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THE 1415 MHZ FOUR-FEED SYSTEM AT THE 300-FOOT TELESCOPE

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I. Introduction

The 20-cm four-feed system, when mounted on the 300-foot telescope, provides four antenna beams offset from the optical axis so that a 40' declination strip may be surveyed with drift scans spaced 5' apart (one-half of a half-power beamwidth) in two days' observing. Alternatively, a 5° declination strip may be scanned at 2.5°/min in five days' observing. The sensitivity and stability are adequate to reach the confusion limit during drift scans. Either beam switching or load switching may be used. The feed arrangement is flexible, since the entire feed assembly may be demounted and exchanged for another unit.

This report discusses the performance of the system as determined during the initial 9-day observing period October 9-18, 1967. The feed arrangement, antenna patterns, sensitivity, and stability of the system will be discussed in turn.

II. The Feed Arrangement

Difficulties have been experienced in the past (Ross and Terzian, EDIR No. 37, 1964) when feeds were mounted off-axis at the 300-foot. J. Baars (private communication) has made numerical computations of the characteristics of paraboloids with off-axis feeds. These indicate that a decrease in gain in the offset beam is to be expected, as well as a coma lobe on the line joining the optical axis with the offset beam, at a distance of 1.6 HPBW from the offset beam. Baars' curves of coma lobe intensity and gain decrease are shown in Figure 1. It is apparent that the area near the focal point is at a premium, since the coma lobe intensity is roughly proportional to the square of the beam offset. The present design is limited to four closely-spaced feeds for this reason. They are given nearly equal offsets of about 1.6 HPBW to insure identical performance at each declination. With this offset the expected gain decrease is 3.5%, and the expected coma lobe intensity is -17.5 dB.

The feed arrangement used in October, 1967 is shown in Figure 2. Standard rectangular horns have been used, with the E-vectors north-south. The declination spacing between the upper and lower horns is 20', with 2.5' spacing* within each pair. For the dirft scan survey, the telescope declination was changed 5' each day for four days.

The offset between the east and west horns is 25', with 1.6' spacing within each pair. The latter corrects approximately for the 2' cos δ offset in right ascension which would otherwise be obtained during 2.5°/min scans. A complete region near declination 0° may be surveyed at 2.5°/min by interleaving the scans from five days' observing, if each day the right ascension at the start of the scan is displaced by 5'. Wider declination zones require multiples of five days.

When beam switching is used, each northern feed is switched against the feed to its south, so that discrete sources appear as S-curves during 2.5°/min scans. Beam-switching may also be used during drift scans for greater sensitivity, at the cost of an increased confusion level.

III. Antenna Patterns

The antenna patterns of the four-feed system down to the 15 dB level, taken from 2.5°/min scans through Virgo A, are given in Figure 3. The data are rather scanty, but there is little evidence of asymmetry or coma lobe in the data available.

The 18, 21 and 24 dB contours for feed No. 1 obtained from a 2.5°/min scan through CAS A (declination 58°) are shown in Figure 4. Here the grid of scans is more dense, due to the high declination. It is not certain that the pattern would be the same at lower declinations, since the telescope surface is optimum at declination 8°. The present pattern compares favorably with the on-axis pattern obtained on CAS A in February 1967 when the 20/40 cm system was on the telescope. The latter is shown in Figure 5 for comparison.

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* This has been changed to 5'; cf. section VI.

The present antenna patterns are not intended to be definitive, and a considerably more extensive program of measurement would be needed before accurate results on extended sources or the background continuum could be obtained. Nevertheless these qualitative results are in agreement with the theoretical prediction that a beam offset of 2 HPBW or less does not lead to significant deterioration of the antenna pattern.

IV. Sensitivity

The radiometer and system noise temperatures are shown in Table I.

TABLE I

Equivalent Noise Temperatures

Unit	Radiometer	System	System-Radiometer
1	123 °K	174 °K	51 °K
2	111	162	51
3	(153)	(188)	(35)
4	115	170	55

The radiometer temperatures were measured in the laboratory using a hot-cold load. The system temperatures were measured on the telescope by switching between signal and comparison (=300 °K). Unit 3 gave erratic results, apparently due to a defective coupler. The principal sources of radiometer noise are coupler + ferrite switch (40 °K), parametric amplifier (70 °K), and transistorized second stage (10 °K). The system temperature includes the external sources of noise: sky background, spillover, ground radiation through the mesh, and radiation by the mesh. A careful attempt was made to determine the change of system temperature as a function of zenith angle, but no change was found, even at declination -18.5°. Any change greater than 3 °K would have been found.

