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Seeger, C.L.

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ASTRONOMY AND THE OBSERVATORY AT LEIDEN

400 Mc/s PARTIAL ECLIPSE OBSERVATIONS ON 30 JUNE 1954

BY C. L. SEEGER

This paper presents the 400 Mc/s partial eclipse data obtained with a simple radiometer at a station just north of The Hague on 30 June 1954. Sources of error likely to affect precision eclipse observations of this type are discussed, the present apparatus providing numerical examples. Calculated data for the corresponding geometric eclipse are given.

Urban interference limited the accuracy of the observations to one percent. Within this limit, the solar flux appeared to be constant and the eclipse curve was smooth. At first and last geometric contacts, the flux was between 98 and 99½ percent of the unobscured value. At maximum phase, when the exposed area of the solar disk was 23.4 percent, the flux was 28½ percent. The radio eclipse curve was asymmetric with respect to the geometric curve. Qualitatively, this asymmetry is consistent with a symmetric solar brightness distribution in which the equatorial regions are brighter than the polar regions.

1. *The geometric eclipse.*

The geographic position of the antenna, kindly supplied by the Netherlands Topographic Service, was

$$\lambda = 04^\circ 19' 46''.0 \pm 0''.4 \quad \text{East of Greenwich}$$
$$\varphi = 52^\circ 06' 49''.8 \pm 0''.4.$$

The linear co-ordinates of the observing station were calculated according to the dimensions of HAYFORD's Spheroid, viz. an equatorial radius of 6378.388 km and a polar radius of 6356.912 km.

The calculation of the geometric eclipse was carried out by standard methods based on the Besselian co-ordinates given by GRÖNSTRAND [1]), who used the following empirical corrections derived from solar and lunar observations:

$$\Delta\alpha_\odot = 0^s.070 \qquad \Delta\alpha_{\leftmoon} = -0^s.157$$
$$\Delta\delta_\odot = -0''.06 \qquad \Delta\delta_{\leftmoon} = -0''.17$$

which correspond to

$$\Delta L_\odot = 1''.00 \qquad \Delta L_{\leftmoon} = -2''.00 \qquad \Delta\beta_{\leftmoon} = -0''.50$$

where L is the mean longitude and β the latitude. Corrections for the short-period terms of nutation are included in these figures.

GRÖNSTRAND also assumed:

Moon's radius/Earth's equatorial radius = 0.272274,
Equatorial horizontal parallax of Sun at 1 A.U. = 8″.790,
Semidiameter of Sun at 1 A.U. = 959″.63.

The results of the computations are summarized in Tables 1 and 2. Calculation of the moments of first and last contact in higher approximations gave corrections less than 3^s, so the error is estimated to be $1^s.5$. The error in the moment of greatest phase was found to be about 5^s. The error in any quantity in Table 2 should be less than two units in the last decimal communicated.

TABLE 1

U.T. of first contact	$11^h 21^m 56^s$
U.T. of greatest phase	$12^h 40^m 11^s$
U.T. of last contact	$13^h 55^m 14^s$

In Figure 1 and Table 2, the symbols have the following meanings:

N = celestial North-pole,
d = separation of the centers of the Sun and the Moon, in units of the *apparent* angular radius of the Sun,
$r_{\leftmoon}$ = apparent radius of the Moon, in the same units as d,
ω_1 = position angle of the Moon's center with respect to the Sun's center, measured east from the celestial North-pole,
ω_2 = position angle of the Moon's center with respect to the Sun's center, measured east from the Sun's axis of rotation.

The difference $\omega_1 - \omega_2$ is the position angle of the Sun's axis of rotation. This was interpolated for each

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[1]) *Stockholms Observatorium Annaler* **16**, nr. 2, pp. 8-9, 1950.

