be related to those from other observatories, in order to calibrate the system.

On the other hand, the fixed, crossed-polarization antennas give the advantage of twice the number measurements, and thus the instrumental sensitivity is increased by $\sqrt{2}$.

We now describe the general scheme for one of these frequencies.

V. Sensitivity and Stability -- Meaning of the Measurements

After the correlators two systems are possible, depending on the ultimate sensitivity required. In the simplest system, the analog to digital converters follow directly after the correlators. These have a slow drift of as much as 1 mV per hour. The tubes are able to drive the correlators with a noise voltage of approximately 20 volts. With a system temperature of T °K, the drift will be $\frac{\Delta T}{T} = 2 \cdot \frac{1 \text{ mV}}{20 \text{ V}} = 10^{-4}$.

The records of the correlators indicate that this drift is quite regular. We admit that it is an approximation to say that ΔV is proportional to the measuring time.

With τ defined as previously

$$\Delta V = 3 \cdot 10^7 N\tau \text{ volts}$$

and at the end of a time $N\tau$ we will have a temperature error

$$\begin{aligned} \frac{\Delta T}{T} &= 2 \cdot \frac{3 \cdot 10^{-7} N\tau}{20} \\ &= 3 \cdot 10^{-8} N\tau. \end{aligned}$$

We wish this error to be smaller than the normal receiver noise errors.

$$\frac{\Delta T}{T} = \frac{1}{\sqrt{BN\tau}}$$

B is the passband (losing $\sqrt{2}$ due to correlation, and gaining $\sqrt{2}$ due to two polarizations). Hence

$$3 \cdot 10^{-8} N\tau < \frac{1}{\sqrt{BN\tau}}$$

As $B \simeq 10^7$ we have $N\tau < 500$. For $T = 300$ °K, the limit for $N\tau = 500$ is

$$\Delta T \simeq 300 \cdot 3 \cdot 10^{-8} \cdot 500 = 4.5 \times 10^{-3}$$

This number has no physical significance, in particular because the sun's contribution in the region of 15 to 30 °K (assuming equal stability), may be $5 \cdot 10^{-2}$ degrees for the sun itself over 500 seconds.

On the other hand, we are discussing the measuring precision of a point in the sky where the physical problem is more that of measuring a zone of sky of aperture in times the distance between two just separable points. The temperature error due to the drift is always the same perhaps $\frac{\Delta T}{T} \simeq 3 \cdot 10^{-8} N \cdot \tau$ while the error due to fluctuations becomes

$$\frac{\Delta T}{T} = \frac{1}{\sqrt{BN\tau/n}}$$

for each distinct point in the observed field.

As previously, we find

$$\Delta T = 5 \cdot 10^{-3} \sqrt{n}$$

For $n = 120$ $\Delta T = 2.5 \times 10^{-2}$ °K

$$N\tau = 2.5 \times 10^3 \text{ sec}$$

(To obtain the order of magnitude of the field, we take approximately five measurements per half-power beamwidth, perhaps 24 beamwidths for $n = 120$).

These numbers appear to give a good indication of the limits of the simple system: analog-to-digital converters after the correlators: for sky coverage of the order of 25 beamwidths and an observing time of 1 hour, the fluctuation error is $\frac{2.5}{100}$ °K (corresponding to $\frac{1}{4}$ °K from the sun). At 5000 MHz the field is 25 arc minutes and at 1420 MHz is 1.5°.

If we envisage reducing the drift by a modulation before the correlator with selective amplification and synchronous detection after (the system used for the multi-channel 21 cm receiver), we can only gain in determining source temperatures since we

do not think that the sun's temperature stability permits any improvement in fluctuation errors.

The simple system appears to be justifiable.

Possibly the voltage can be divided by 2 at the correlator, as a result of which the relative drift will be double, and in the case which we consider a ΔT better than $5 \cdot 10^{-2}$ °K, all other things being equal.

$$(\Delta T \approx 6 \cdot 10^{-2}, N\tau \approx 1500 \text{ sec}, n = 120).$$

Drift Due to Gain Instabilities

In allowing a gain drift of 10^{-3} for each receiver before correlation, 15° of signal is required for $\Delta T_{\text{signal}} = \frac{3}{100}$ °K. Actually $V_{\text{signal}} = g_1 g_2 T_{\text{signal}}$

$$2 \frac{\Delta g}{g} = \frac{\Delta T_{\text{signal}}}{T_{\text{signal}}}$$

$$T_{\text{signal}} = \frac{3}{(100)^2} \cdot 10^3 = 15^\circ.$$

Measurement of a Relatively Emissive Continuous Background

Such a background may be left to the final observing program.

VI. Digitalization - Recording

The use of a classical recorder, at least on one channel, is provided. We must decide whether to make the recorder read all four channels in turn, but the digitalization is imperative. The stability of the Manning converter (a. to d.) is better than 1 mV per hour. It is thus usable directly after correlation. Its dynamic range is perhaps 10 V on one scale.

First Possibility

Measurements to $5 \cdot 10^{-3}$ °K may be made to the point where $N\tau = 50$ sec of integration.

For each measurement (with approximately 1 second of integration) we have a standard deviation of about 0.1 °K.

The dynamic range is 50 °K (approximately 10 V max.).

For each measurement it is necessary to quantize the signal in $\frac{50}{0.1} = 500$ levels: i. e., to 3 significant figures.

Second Possibility

Serious measurements can never achieve better than $\frac{3}{100}$ °K, due to the sun.

If we take $T_R = 300$ °K, $B = 10^7$, $\sigma = 1$

$$\Delta T = \frac{1}{10}^\circ \text{ for one measurement.}$$

In less than 10 measurements we reach the measuring limit for a point in the sky. Although we have a theoretical dynamic range of 300 °K, in fact we are satisfied with 30 °K (using several ranges for the strong sources). Hence the quantization should be for $\frac{30}{0.1} = 300$ levels: i. e., to 3 significant figures.

Conclusion

Whichever of the two above possibilities we use, 3 figures are sufficient if readings are taken approximately every second: this time depends on the mode of observation.

For all frequencies it is necessary to punch

$$4 \times 3 = 12 \text{ figures}$$

in a time small compared with 1 sec ($\frac{1}{10}$ sec, say). This is possible with the Bull punches which we already have (one punch per frequency); or we could use a more rapid punch, with a punch signal < 1 m sec (price = 25,000 Fr.).

For the 610 MHz receiver, we can measure every 3 seconds; then the 12 numbers in 300 m sec is achieved without a punch memory.

VII. Standardization of Elements, and Possible Multiplication

For obvious reasons, we require as many identical elements as possible for all reviewers. In particular, this will fix the pass-band: less than 10 MHz if the 610 MHz system is excluded, or 8 MHz if it is used.

Digitalization and recording systems are the same, and function in the same sequence.

If we make non-simultaneous measurements at 3 frequencies, an extra simplification is introduced: large parts of the receivers can be common beyond the high frequency portion (as required). This is directly involved with the description of the carriage and the observation procedure; it is therefore fundamental that these problems are studied in considerable detail as a function of the probable astronomical programs (spectral measurements, size of objects, etc...).