Due to lack of observing time, no accurate measurement of aperture efficiency could be made. From the little data available, a value of 30% ± 5% is deduced, but this depends critically on the thermal calibrations.*

The nominal bandwidth of the system is 60 MHz. Hence an rms noise of

$$\Delta T = 2T_s(B\tau)^{-1/2} = 2 \times 175 \times (60 \times 10^6 \times 4)^{-1/2} = 0.022 \text{ °K}$$

is predicted for a time constant of 4 seconds (= 0.1 HPBW for a drift scan near declination 0°). Verification of this value cannot be made directly from a single scan since the confusion level has about the same value. However, the four pairs of scans made at declination 18° 05' on the nights of 11/12 October and 15/16 October 1967 have been used to determine the root mean square flux density and the root mean square noise level separately (cf. M. Davis, B.A.N. 19, 208, 1967). In each case the second scan has been subtracted from the first and the result divided by $\sqrt{2}$, giving a confusion-free scan with the same noise level. The average rms for the four systems was determined to be 0.025 °K for a four-second time constant.

V. Stability and Confusion Level

The stability of the system has been studied, using the confusion-free records described in the preceding section, by continually doubling the time constant (in the computer) and determining at what point this fails to yield the expected $\sqrt{2}$ improvement in the rms. The results are shown for each system in Figure 6. For comparison, the rms noise predicted for a perfectly stable 175 °K system with 60 MHz bandwidth is also shown. It is apparent that the four systems begin to deteriorate at a time constant of 4 seconds. For a time constant of 32 seconds, ΔT is about twice the theoretical value.

Nevertheless, the four-feed system is limited more by the finite resolving power of the 300-foot telescope rather than by instrumental instability. A root mean square confusion level of 0.043 f.u. (= 0.029 °K) has been determined by comparing

* A more accurate value of 29 percent was obtained in December, 1967.

the ΔT obtained above for the confusion-free scans with the ΔT obtained when the scans are averaged in the normal manner (but with sources > 0.3 f.u. edited out). The results for the mean of all four channels are shown in Figure 7. (Note that the system noise from Figure 6 has been converted to equivalent flux units, using the factor 1.5 f.u./°K.)

VI. Alternate Feed Arrangements

The feed arrangement is reasonably easy to modify. The system used in October, 1967, with its inherent 1/4-HPBW spacing, has been modified to one which has 1/2-HPBW (5') north-south spacing between feeds 1 and 2 and between feeds 3 and 4. This will permit a 40' zone in declination to be scanned in just two days, or, if four days are available, these scans may be repeated or new scans may be interleaved to give 1/4-HPBW spacing.

Other feed arrangements could be made up if there were sufficient interest. Roberts will use two polarizations of an on-axis feed for hydrogen-line work in February 1968 to double his effective observing time. In fact, all four radiometers could be coupled to a single feed having both polarizations, since the radiometers are connected to the feed only half of the time when load-switching is used. Another possibility would be 3 (possibly 4) feeds separated by 5' in declination, so that a complete continuum flux and position measurement can be made in one day. It would probably be necessary to put up with some coma lobe and loss of gain in the off-axis feeds with this arrangement, however.

VII. Summary

The principal design goal of the four-feed system has been a unit capable of completing an extra-galactic source survey over 10° of declination within a reasonable amount of observing time and complete to the resolution limit of the 300-foot telescope. An area of 38 square degrees taken from the drift scan survey made during October has been reduced, and the results are shown in Appendix A. It appears that this principal design goal has been reached.

Secondary design goals have been 21-cm line work (non-degenerate paramps) and rapid coverage of larger areas of sky to a higher flux limit (beam-switching). Finally, the feed arrangement is reasonably flexible, so that the principle limitation in this area is more likely to be one of telescope scheduling than of instrumentation.

APPENDIX A

Survey Results

Four-feed Survey 0^h—$5^h\ 20^m$, $17^\circ\ 50'$—$18^\circ\ 20'$

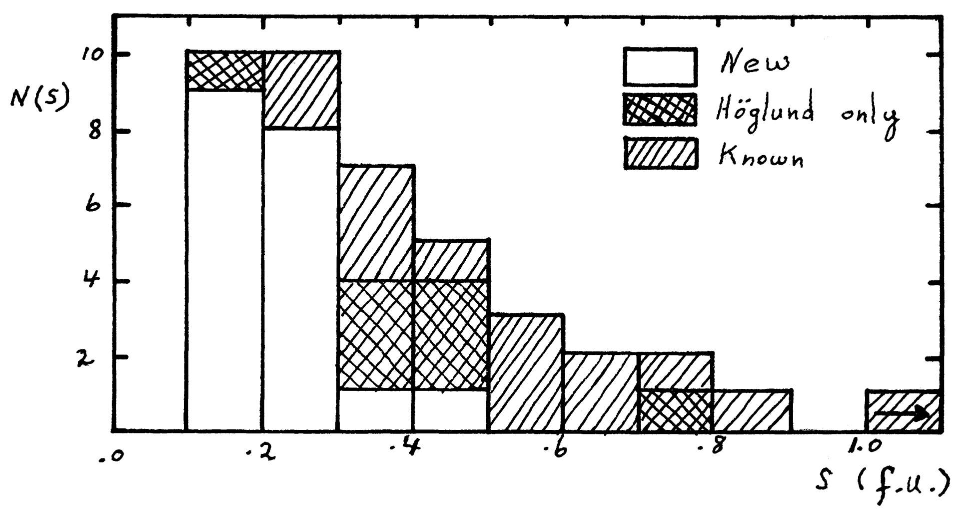
1) Area surveyed: 38 square degrees

2) Sources found: 41

3) Comparison with other catalogues:

Catalogue	Number of Sources	Number Found
4C	11	11
Parkes	4	4
Höglund	9	9
VRO	10	3

(18°—$18^\circ\ 20'$: 7 Höglund sources, 26 Survey sources)



Number of sources in each flux interval.