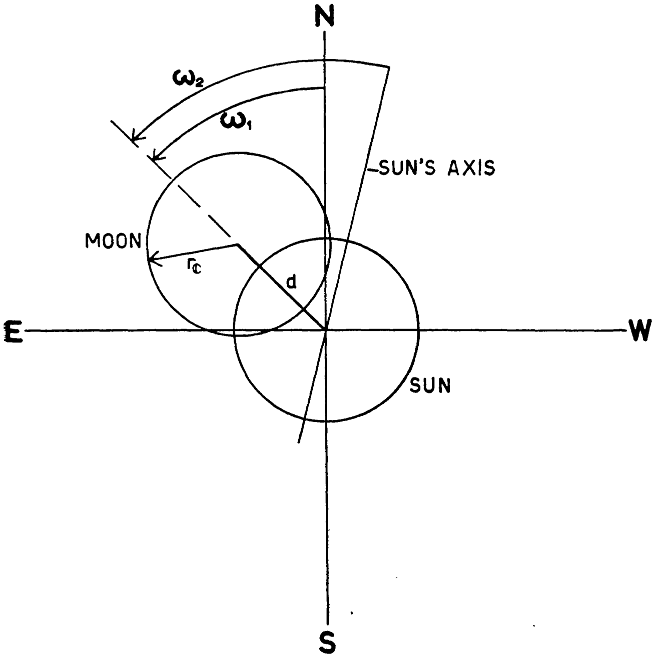
TABLE 2

Time (U.T.)	d	$r_{☾}$	ω_1	ω_2	Non-eclipsed area
h m s			° ′ ″	° ′	%
11 20 00	2.0859	1.0379	−65 07 50	−61 57.5	100.00
11 21 54	2.0473	1.0379	−64 49 15	−61 39.0	100.00
11 26 00	1.9374	1.03785	−64 07 00	−60 57.0	98.65
11 30 00	1.8387	1.0378	−63 20 50	−60 11.0	96.25
11 35 00	1.7157	1.0378	−62 17 05	−59 06.0	92.35
11 40 00	1.5932	1.03775	−61 04 25	−57 54.5	87.75
11 50 00	1.3503	1.0377	−58 02 50	−54 53.0	76.90
12 00 00	1.1117	1.0376	−53 47 10	−50 37.5	64.60
12 10 00	0.8850	1.03745	−47 20 00	−44 10.5	51.80
12 20 00	0.6678	1.0373	−36 38 35	−33 29.0	38.80
12 30 00	0.4955	1.0372	−17 26 55	−14 18.0	28.15
12 35 00	0.4411	1.0371	−02 56 40	+00 12.0	24.70
12 40 00	0.4198	1.0370	+13 45 20	16 54.0	23.40
12 40 15	0.41975	1.0370	14 38 20	17 47.0	23.35
12 41 00	0.4209	1.0370	17 36 10	20 35.0	23.45
12 45 00	0.43855	1.0369	31 18 25	34 27.0	24.60
12 50 00	0.4915	1.0368	46 02 40	49 11.0	27.95
13 00 00	0.6652	1.0366	65 47 00	68 55.0	38.70
13 10 00	0.8843	1.0364	76 44 20	79 53.0	51.80
13 20 00	1.1240	1.0362	83 17 50	86 26.0	65.30
13 30 00	1.3747	1.0359	87 35 00	90 43.0	78.15
13 40 00	1.6325	1.0357	90 35 30	93 43.0	89.35
13 45 00	1.7635	1.03555	91 47 00	94 54.5	94.05
13 50 00	1.8956	1.0354	92 49 10	95 47.0	97.80
13 55 11	2.0201	1.0353	93 47 40	96 53.0	99.90
14 00 00	2.1631	1.0351	94 32 15	97 40.0	100.00

point in Table 2 from the following values given in the *Berliner Jahrbuch* 1954:

30 June 1954 0^h U.T. $\omega_1 - \omega_2 = -3^\circ.39$
1 July 1954 0^h U.T. $\omega_1 - \omega_2 = -2^\circ.93$

FIGURE



Co-ordinate system

2. *The antenna.*

Through the kindness of Prof. J. L. VAN SOEST, the antenna used in these measurements was the 7.5 meter, alt-azimuth mounted "giant Würzburg" antenna belonging to the Physics Laboratory of the Netherlands Organization for Applied Research (T.N.O.). Dr S. GRATAMA, also of this laboratory, arranged for the installation of altitude and azimuth indicators with a least count of 0°.1 and for the adjustment of the dipole-and-reflector feed.

Using the sun as a test source, the form of the primary antenna beam was found to be closely similar to that shown in Figure 1 of *B.A.N.* No. 452, except that the half-power beam widths were 7° in the horizontal direction and 10° in the vertical. During the eclipse run, the altitude of the sun was in the range 43 — 61°. In order to minimize interference from sources on the horizon, the dipole feed was placed in a vertical plane. Since the antenna was not equipped for automatically following the sun, it was necessary to reset the antenna at least every two minutes in order to keep the sensitivity constant to within about 0.1% of the mean.

The altitude and azimuth indicators were calibrated the day before the eclipse by sweeping the beam back and forth across the sun and comparing the mean positions of the recorded maxima with positions determined from the *Nautical Almanac*. The solar flux appeared to be very constant and these tests indicated that the pointing error should be no greater than about ± 0°.1.

The dipole was connected to the receiver by 12 meters of polythene insulated RG-8/U coaxial cable with an insertion loss of about 1.5 db. Because the receiver was adjusted for a low noise figure, the receiver input circuit was mismatched to the cable and, therefore, the noise power delivered to the recorder was a sensitive function of the cable output impedance. While the support for the dipole was found to be sufficiently rigid, considerable difficulty was experienced with dressing the cable so that the flexing which accompanied changes in the altitude settings would not produce noticeable variations in the apparent signal level. A temporary solution was achieved for the present case, but it is clear that the use of this general type of cable, under similar physical and electrical circumstances, should be avoided ^{1}).

3. *The receiver.*

The receiver was still in development at the time of the eclipse and it was necessary to use it as a

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^{1}) This effect, which varies with time, temperature, humidity and manufacturer, appears to be a normal property of many "flexible" high-frequency cables and, in the present case, would preclude accurate galactic flux density measurements.

normal super-heterodyne, driving a Philips recording potentiometer (Type PR2000) by means of a cathode follower equipped for depressed zero operation. The receiver consisted of a 400 Mc/s r.f. amplifier, crystal controlled mixer, 50 Mc/s i.f. pre-amplifier, precision push-button attenuator, main i.f. amplifier, high-level detector and cathode follower. DC plate and AC filament supplies were regulated to better than 0.1%.

The 400 Mc/s amplifier used preliminary examples of the Philips EC56 coplanar triode arranged in the cascode connection of WALLMAN, MACNEE and GADSEN [1]). The noise figure at the time of the eclipse is not known; however, despite the small effective cross section of the antenna and the losses in the cable, the signal-to-noise ratio on the sun was about 3/4 [2]). Because of this favorable ratio, the only source of receiver drift believed to be significant in the eclipse measures was the method used at that time to cool the EC56 tubes. This made the high frequency gain unnecessarily sensitive to changes in ambient temperature.

In a receiving system such as the one described here, the last i.f. amplifier stage and the detector should be the only appreciably non-linear elements between the antenna and the recorder. Because some degree of non-linearity appears to be unavoidable at the present time, and since its importance increases with the signal-to-noise ratio, a combination of circuits was chosen which seems to provide an unusually stable transfer characteristic. Briefly, a high-level (6.5 watt) last i.f. amplifier stage drives a "constant input impedance" detector [3]) through a coupling circuit which allows a high and uniform gain over a 10 Mc/s bandwidth. Thus, compared to the usual 1.5 watt amplifier and diode, a relatively high detector output is permissible along with a much lower i.f. non-linearity, greater freedom from valve aging effects, and the overall power-frequency response is effectively independent of the operating level.

Since it is possible, in this case by using built-in controls, to determine the form of the transfer characteristic, in arbitrary units, to a degree of precision which is limited only by the receiver stability and the patience of the operator, the absolute accuracy of the determination depends only on the reliability of the available standard of power ratio. One accurately known ratio is sufficient, but several are more convenient [4]).

For the eclipse, the transfer characteristic of the main i.f. amplifier, detector and cathode follower was measured over the appropriate range with the following results:

$$P \sim E^{1.57 \pm 0.02} \qquad (1)$$

where P is the input power to the receiver and E is the average cathode follower output voltage, measured above the voltage corresponding to zero input power to the detector. Such a simple expression would not have been sufficiently accurate if the signal-to-noise ratio had been three times greater.

The recorder was calibrated against a standard voltage divider. Its non-linearity and instability were found to be 0.1% or less, which corresponds to a deviation of the inked line less than one-tenth the smallest (2.5 mm) scale division.

