THE METHOD OF LUNAR OCCULTATIONS AND ITS APPLICATION TO A SURVEY OF THE RADIO SOURCE 3C212

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Summary

It is shown that the observations of occultations of radio sources by the Moon permits the measurement of source positions to an accuracy of the order of 1″. Information is simultaneously obtained on source diameters down to a limit of 1″. The effective beam width of the system on metre wave-lengths is of the order 1/500 sq. degree, and the results are therefore free from the effects of confusion out to distances exceeding those reached in any existing survey. In addition the measurements are not affected by refraction in the Earth's ionosphere or troposphere.

The method is illustrated by an analysis of the results obtained from two occultations of the radio source 3C212. The position of this source is derived to an accuracy of 3″. It is shown to be asymmetrical, the diameters along the major and minor axes being 15″ and 7″ respectively.

It is suggested that because of its high resolution the method may prove a powerful tool for the investigation of the number/intensity relationship of the discrete sources. It is also pointed out that by carrying out the observations at two frequencies, one above and one below 100 Mc/s, it should be possible to obtain valuable information on a possible lunar ionosphere and perhaps also on other ionized regions in the interplanetary, and possibly interstellar, medium.

1. *Introduction.*—One of the most important problems in radio astronomy at the present time is the identification of the Class II radio sources. Several thousand of these sources have now been observed, but only a small fraction have been identified with visible objects; nevertheless it is generally agreed that the majority are extra-galactic objects of high luminosity at great distances. The reliable identification of these remote sources requires positional accuracies of the order of seconds of arc and as a confirmation of any proposed identification it is desirable that angular diameter information should be obtained in addition to the accurate position measurements; for the more distant sources this requires diameter measurements down to a limit of the order of 1″.

However, it is only for a few of the intense sources that the positional errors have been reduced to less than one minute of arc, while the only observations at present available which give information on such small angular diameters are the Jodrell Bank measurements on a number of selected sources from the Cambridge and Sydney Catalogues (1). The extension of these accurate measurements to the weaker sources (which will be necessary to increase significantly the number of reliable identifications of the more remote sources) poses serious difficulties due to the high primary resolution required to minimize the confusion effects

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of nearby sources. It is the purpose of this paper to show how the observation of lunar occultations with equipment which can track the Moon continuously provides a method of carrying out a high resolution survey of the radio sources which yields the required positional and diameter information simultaneously. The observations are restricted to zodiacal radio sources, but this is not a serious limitation in view of the high resolution of the system; it may also be noted that, for these low declination sources, existing measurements are least reliable and precise declination measurements most desirable.

A preliminary survey of the radio sources using the method of lunar occultations was carried out in 1958, culminating in a full-scale investigation of the method towards the end of 1960. The full analysis of these observations will be published later. In the present paper we illustrate the potentialities of the method by an account of an investigation of the radio source 3C212, based on two occultations: the first on 1960 December 8, and the second on 1961 January 31. A preliminary account of the first occultation and the estimation of the source position to better than 5″ has already been published (2).

2. *The method of lunar occultations*

2.1. *Method of observation.*—The method described requires a fully steerable aerial with a half-power beamwidth considerably greater than the diameter of the Moon. With the aerial beam directed towards the centre of the Moon the received power is recorded continuously as the Moon moves across the sky. As a source enters the aerial beam there will, under ideal conditions, be a gradual increase in received power followed by a gradual fall as the source passes out of the beam. The actual time of transit across the beam will depend on the beamwidth, but it will be of the order of several hours and hence of the order of the total observing period. Taking into account slow period drifts, the presence of other sources in the beam at the same time and also gradients in the background noise, it is unlikely that the transit of the source through the beam will be observed except for the more intense sources. However, for those sources which pass behind the Moon there will be a sudden fall in level as the source disappears followed by a corresponding rise as the source reappears. It is these sudden changes in level which are of interest and these should be easily observed provided they are greater than the random noise fluctuations and provided the receiver has the necessary gain stability.

2.2. *Shape of the occultation curves.*—On metre wave-lengths the angle subtended at the Earth by the first Fresnel zone at the limb of the Moon is of the order of 10″. For sources with an angular size less than about 10″ the Moon must therefore be considered as a diffracting screen; in relation to the size of a Fresnel zone the curvature of the Moon's limb is small and the occultation curves may be considered as diffraction curves at a straight edge. The actual shapes of the curves depend on the angular diameter and brightness distribution of the occulted source. In this preliminary analysis we have calculated a series of curves for different widths of a uniform strip source which passes diametrically behind the Moon. In calculating these curves the effect of local irregularities of the Moon's limb has been neglected. These irregularities, while not negligible, as they can be as large as 2″, are not likely to affect the general conclusions; they will probably exhibit themselves as fine structure in the diffraction pattern.