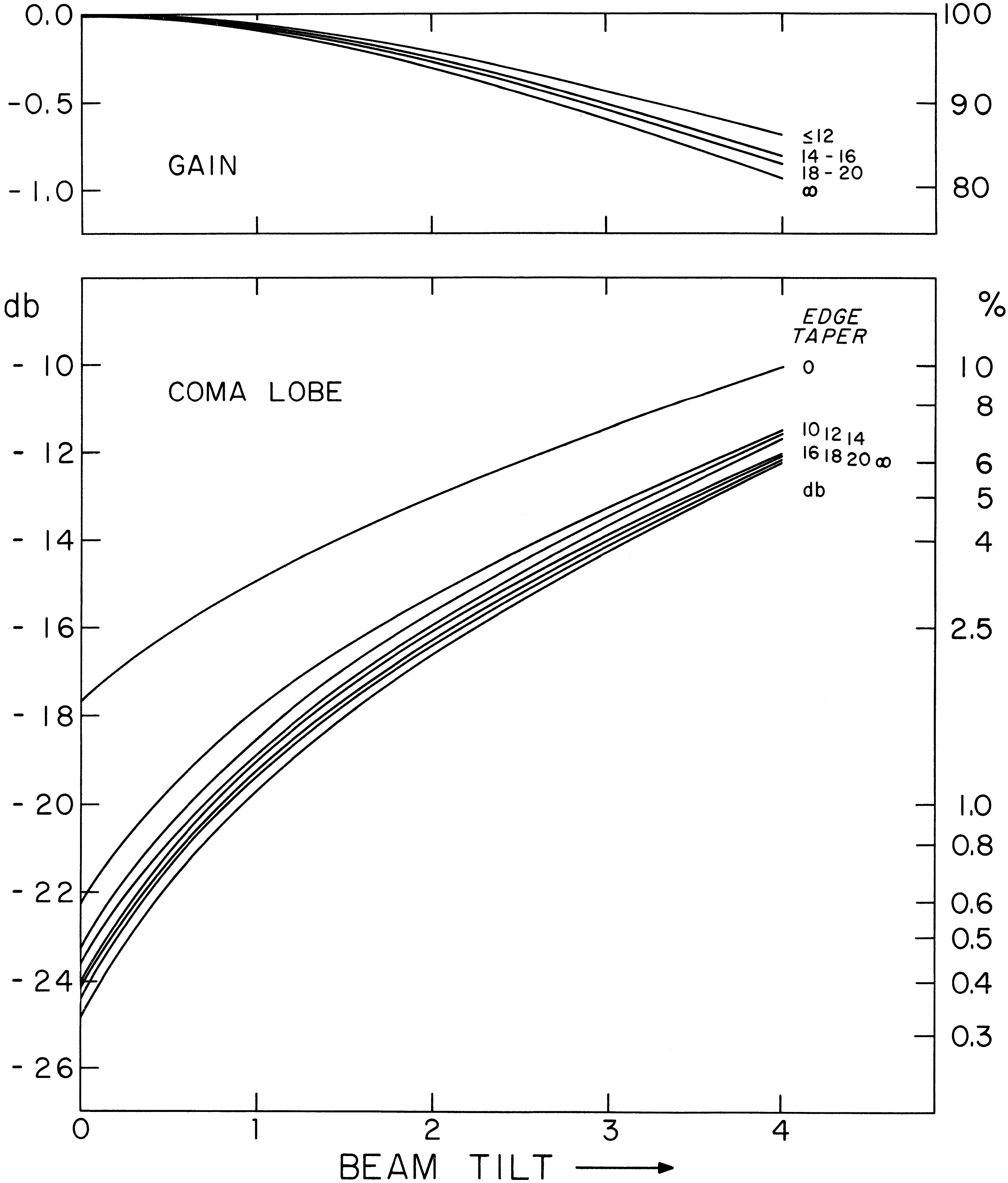


Figure 1. Theoretical values of gain decrease and coma lobe intensity as a function of beam offset. The beam offset is measured in units of half-power beamwidths.