4. *Observing procedure.*

Continuous operation of the receiver for several days prior to the eclipse showed it to be adequately stable except for the effect of temperature variations on the r.f. amplifier. Before, during and after the eclipse run, there was no evidence of appreciable irregular variations, or "jumps", in either the gain or the internally generated receiver noise. During the eclipse, the operators remained shut in with the equipment so as to minimize temperature changes.

Because of exceptional pulse-transmitter interference in the neighbourhood of 400 Mc/s, the high-frequency bandwith was reduced to 0.9 Mc/s. This increased the recorded "white" noise level by the factor $\sqrt{11}$, so that the peak-to-peak noise amplitude on the record was about 1% of the signal from the unobscured sun.

It was necessary to observe the eclipse in directions lying right over The Hague. To improve the chance of subtracting the effect on the record of interference due to the urban noise level, the electrical response was limited only by a single low-pass filter section with an RC product of $0^s.1$, and the recording paper speed was set to 6 cm/min. The recorder response was dead beat at all signal levels and required $0^s.8$ to complete deflection on the application of a full scale (25 cm) step function input signal.

Systematic observing began about two hours before the start of the eclipse and continued for one hour after last contact. The procedure was the following:

1. The antenna was adjusted every two minutes so that the maximum of the main lobe would be

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[1]) *Proc. I.R.E.* **36**, nr. 6, June 1948.

[2]) A description of this amplifier and certain other particulars on the receiver will appear elsewhere.

[3]) See, for instance, SQUIRES and GOUNDRY, *Electronics* **25**, April 1948.

[4]) The writer is indebted to Dr J. P. HAGEN of the Naval Research Laboratory, Washington, D.C., for a check calibration of the Daven attenuator used here. This unit gives independent steps of 1, 2, 3, 4, 10 db. Six years experience with several of these units has shown the life-performance of the push-button switch to be excellent.

directed at the center of the sun in the middle of this interval. Scale readings were compared with the previous instructions before making a new setting.

2. At least every ten minutes, the receiver was disconnected from the antenna cable and connected to a broad-band 50 ohm resistor at ambient temperature in order to provide a reference level on the record. The General Radio Company Type 874 hermaphrodite connector used here has proved its superiority to any other type of connector tried with this equipment, such as the Type "N", etc. Tests have shown the "random connector error" to be many times smaller than the smallest permissible reading on the eclipse record. Furthermore, the quick-disconnect feature permitted satisfactory reference level insertion with a total off-sun time of only 30-40^s.

3. Time marks accurate to a fraction of a second were added to the record at frequent intervals by using an electric clock and a chronometer to interpolate between time signals received from (a) BBC broadcasts and (b) telephoned counts by Mr DE LAAN, of the PTT time service laboratory, to whom thanks are due for filling in during a busy period when the radio transmissions were smothered by interference.

4. A continuous aural and oscillographic monitoring of the detector output noise was maintained and remarks about the interference were inserted on the record.

5. Before and after the eclipse, a number of comparisons were made between the reference level and the level recorded with the antenna pointed at the celestial north-pole. Then, at 15^h U.T., the north-pole readings were compared with that obtained with the antenna directed at the zenith (R.A. 9^h 48^m, Dec. 52°.1).

6. Whenever the reference level had drifted from an arbitrary value by as much as one or two percent of the maximum solar signal, it was returned to the original value by means of a vernier *gain* control.

5. *Data reduction.*

On the eclipse record, the unobscured sun gave a deflection of nearly 20 cm. The fluctuation noise appeared as a fine granulation of the trace about 2 mm wide, peak to peak. Interference by the irregular noise level from The Hague was clearly the factor limiting the precision with which the record could be read with profit. The receiver never produced any irregular, downward "jumps" and, since interfering signals would only increase the deflections, the effect of the interference could be minimized by reading along the lowest dips of the trace, thus taking advantage of every momentary lull in the interference. The validity of such a reading method depends, of course, on the correctness of certain assumptions about the nature of the desired signal and about the performance of the observing equipment. In the present case, reading along the dips, even if there were only three or four, each lasting but a fraction of a second, noticeably reduced the scatter in the tabulated data, when compared with readings obtained by the more usual method which estimates the mean position of a fuzzy line after omitting the obvious positive peaks.

In this way, each two-minute section of the record was averaged for a single mean-minimum deflection corresponding to the time when the maximum of the antenna pattern was directed at the center of the sun. The north-pole, zenith and reference registrations were read in a similar manner. All measures were tabulated to the nearest 0.5 mm.

There were at most five eclipse readings between consecutive reference level determinations and linear interpolation was used to estimate intermediate values. All reference levels were converted to equivalent 15^h U.T. zenith readings. Using equation 1, each observation of the sun was transformed to a relative power above a zero level defined by the apparent power received from the zenith at 15^h on the day of the eclipse. Finally, this relative power scale was normalized about the value which was estimated to represent the flux from the unobscured, interference-free sun. This estimate was formed by assuming, once again, that the equipment was relatively fault free; that the unobscured solar flux was constant throughout the eclipse run; and that the lowest deflections during the periods before and after the eclipse represented the best possible approach to the deflection which would have been obtained under ideal conditions.

The data obtained in this way are given in Table 3. P is the apparent power received from the sun. The column headed A lists the corresponding percentage of the uneclipsed solar disk as obtained by interpolation of the data in the last column of Table 2. The radio and geometric eclipses are plotted against U.T. in Figure 2 for the interval 11-14^h U.T. Figure 3 shows (a) $P-A$, (b) the variation in the reference level, and (c) the altitude of the sun, throughout the eclipse run.