The calculated curves are plotted in Fig. 1. The abscissae are plotted in units of v, which is related to the scale of the diffraction pattern by:

$$\theta = v\sqrt{(\lambda/2d)},$$

where θ = angular scale of the diffraction pattern, λ = the wave-length, and d = the distance of the Moon.

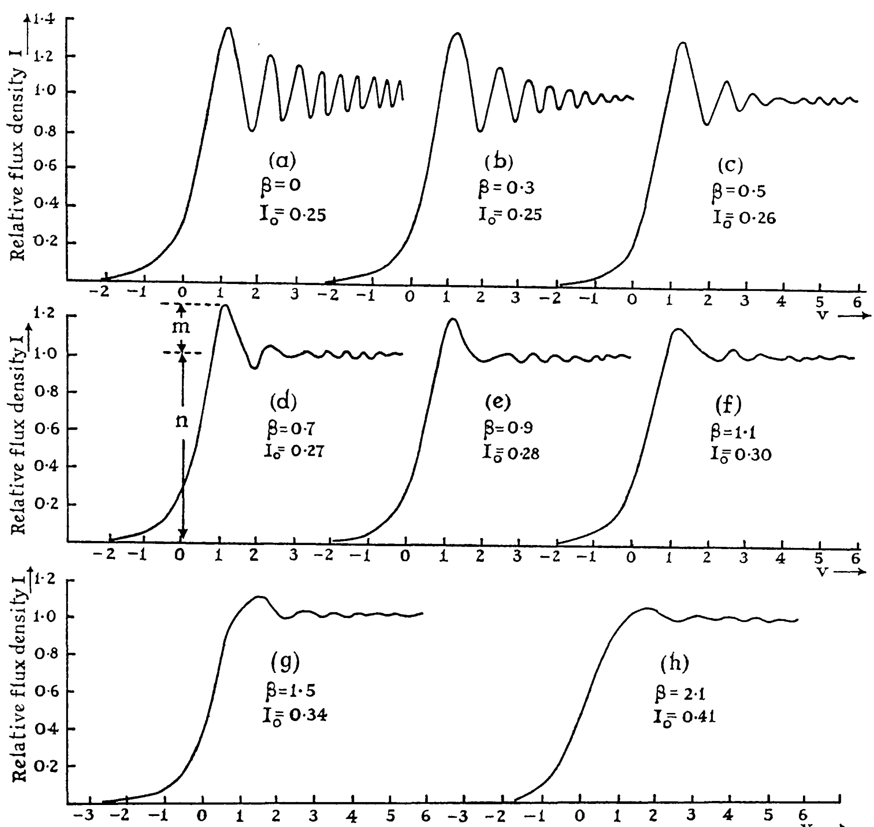

FIG. 1.—*The shape of the occultation curves for a uniform strip source calculated for different values of angular diameter* ω, *where* $\omega = \beta\sqrt{(\lambda/2d)}$. *The angular scale of the patterns is given by* $\theta = v\sqrt{(\lambda/2d)}$, *where* λ *is the wave-length and* d = *the distance of the Moon. For* λ = 1·25 *metre, one unit of* v *corresponds to approximately* 8″.

Abscissa: units of v. (v = 0 *corresponds to the edge of the geometrical shadow.*)

Ordinate: relative flux density (I). I = 1 *corresponds to the flux density of the unobstructed wave.* I_0 *is the relative flux density at the edge of the geometrical shadow.*

At the frequency of 237 Mc/s, at which we have carried out a preliminary test of the method, the units of v correspond to approximately 8″, or about 16 seconds of time.

2.3. *Measurement of angular diameter.*—It may be noted that for sources of small angular diameter there is an increase in flux density near the Moon's limb which can reach almost 40 per cent of that due to the unobstructed source. The sensitivity is therefore increased by a significant amount over that which can be achieved using the aerial in the conventional manner. This increase in level should be readily detectable even for those sources for which the whole diffraction pattern cannot be studied in detail. The magnitude of the increase depends on the diameter of the source. It follows that the width of the equivalent strip source can be estimated by a simple measurement of the ratio of this increase in level to the fall in level produced by the occultation, i.e. the ratio m/n in Fig. 1 (*d*). In Fig. 2 we have plotted this ratio as a function of diameter. For moderately intense sources it should be possible to measure diameters in this way down to a limit of about $0 \cdot 3v$. For more intense sources where the diffraction pattern can be investigated in more detail it will be possible to extend this limit and measure diameters of less than $0 \cdot 1v$. At a frequency of 237 Mc/s these limits correspond to angular diameters of $2'' \cdot 5$ and $0'' \cdot 8$ respectively. From an analysis of the detailed structure of the diffraction pattern it should also be possible to obtain information on the brightness distribution across these intense sources.