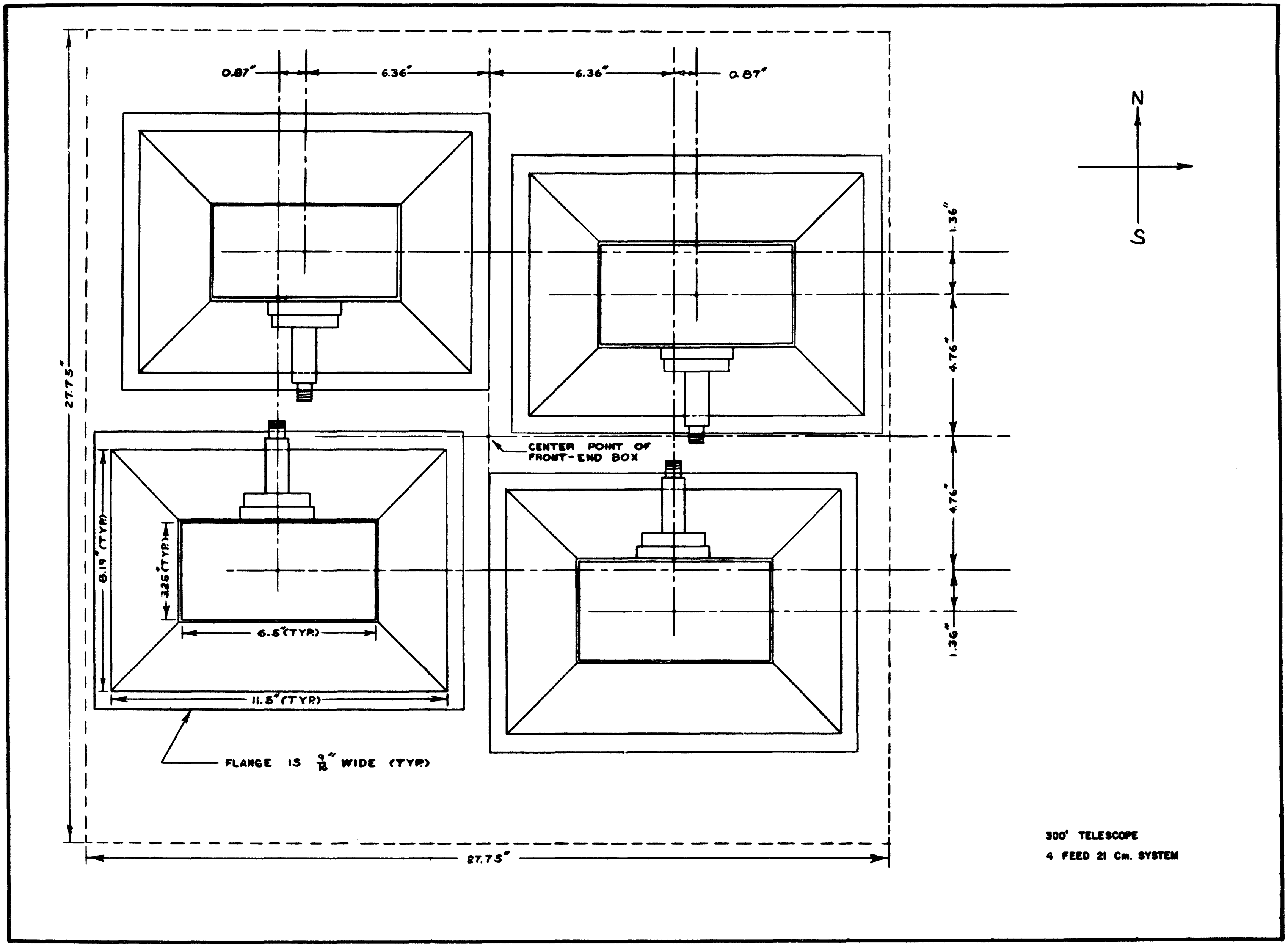


Figure 2. The feed arrangement used in October, 1967. In the more recent arrangement the scale has been changed from 1.38 cm/minute of arc to 1.30 cm/minute of arc, and the left-hand pair and right-hand pair of feeds are separated vertically by 5' rather than by 2.5' (= 1.36 inches) shown here.