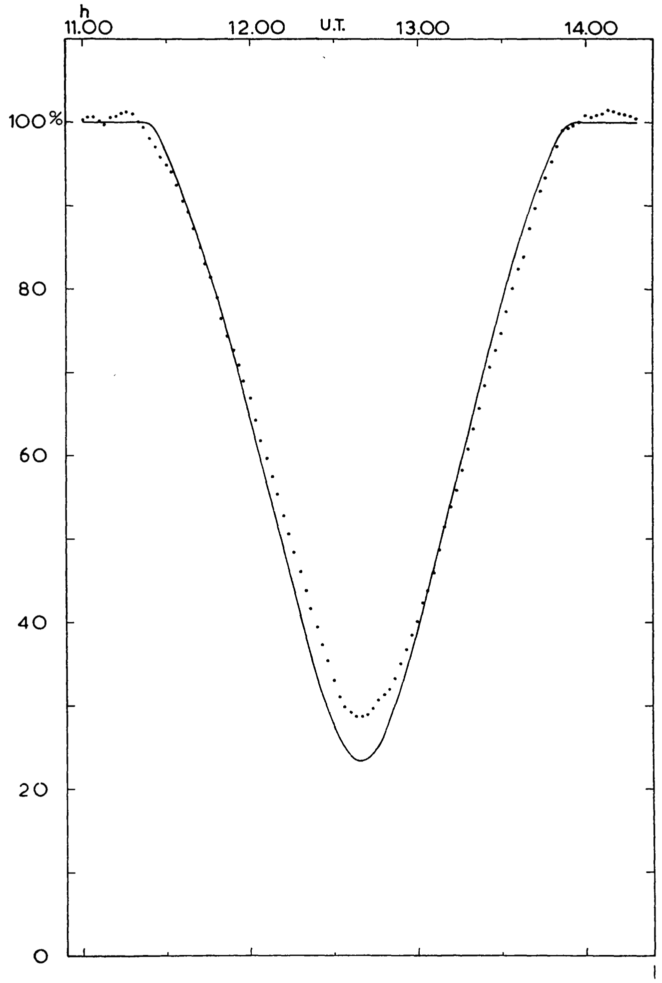
6. *Sources of error.*

The aims at which radio eclipse curves are commonly directed cannot be reached unless such measurements are performed with exceptional care. In favorable circumstances, the present state of the art should permit the attainment of accuracies approaching 0.1%, at least for the shorter wavelengths.

TABLE 3

Time (U.T.)	*P*	*A*	Time (U.T.)	*P*	*A*	Time (U.T.)	*P*	*A*
h m s	%	%	h m s	%	%	h m s	%	%
9 30 13	102.7	100.0	11 20 13	100.0	100.0	13 10 13	51.4	52.0
9 32 13	103.0	„	11 22 13	99.4	99.9	13 12 13	53.8	54.7
9 34 13	103.1	„	11 24 13	98.0	99.3	13 14 13	55.8	57.4
9 36 13	103.2	„	11 26 13	97.0	98.5	13 16 13	58.2	60.1
9 38 13	102.1	„	11 28 13	95.8	97.4	13 18 13	60.8	62.8
9 40 13	101.2	„	11 30 13	94.9	96.1	13 20 13	63.2	65.5
9 42 13	101.4	„	11 32 13	94.0	94.7	13 22 13	65.6	68.2
9 44 13	102.1	„	11 34 13	92.4	93.1	13 24 13	68.4	70.8
9 46 13	102.3	„	11 36 13	90.5	91.3	13 26 13	70.6	73.4
9 48 13	102.1	„	11 38 13	89.2	89.4	13 28 13	72.7	75.9
9 50 13	101.8	„	11 40 13	87.2	87.5	13 30 13	74.7	78.4
9 52 13	101.7	„	11 42 13	84.9	85.4	13 32 13	77.3	80.9
9 54 13	101.9	„	11 44 13	83.0	83.3	13 34 13	80.1	83.0
9 56 13	102.4	„	11 46 13	81.3	81.1	13 36 13	82.4	85.2
9 58 13	102.9	„	11 48 13	78.9	79.0	13 38 13	83.8	87.4
10 00 13	102.9	„	11 50 13	76.4	76.7	13 40 13	87.2	89.5
10 02 13	103.0	„	11 52 13	74.3	74.3	13 42 13	89.6	91.5
10 04 13	102.2	„	11 54 13	72.6	71.9	13 44 13	91.7	93.4
10 06 13	102.0	„	11 56 13	70.9	69.4	13 46 13	93.2	95.1
10 08 13	101.0	„	11 58 13	68.9	66.9	13 48 13	95.2	96.6
10 10 13	102.0	„	12 00 13	66.9	64.3	13 50 13	97.0	97.9
10 12 13	102.0	„	12 02 13	64.2	61.7	13 52 13	99.0	98.9
10 14 13	102.0	„	12 04 13	61.7	59.2	13 54 13	99.2	99.7
10 16 13	102.0	„	12 06 13	59.6	56.6	13 56 13	99.5	100.0
10 18 13	100.8	„	12 08 13	57.5	54.0	13 58 13	99.9	„
10 20 13	100.8	„	12 10 13	55.3	51.5	14 00 13	100.8	„
10 22 13	100.9	„	12 12 13	52.7	48.9	14 02 13	100.6	„
10 24 13	99.7	„	12 14 13	50.6	46.3	14 04 13	100.8	„
10 26 13	100.1	„	12 16 13	48.4	43.7	14 06 13	101.0	„
10 28 13	101.1	„	12 18 13	46.1	41.1	14 08 13	101.5	„
10 30 13	101.1	„	12 20 13	43.8	38.5	14 10 13	101.2	„
10 32 13	101.2	„	12 22 13	41.6	36.0	14 12 13	101.0	„
10 34 13	101.3	„	12 24 13	39.5	33.7	14 14 13	100.9	„
10 36 13	101.1	„	12 26 13	37.3	31.5	14 16 13	100.7	„
10 38 13	101.3	„	12 28 13	35.4	29.6	14 18 13	100.4	„
10 40 13	100.7	„	12 30 13	33.1	27.9	14 20 13	—	„
10 42 13	101.6	„	12 32 13	31.1	26.3	14 22 13	102.0	„
10 44 13	101.4	„	12 34 13	29.8	25.0	14 24 13	101.9	„
10 46 13	101.8	„	12 36 13	29.2	24.1	14 26 13	101.8	
10 48 13	101.6	„	12 38 13	28.7	23.5	14 28 13	100.8	„
10 50 13	100.7	„	12 40 13	28.7	23.4	14 30 13	101.1	„
10 52 13	100.8	„	12 42 13	28.9	23.6	14 32 13	101.6	„
10 54 13	101.2	„	12 44 13	29.6	24.3	14 34 13	101.6	„
10 56 13	100.8	„	12 46 13	30.6	25.2	14 36 13	101.2	„
10 58 13	100.9	„	12 48 13	31.3	26.5	14 38 13	—	„
11 00 13	100.3	„	12 50 13	31.8	28.1	14 40 13	101.2	„
11 02 13	100.6	„	12 52 13	33.2	29.8	14 42 13	101.6	„
11 04 13	100.7	„	12 54 13	35.0	31.9	14 44 13	101.5	„
11 06 13	100.2	„	12 56 13	36.7	34.1	14 46 13	101.3	„
11 08 13	99.7	„	12 58 13	38.5	36.4	14 48 13	100.8	„
11 10 13	100.6	„	13 00 13	40.1	38.7	14 50 13	100.6	„
11 12 13	100.7	„	13 02 13	42.3	41.4	14 52 13	100.8	„
11 14 13	101.1	„	13 04 13	43.7	44.0	14 54 13	100.4	„
11 16 13	101.2	„	13 06 13	45.9	46.6	14 56 13	100.6	„
11 18 13	101.0	„	13 08 13	48.6	49.3	14 58 13	101.4	„