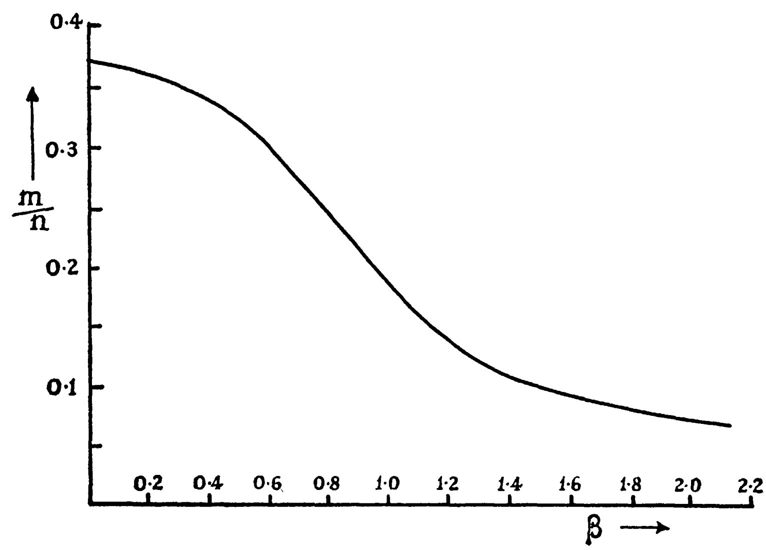

FIG. 2.—*The intensity of the first diffraction lobe as a function of the angular diameter of the equivalent strip source.*

Abscissa: units of β. The angular diameter (ω) is related to β by $\omega = \beta\sqrt{(\lambda/2d)}$.

Ordinate: Ratio of the intensity of the first diffraction lobe (m) to the intensity of the unobstructed wave (n).

When the angular diameter of the occulted source is greater than about $1 \cdot 5v$, the diffraction pattern is smeared out, but diameter information is then readily obtained from the slope of the occultation curves which differs considerably from the slope produced by a point source. If the diameter is greater than about $5v$, the diffraction effects are negligible and the diameter can be estimated directly from the time taken for the source to be occulted. For the sources of intermediate diameter ($> 1 \cdot 5v$ and $< 5v$) the slopes of the observed curves may be compared with the theoretical slopes for curves of different diameters. In this comparison it is necessary to consider the path of the source behind the Moon, for if the source passes a distance b from the centre the time scale of the diffraction pattern is increased by a factor $a/(a^2-b^2)^{1/2}$ over that for a central occultation, where a is the Moon's semi-diameter. This factor is equal to t/s, where t is the duration of a central occultation and s the observed duration. The "observed duration" refers to the time interval between transits of the source across the Moon's limb, and before this can be estimated accurately it is necessary to know the diameter of the source which is the required parameter. An accurate value for the diameter must therefore be made by a method of successive approximation, but in general it is sufficiently accurate to make the measurements to the 50 per cent points of the occultation curves.

It should be noted that the diameter measurements of the equivalent strip source always refer to a direction radial to the Moon's centre. For a source which passes some distance from the centre of the Moon, the radial lines at immersion and emersion define two axes across the source, the angle between these axes depending on the exact conditions of the occultations. The occultation then provides two pieces of diameter information and enables a rough estimate to be made of the shape of the source. Observations of a second occultation which would provide information along a different axis or axes would give a fairly detailed picture of the shape of the source.

2.4 (*a*) *Position measurement.*—Having estimated the angular diameter, the times of immersion and emersion can then be measured. These two times define two positions of the centre of the Moon and hence two circles of radii equal to the respective semi-diameters of the Moon. The points of intersection of these two circles then give two possible positions of the source, one on either side of the Moon's path and perpendicular to its direction of motion.

The ambiguity in position can be resolved by observing a second occultation of the source but in many cases this will not be necessary. Thus the position may have already been measured with sufficient accuracy by ordinary methods to decide between the two positions or it may be possible to measure it using the aerial system in the conventional manner.