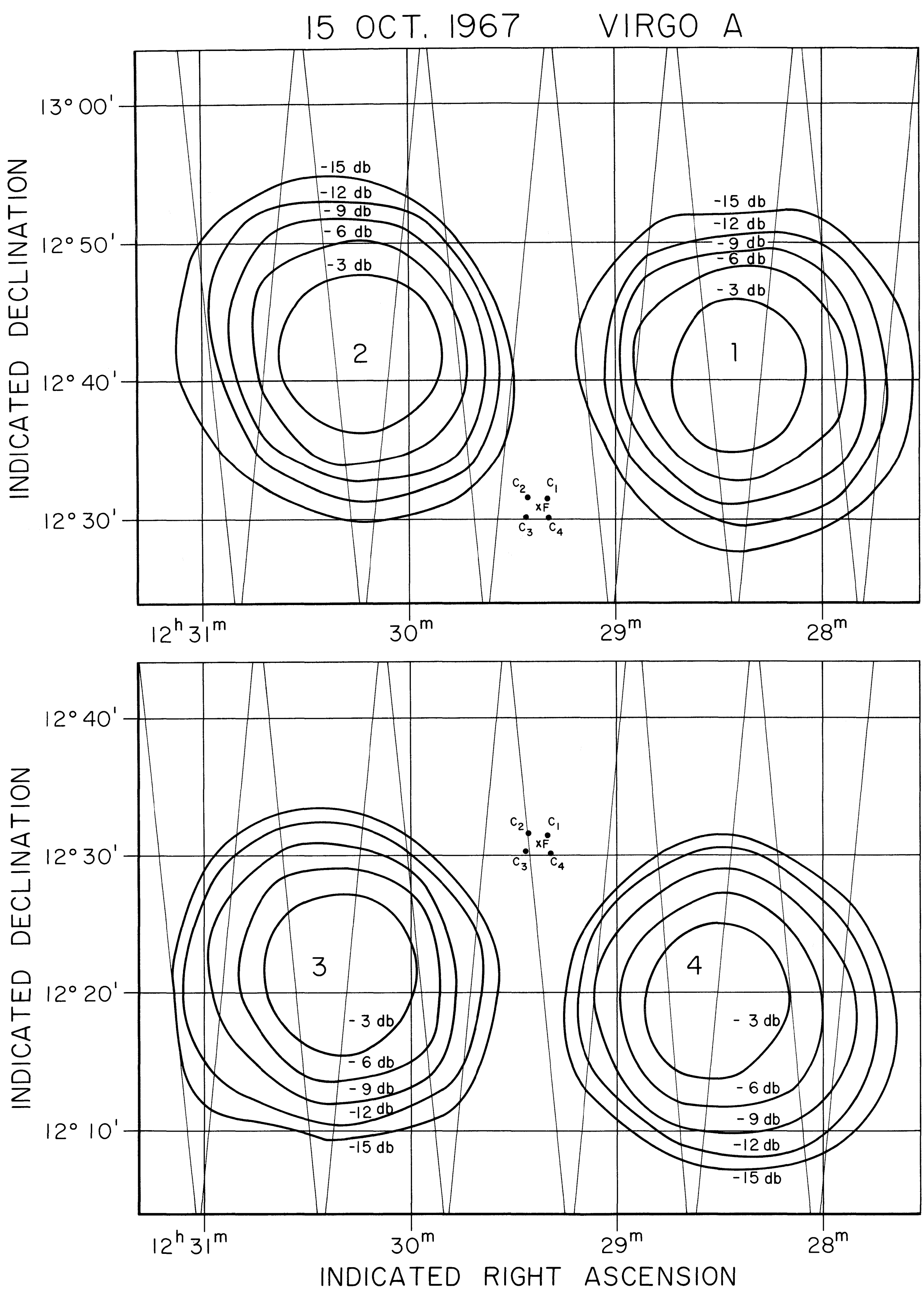


Figure 3. Antenna patterns based on two 2.5°/min wobbles through Virgo A. The optical axis (F) and expected coma lobe positions (C) are shown. The coordinates are indicated sidereal time and declination. No correction has been applied for the broadening of the beam in the direction of the scan due to the 0.3 second time constant.