FIGURE 2



Eclipse of 30 June 1954 as observed near The Hague. Dotted line, ..., 400 Mc/s power (P) received from the sun. Solid line, ——, computed geometric eclipse curve (A).

But circumstances and facilities are often far from ideal and it is reasonable to suppose that many of the published measurements would fall in the 1-10% range. While the literature of the past decade contains numerous discussions of radio eclipse observations, it has not been customary to discuss the details of the techniques employed. Hence, it is often difficult to judge the quality of the conclusions, which makes the data less useful for a critical discussion of solar models.

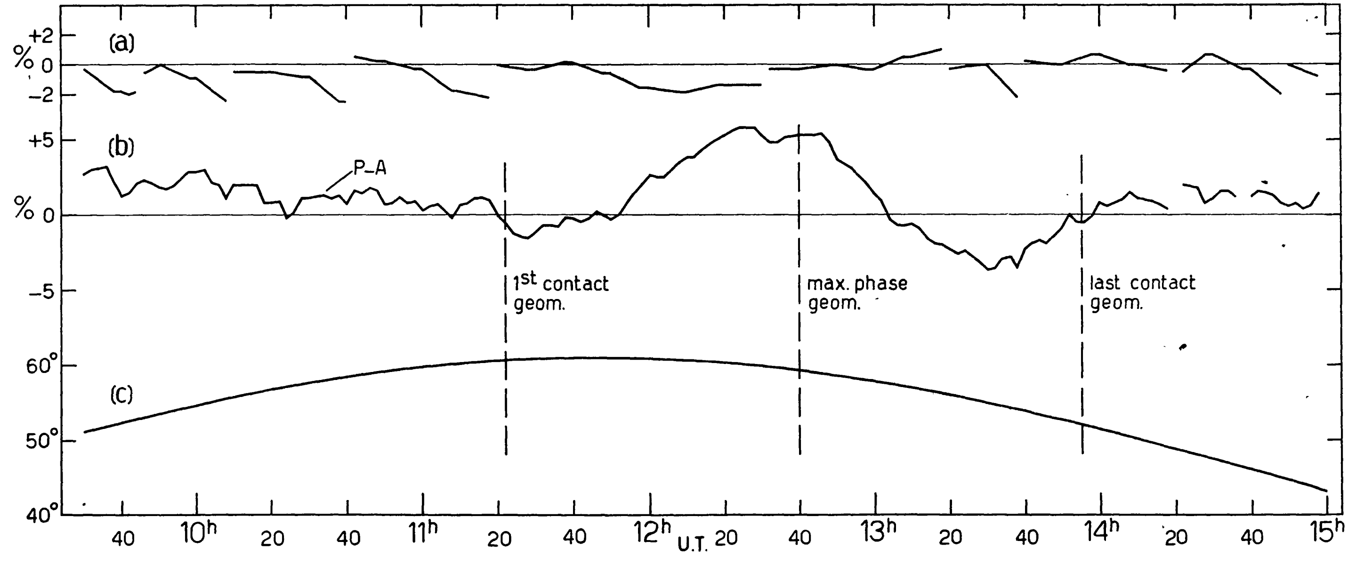
The difficulties met in the present instance are similar in many respects to those encountered by others in the past and perhaps to be expected in the future. Since the problems of the radio technique are not necessarily obvious, it seems desirable to discuss some of the sources of error likely to affect precision radio eclipse observations, with the present apparatus providing numerical examples.

(A) PHYSICAL CIRCUMSTANCES.

These are the ultimate factors limiting the attainable accuracy in radio eclipse observations where the whole sun-moon system is encompassed by the central portion of the main antenna beam.

I. *The state of solar activity.* With simple equipment, such as that used here, the degree of solar activity will determine the nature of what is, in effect, observed. When the solar flux is steady, the general features of the coronal brightness distribution can be recorded. If one or more stormy regions are present, the result is likely to be confined to data on the positions of these regions and some information on their extent and brightness. Considerably more refined

FIGURE 3



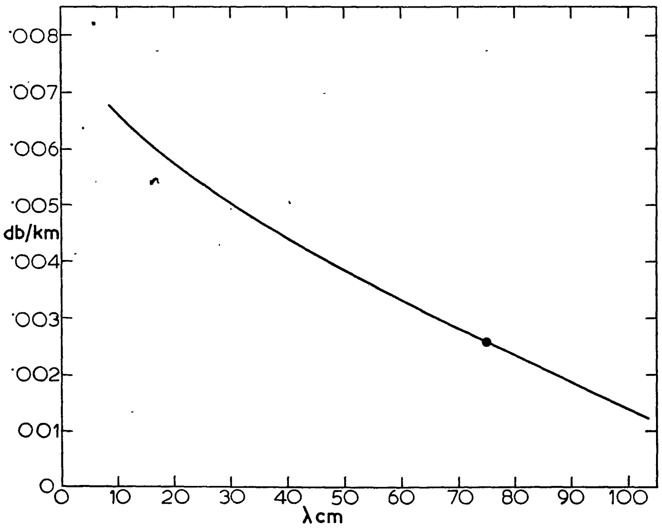
Curve *(a)*: Reference level drift curve. The ordinate unit is per cent of the 400 Mc/s power received from the unobscured sun. Curve *(b)*: The differential eclipse curve, or (P - A) from Table 3. The ordinate unit is the same as for curve *(a)*. Curve *(c)*: Altitude of the sun throughout the eclipse run.

observing techniques should be used when there is pronounced solar activity. In any event, since not even the coronal background brightness distribution is radially symmetric, two or more co-ordinated observing stations are required in order to take good advantage of an eclipse.