If necessary the calculated position can be used to calculate more accurately the path of the source behind the Moon and derive a more accurate value for the diameter. The true position and diameter can thus be estimated by a method of successive approximations. In practice only one stage of this process will be required.

2.4 (*b*) *The positional accuracy.*—The effective solid angle of reception is determined not by the size of the aerial beam, but by the size of the diffraction pattern at the Moon's limb. On metre wave-lengths the solid angle subtended by this pattern is of the order of 1/500 sq. degree. Assuming that the confusion limit of a survey occurs at a source density of 1 source per 25 beam areas, it follows that a survey by the method of lunar occultations should be reliable up to a source density of about 60 000 sources per steradian. This is greater by a factor of about 100 than the limit set by confusion for the present Cambridge aperture synthesis survey and unlikely to be attainable due to sensitivity limitations. The survey will therefore be sensitivity limited and the results unaffected by confusion.

As position measurements are made relative to the known position of the Moon, they are also unaffected by refraction in the Earth's ionosphere or troposphere. Thus if we neglect the effects of irregularities in the limb of the Moon (which can amount to a maximum of $2''$) and any refraction in a possible lunar ionosphere, the only source of error lies in the measurement of the times of immersion and emersion.

To a sufficiently close approximation we may consider the motion of the Moon over the period of the occultation to be confined to a change in right ascension. The R.A. is then defined by the mean time of the occultation. As the Moon moves about $30'$/hour an error of 1 min in measuring this mean position produces an error of $30''$.

The declination of the source is defined by the duration of the occultation which determines the difference (b) between the declination of the source and the declination of the Moon at the mid-point of the occultation. The change in b produced by an error $2\delta s$ in the duration is given by $b = -\delta s \cot \theta$ (see Fig. 6). The error in declination (δb) therefore depends on the circumstances of the occultation. If the source passes close to the centre of the Moon an error of 1 min in the duration produces a declination error of 3′, while if the source passes at a distance of 12′ from the centre the same error in duration results in a declination error of only 12″.

The accuracy of measurement will depend on the intensity of the source, but as the time taken for a source of small angular diameter to be occulted (and it is for these small angular diameter sources where accuracy in positioning is most desirable) is only of the order 20^s, then even for the weakest sources measurements can be made to this order of accuracy. For the more intense sources measurements can be made to an accuracy of a few seconds of time giving an error in R.A. of the order of 1″ and in declination, even under the worst conditions, of the order of 15″. It may be noted that in general a source is occulted more than once in any lunar cycle, the occultations occurring at intervals of a few months. As the occultations occur under different conditions at least one will be favourable to a declination measurement and allow it to be measured to an accuracy of the order of 1″.

Thus, provided a source can be detected it should be possible to measure its position to an accuracy of about 10″ in each coordinate while, if it produces a deflection which is several times greater than the random fluctuations in the receiver output, its position can be measured to 1″.

When several occultations occur on the same record there may be difficulty in associating correctly the rises and falls in level. This will occur if the sources have about the same flux density. In some cases it will be possible to resolve this difficulty from a knowledge of the maximum duration of the occultation, the different slopes associated with sources of different diameters or from approximate positions determined by other methods. More complicated regions will certainly require further occultation observations when the Moon is again in the same region of sky. These additional observations are desirable in any case as a check on the reliability of the observations. It is not likely that this difficulty in interpretation of the records will be serious; at worst it will result in more than one possible position for the source, each position being accurate to a few seconds of arc.

3. *The observations of 3C212*

3.1. *Apparatus and method of observation.*—The measurements were made at a frequency of 237 Mc/s using the 250 ft radio telescope at Jodrell Bank in conjunction with a Dicke-type receiver which had a bandwidth of 2 Mc/s and an output time constant of 4^s. The receiver output was recorded continuously with the telescope in automatic motion following the centre of the Moon.

The measured beamwidth of the aerial was about 1°·2 between the half-power points and therefore covered an area considerably greater than the Moon's disk; this ensured that any source which passed behind the Moon did so near the maximum response of the aerial polar diagram.

The equipment was calibrated on the intense radio source I.A.U. 08N4A which was assumed to have a flux density of 50×10^{-26} w. m^{-2} (c/s)$^{-1}$ at 237 Mc/s.