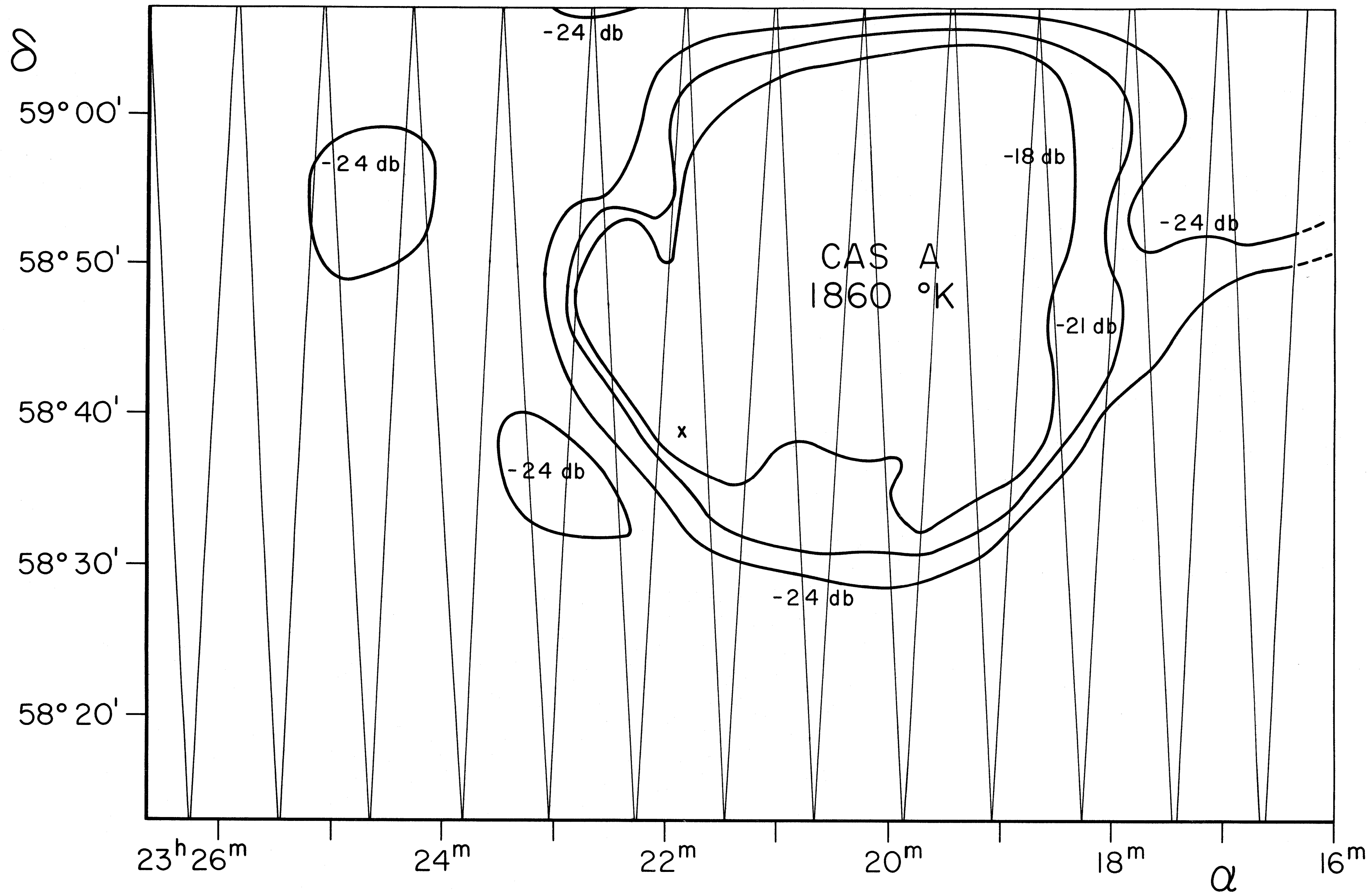


Figure 4. Low-level antenna pattern of feed number 1, based on a 2.5°/min wobble through CAS A. The -24 dB contour at the upper left is due to crosstalk between feeds 1 and 2.