II. *Lunar edge diffraction.* At decimeter and meter wavelengths, diffraction at the edge of the moon introduces an appreciable smoothing effect. At 400 Mc/s, the width of the first Fresnel zone is about 9″, or approximately one percent of the sun's radius. Furthermore, since the moon moves at a rate of about 1800″/hr, any variation on the record which is completed in a time appreciably less than 18ˢ cannot be produced by occultation, but must be the result either of some form of interference or an intrinsic change in the radiation level from the unobscured portion of the sun. While this limits the accuracy with which one may reconstruct the true solar brightness distribution, it may very well be a help in analyzing the record.

III. *Absorption, refraction and scattering effects.* Atmospheric absorption is appreciable for wavelengths shorter than about one meter. Down to 10 cm, it is almost entirely due to the paramagnetism of the O_2 molecule. The pertinent theory is sufficiently well developed so that one may calculate the total absorption to a satisfactory degree of precision, at least for elevation angles greater than 5°. Figure 4, after VAN VLECK [1]), shows the wavelength dependence of oxygen absorption, in decibels per kilometer of normal atmosphere (20°C and 760 mm Hg). Table 4 shows the total absorption expected at 400 Mc/s as a function of the elevation angle of the source. VAN VLECK's data have been increased by 10% to provide a rough allowance for the variation of temperature with height above the earth's surface. The secant law is assumed for elevation angles above 10°.

FIGURE 4



Atmospheric attenuation, in db/km of normal air (20°C and 760 mm Hg), versus wavelength. Data from VAN VLECK.

TABLE 4

True elevation	Apparent elevation	Kilometers of normal air	Percent absorption	Apparent atmospheric temperature °K
°	°			
0.5	1	216	15.2	39
1.7	2	158	10.9	27
4.9	5	83	5.6	14
9.9	10	46	3.1	7.6
	20	23.4	1.6	3.9
	30	16	1.06	2.7
	40	12.5	0.82	2.1
	50	10.4	0.68	1.7
	60	9.3	0.61	1.5
	70	8.5	0.56	1.4
	90	8.0	0.53	1.3

Figure 3c and Table 4 show that, under the favorable conditions of this eclipse, the atmospheric attenuation varied systematically, back and forth, over a range of 0.2%.

Absorption not only decreases the solar radiation but also modifies the apparent signal by changing the effective background brightness in the line of sight, as shown by the figures in the last column of Table 4. The importance of this effect increases with decreasing antenna directivity. In the present case, it is negligible.

Below 10 cm, the problem becomes much more severe. In addition to the rapidly increasing oxygen absorption, there is a contribution from the variable water vapor content of the atmosphere. Thus, nearly simultaneous atmospheric extinction measurements are likely to be necessary when attempting accurate solar observations [2]).

There is some evidence, as yet mostly unpublished, which indicates that the signal from the quiet sun is occasionally diminished in an irregular fashion for periods lasting tens of seconds or more, perhaps by some form of scattering or absorption which may differ from the scintillation phenomena encountered in the observation of radio "stars". As the technique for observing the quiet sun improves, one can expect more precise information on an effect which is likely

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[1]) *Radiation Laboratory Series*, Vol. **13**, pp. 646-692, McGraw-Hill Book Co., 1951.

[2]) VAN VLECK, *op. cit.*

to escape notice during times of moderate to high solar activity [1]).

When eclipses occur at times of considerable solar activity, observation of small bright regions is likely to be impaired by ionospheric scintillation, particularly at meter wavelengths and low elevation angles [2]). At shorter wavelengths and low angles, variable tropospheric refraction can produce the same sort of difficulty.

Transmitters well beyond the horizon have been identified as the primary sources of signals which appear to originate high in the sky. Presumably, this effect, since it appears to depend on meteorological conditions, is a form of the atmospheric scattering discussed by BOOKER and GORDON [3]). The writer has observed this to be an appreciable source of interference on 200 Mc/s.

(B) ANTENNA DIRECTIVITY.

I. *Non-uniform sensitivity.* It would have been difficult to obtain a satisfactory eclipse curve without accurate, automatic guiding if the half-power beam widths had been on the order of 2°. Also, it would have been necessary to carry out tedious corrections for the non-uniform sensitivity over the face of the sun. With a $7° \times 10°$ beam, however, no error as great as 0.1% should be expected from either the two-minute, step-by-step guiding or the shape of the main beam.

II. *Background brightness.* The large beam width may have introduced an appreciable error in the power scale used in the data reduction. The zero on this scale was assumed to correspond with the registration from the zenith at 15^h when the antenna was pointed at a region far from the Milky Way ($l = 131°$ and $b = +50°$). But the sun ($l = 158°$ and $b = +9°$) was barely one half-power beam width away from the galactic plane. The 400 Mc/s galactic radiation from both of these regions should be low, but how low is very uncertain at the present time. And it is the differential brightness which determines the zero-point error. Unfortunately, it was not possible to determine this difference directly, but one can estimate the likely range of the resulting error. Calculating the axial directivity from the known half-power beam widths and using the expressions for the power absorbed by an antenna from a point source and from an extended source, one finds that, for the data in Table 3, the assumed zero power level is too low by the following amount,

$$\Delta P_0 = (0.06 \pm 0.01)\,(\Delta T/T_D)\, 6 \times 10^5\,\%, \qquad (2)$$

where ΔT is the difference in degrees Kelvin by which the background brightness near the sun exceeded the zenith brightness, and T_D is the mean brightness temperature of the $\frac{1}{2}°$ sun. Thus, for a mean solar brightness of 6×10^5 °K and a 10°K differential, the assumed zero was too low by 0.5 — 0.7%. The spread comes from the usual uncertainty in a calculation of the axial directivity from the half-power beam widths.