3.2. *The occultation of* 1960 *December* 8.—A preliminary account of the observation of this occultation has already been published (2). It occurred at an elevation of between 20° and 30° and the background noise level was disturbed by slow period drifts, probably due to ground reflections. Nevertheless, the sharp fall and subsequent rise in received power as the source passed behind the Moon were clearly observed.

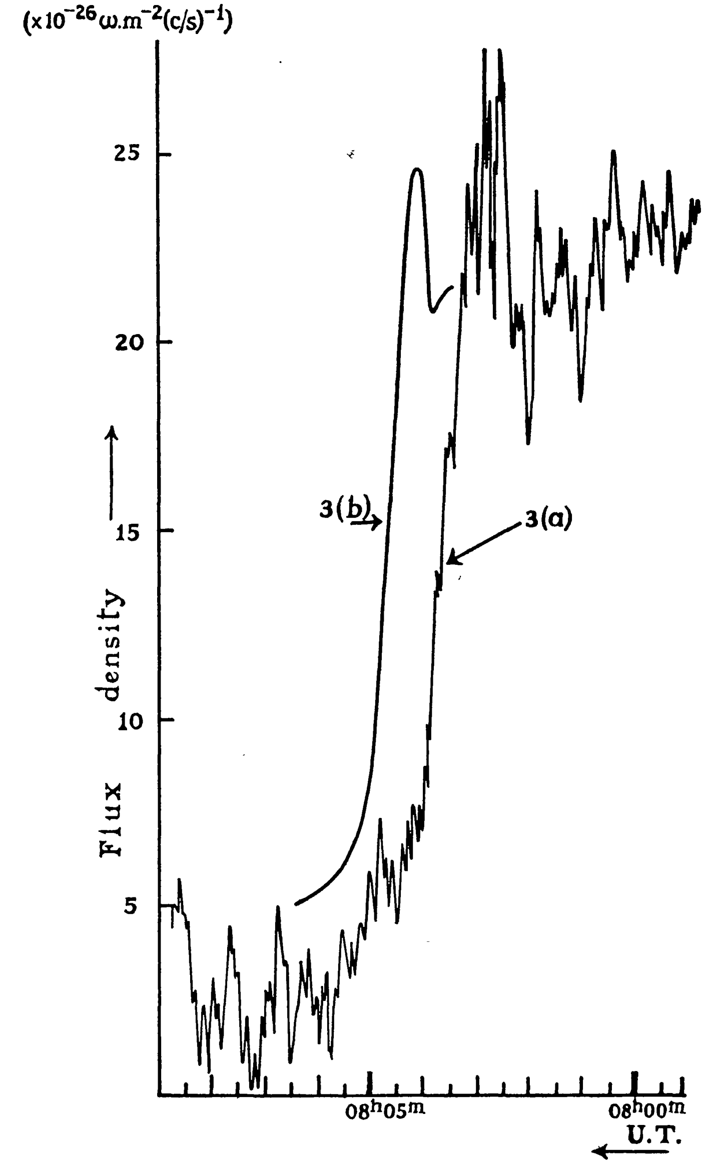

FIG. 3.—(*a*) *Facsimile of the record showing the emersion of* 3C212. *There is a gradient in the background level making the zero of the curve uncertain.* (*b*) *Calculated occultation curve for a strip source of width* 7″ *of arc.*

Fig. 3 (*a*) shows the disappearance of 3C212. The sharp fall in level is shown superimposed on a slight downward gradient in the background noise. This gradient makes the zero point of the occultation somewhat uncertain and is the major source of error in timing the passage of the source behind the Moon.