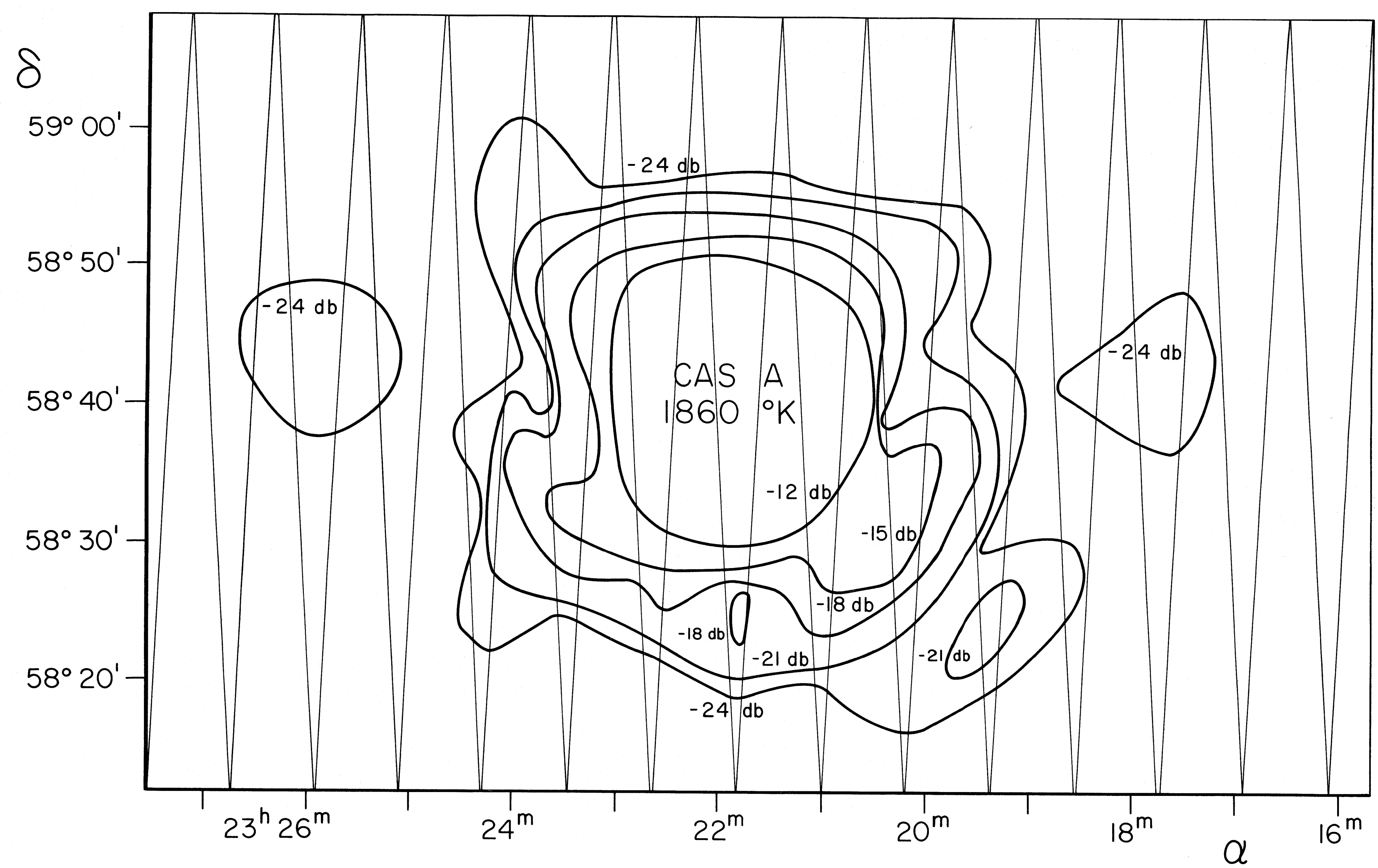


Figure 5. **Antenna pattern of an on-axis 20 cm feed, for comparison with Figure 4.**