III. *Wide-angle response.* The antenna directivity outside of the region covered by the main beam is often one of the most critical and troublesome characteristics of a radio telescope because it is nearly impossible either to measure it or to calculate it with sufficient accuracy. In addition, the antenna is more or less surrounded by interfering sources, some of which lie in the near-field region; and the properties of this region change when the antenna is pointed in different directions. The usual compromise is to design the antenna so as to minimize the side and back response, though improvement here is accompanied by a rapid increase in cost for a given primary beamwidth. Even then, precision measurements may be confined to objects nearer the zenith than the horizon, particularly when using half-power beam widths of 10° or more.

The Würzburg mirror was designed with the focus well inside the aperture and therefore a considerable part of the reflector is a shield to reduce the wide-angle response. Still, it was fortunate that the eclipse occurred at such a favorable altitude. Antenna pattern tests showed that solar radiation reflected by the earth and near-by objects could be ignored when the sun was higher in the sky than 25°. At lower elevations, only very rough corrections could have been attempted because of the irregular terrain. Thermal radiation from the ground, which was also a function of azimuth, could be neglected above 35°. At lower elevations more satisfactory corrections could have been made than for the reflected solar radiation, because the correction would be only a smoothly varying function of the antenna position.

The urban noise sources covered about 150° of the southern horizon and there were numerous reflecting

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[1]) This phenomenon was brought to the writer's attention by Mr A. D. FOKKER (Ionosphere and Radio Astronomy Section of the PTT, Kortenaerkade 12, The Hague, Holland), who has been studying the matter for some time. Subsequently, at an informal meeting of some of those who had observed this eclipse, it appeared that several records showed clear-cut examples of temporary, even repeated fading of the solar signal.

[2]) RYLE, M. & HEWISH, A., *Mon. Not. Roy. Astr. Soc.*, **110**, 381-394, 1950.
SEEGER, C. L., *Jour. Geoph. Res.*, **56**, 2, 1951.
BOLTON, J. G., SLEE, O. B., & STANLEY, G. J., *Aust. J. Phys.*, **6**, 4, 1953.

[3]) *Proc. I.R.E.*, **38**, nr. 4, 1950.

objects close to the antenna. It was for this reason that there is an unavoidable noise residue in the eclipse data after reduction. This residue varies, from an estimated ½% near maximum phase to 1 or 2% during the pre and post eclipse periods, in a roughly smooth manner which appears to correspond with the changes in elevation of the sun (compare Figures 3b and 3c). There was probably some assistance from the fact that the eclipse occurred during the noon recess on a clear day and many people stopped to watch the event. The data for 1242-4-6-8 U.T. contain interference from a motorized bicycle. The driver came right up to the antenna to find out why there was a small knot of people in rapt attendance on an apparently inert object.

(C) TEMPERATURE EFFECTS.

Temperature variations affect the performance of all parts of a radio telescope. Until it has been demonstrated by actual test, no radiometer should be assumed to have negligible temperature sensitivity when discussing its performance to a precision of 1% or better.

I. *The receiver.* It is doubtful whether, during the eclipse run, the temperature inside or outside the operating cubicle varied by as much as 5° C [1]). But a variation was noticed by the operators and its effect can be clearly seen in the reference level drift-curve, Figure 3a. The ordinate is percent of the unobscured sun signal and each break in the curve corresponds to an adjustment of the vernier gain control. The gain of the receiver decreased with rising temperature. The variation in the slope of the drift-curve reflects the morning rise, the still stand or even fall accompanying the eclipse, and the continued rise in temperature after the eclipse. The temperature inside the cubicle probably followed the outdoor variations more or less closely because an exhaust fan was in continuous use to remove the two kilowatts of heat generated by the equipment plus that produced by the two operators. Thus, there was a continuous inlet of cool air which, because of the slight breeze, could not always be prevented from causing fairly rapid, albeit small, changes in the inside ambient temperature.

Variations in the reference level could be caused by changes in gain, changes in the receiver noise figure or by changes in the thermal noise delivered by the reference resistor; and it was known from tests that temperature was the only important parameter in all three respects, barring the sudden appearance of a fault in the apparatus. Furthermore, the temperature coefficient of gain was by far the most serious. Registration of the reference level meant that this source of error could be controlled. In the usual Dicke type receiver, these gain variations would have been effectively disguised, to the detriment of the accuracy of the data.

Examination of the pre and post eclipse strength of the solar signal shows that, within the limit set by the variable interference level, there was no apparent change in the system gain, antenna to recorder, if the sun itself was constant.

II. *The antenna cable.* Without the interference, other temperature effects could have produced noticeable errors and it is worth estimating their likely magnitude on the basis of a 5°.8 (2%) rise above 290°K.

There appear to be no accurate data on the temperature coefficients of attenuation and impedance for cables like the one used here. When the cable is matched both to the antenna and to the receiver, the effect of the temperature coefficient of impedance is likely to be negligible. Under the mismatched conditions required to give a low noise figure with equipment such as that used here, the effect of this coefficient may vary over a wide range and is certain to be important.

The antenna cable attenuation reduced the signal by about 30% [2]). The temperature coefficient of attenuation is difficult to predict, but the order of magnitude can be estimated on the assumption that all the losses are series copper losses subject to the usual temperature coefficient of 0.4% per °C. Under matched conditions, then, the attenuation might increase by about 2.3% and the solar signal decrease by about half this amount. Under mismatched operation, the attenuation will increase somewhat and so will the effect of temperature variation. Obviously, if such a cable must be employed, it would be desirable to carry out tests on the particular length of cable used, both when it is new and at a later date. In any case, direct sunlight should be kept off the cable and only the most gentle flexing permitted.

The thermal noise delivered by the cable loss resistance is appreciable. In this instance it was approximately one third that delivered by the reference resistor.

A change in its temperature introduces a proportional change in the available thermal noise generated in this loss resistance. As far as the receiver is concerned, this is equivalent to an additive increase in the antenna temperature which is independent of

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[1]) Neglected here was one of the first rules of experimental physics, to wit, "Always keep thermometers around experimental equipment, and record the temperatures".

[2]) This value was calculated, assuming the manufacturer's data and matched conditions.

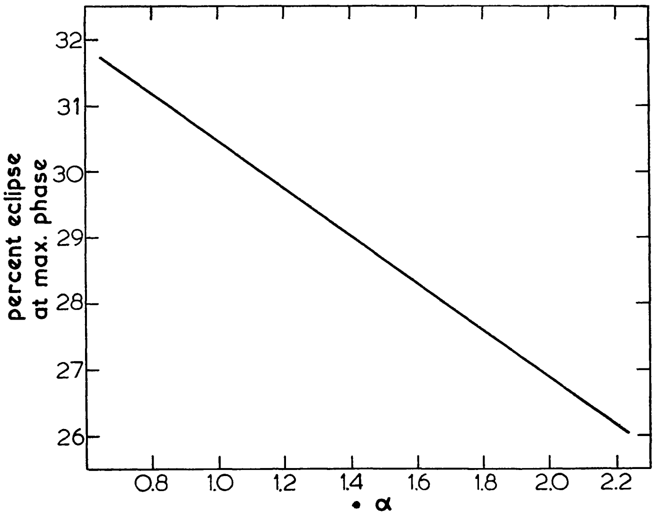
where the antenna may be directed and which will introduce an error unless the thermal noise delivered by the reference resistor increases by the same amount. To a certain extent, this compensation occurred here. For perfect compensation, the temperature rise of the cable and the temperature rise of the reference resistor must be proportional but, in general, not equal. The ratio can be computed on the basis of sufficient test data.

III. *The reference resistor.* It has been found that the temperature coefficient of resistance of the film type resistors commonly used varies widely, depending on their construction. Even two similar units may have coefficients differing by a factor of two, so tests are advisable in each particular case. The deposited carbon resistor used here had a coefficient of approximately −0.05% per °C at 25° C.

Again, because of the mismatched conditions, there are two effects. A −0.26% decrease in the resistance would have decreased the reference level by about 0.1%. An exact value cannot be given because of insufficient data on the particular noise figure adjustment obtaining at the time of the eclipse. Roughly speaking, and for low noise figures, the lower the noise figure the greater is the effect of a change in the reference resistor impedance.

Because of the method employed to compensate for the effect of temperature on the receiver gain, the 2% increase in the available thermal noise of the reference resistor would have produced a decrease in the receiver gain of, approximately, $\frac{-2}{\bar{F}}$ %, where $\bar{F}$ is the receiver noise figure. Actually, the gain would not have decreased by quite this amount because of the decrease in the receiver noise accompanying the decrease in the value of the reference resistor, and because of the tendency of the noise figure to decrease with rising temperature, an effect which has been observed but which remains, so far, unaccounted for.

FIGURE 5



Variation of the calculated depth of the 400 Mc/s eclipse at maximum phase as a function of the value adopted for the exponent in equation 1.

(D) NON-LINEARITY.

The sensitivity of the data in Table 3 to the system non-linearity is illustrated in Figure 5, where the depth of the radio eclipse at maximum phase is shown as a function of the exponent chosen in the power law approximation, equation (1). A change of 0.1 in the exponent gives a 0.4% change in the depth.

Even though the receiver was designed with a view to maintaining a stable non-linear characteristic, experience has shown that it is still necessary to measure this parameter close to the time when its precise value is important.

7. *Conclusion.*

From the preceding discussion, it appears that the dominant source of error in the data is the uncertainty introduced by the variable urban noise level (Section 6. B. III). If this interference had not been present, the eclipse curve would have been much smoother and the accuracy would have been limited by the insufficiently controlled temperature sensitivities.

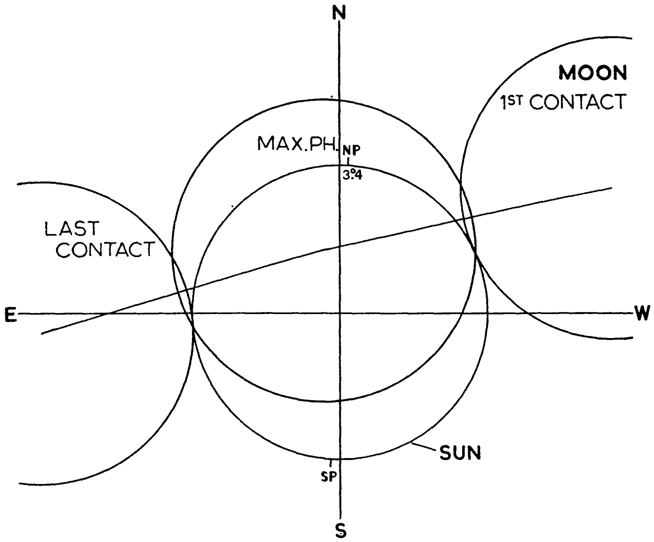
The solar radiation on 400 Mc/s appears to have maintained a very steady value throughout the eclipse run and there was no evidence of any concentrated, bright region contributing as much as 2% of the total flux. The data are sufficiently consistent so that a smooth eclipse curve can be constructed which is accurate to at least 1% except, perhaps, near the times of first and last contact where the error may be as high as $1\frac{1}{2}$%.

The radio eclipse appears to have started $3\text{-}5^{m}$ before the geometric. At first geometric contact, the solar flux was between 98 and $99\frac{1}{2}$% of the unobscured value. Correspondingly, one can estimate that the radio eclipse continued at least 5^{m} after the end of the geometric and that the strength was between $98\frac{1}{2}$ and $99\frac{1}{2}$% at last geometric contact. The radio eclipse reached maximum phase perhaps 2^{m} before the geometric and the radio flux was then no more than $28\frac{1}{2}$%, compared to 23.4%.

No galactic background correction (Section 6.B.II) has been included in the data of Table 3. If a correction seems advisable, and more than 1% seems unlikely at this time, it can be linearly interpolated directly in Table 3. Such a correction will affect chiefly the central portion of the eclipse curve and in such a sense as to increase the depth.

Figure 6 shows the path of the moon relative to the

Figure 6



Position of the moon relative to the sun throughout the eclipse.

sun during the eclipse. Figures 2 and 3b show that there is a definite asymmetry in the radio eclipse curve. Qualitatively, this asymmetry is consistent with a symmetric solar brightness distribution in which the equatorial regions are brighter than the polar regions. Alternatively, of course, there may be a small degree of east-west asymmetry. Thus it is desirable to wait for the appearance of more observational material, not necessarily on 400 Mc/s, before attempting to determine a brightness distribution from these data.

Acknowledgements.

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