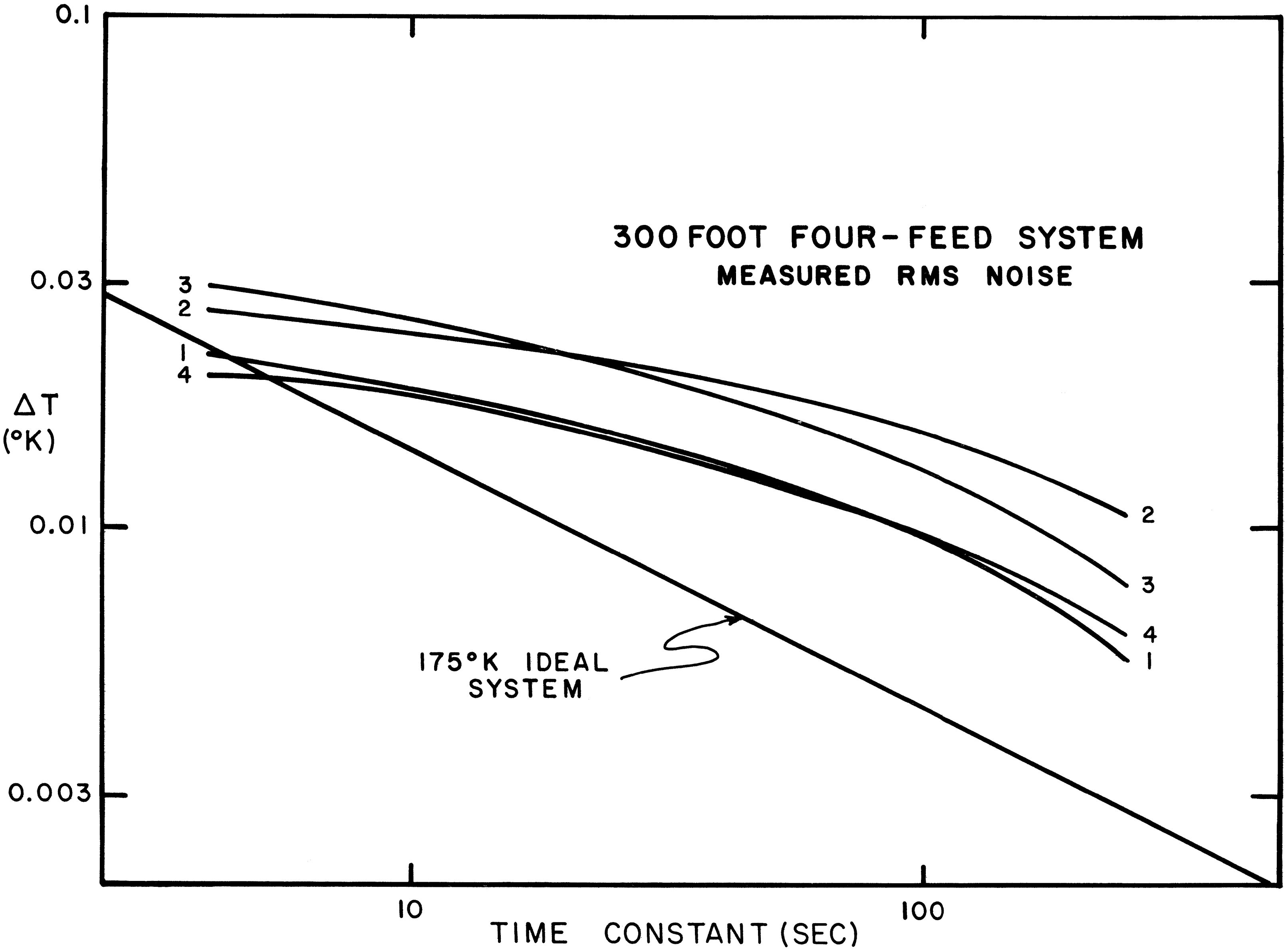


Figure 6. The rms noise behaviour of the four systems, as measured on survey scans. The departure of the real systems from the ideal could be caused by typical receiver unbalance of 1 °K, together with gain variations on the order of 0.05 dB/min.

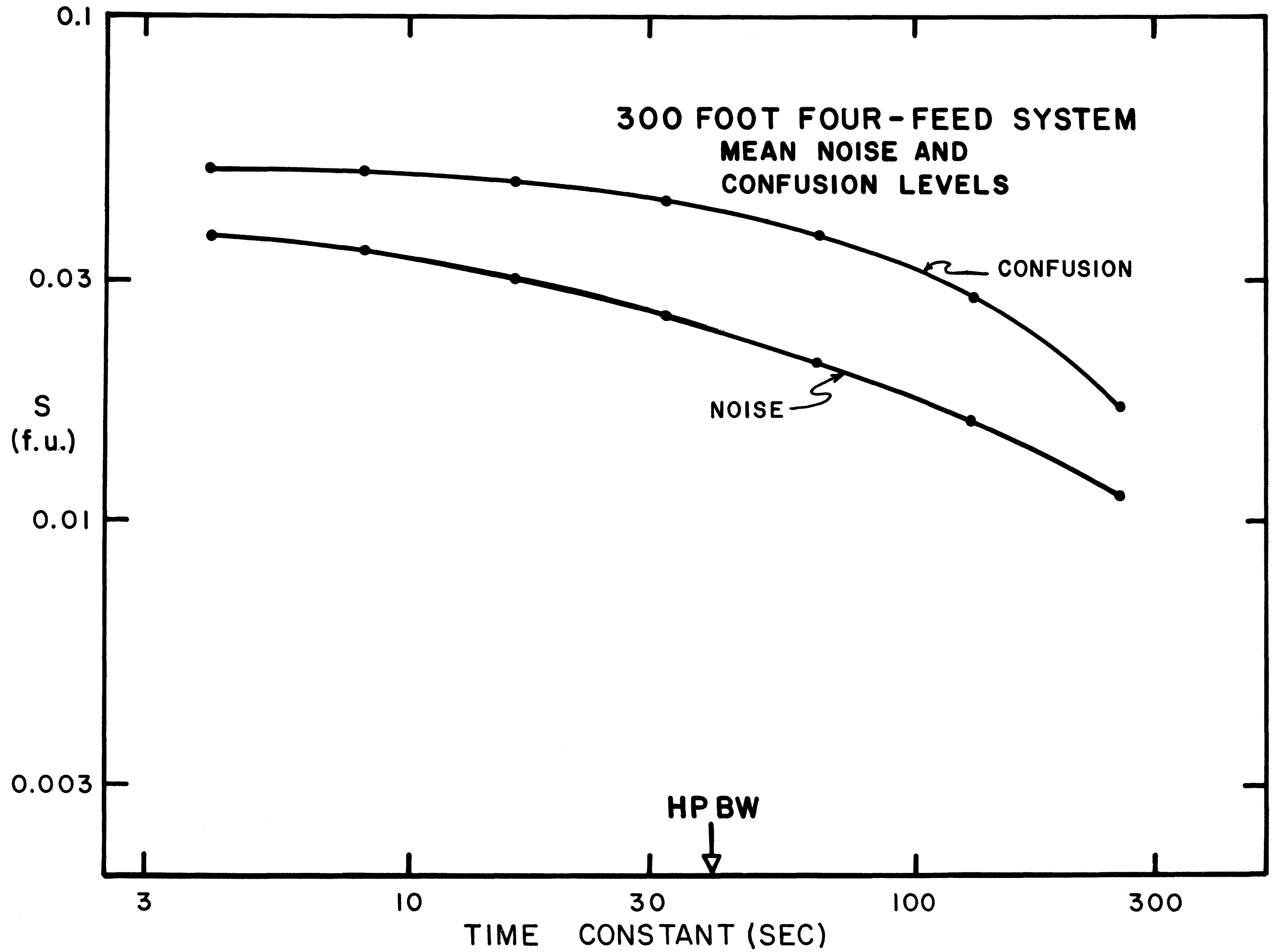


Figure 7. The mean rms noise for all four receivers (taken from Figure 6) compared with the rms flux density ('confusion'), as a function of time constant.