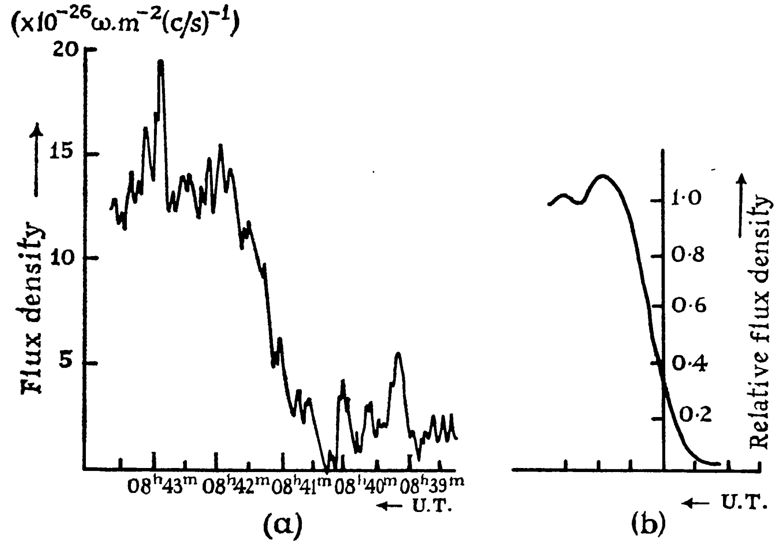

FIG. 4.—(*a*) *Facsimile of the record showing the emersion of* 3C212 *on* 1960 *December* 8. (*b*) *Calculated occultation curve for a source of width* 15″.
Abscissa: Universal Time. Scale: 1 *division represents* 30 *seconds U.T.*
Ordinate: change in flux density above an arbitrary zero.

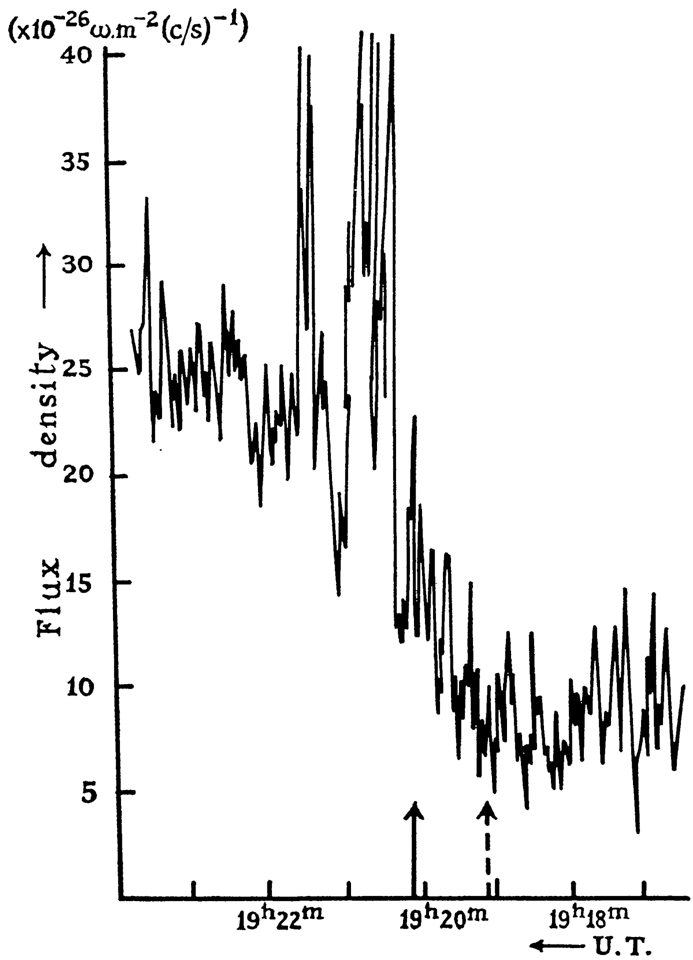

FIG. 5.—*Facsimile of the record showing the emersion of* 3C212 *on* 1961 *January* 31. *The solid arrow shows the calculated time of emergence of* 3C212 *based on the position calculated in Section* 4.2 (*b*). *The broken arrow shows the corresponding time calculated for the alternative position given in the footnote.*

Fig. 4 (*a*) shows the relevant section of record to illustrate the reappearance of the source; the scale of this record is smaller by a factor of two than the scale of Fig. 3.

3.3. *The occultation of* 1961 *January* 31.—Subsequent to the above measurements an attempt was made on 1961 January 31 to observe a second occultation which had been predicted by H.M. Nautical Almanac Office. Unfortunately, a full investigation of this occultation was not possible because high winds prevented the use of the telescope for much of the relevant portion of the observing period. These high winds prevented any observations being made of the immersion of the source, but advantage was taken of a brief lull in the wind speed to observe its emersion, which is shown in Fig. 5. The high noise level is due to the heavy rain during the observing period.

4. *Analysis of results*

4.1. *Flux density.*—It can be seen from Fig. 3 that the change in level as the source passed behind the Moon corresponds to a fall in received power of 16×10^{-26} w. m^{-2} (c/s)$^{-1}$. The observed rise in level at emergence, however, corresponds to only 12×10^{-26} w. m^{-2} (c/s)$^{-1}$. This difference indicates that the Moon was not in the centre of the beam, but displaced off axis, possibly due to a small displacement of the beam from the axis of the telescope. A comparison of the changes in level at immersion and emersion indicates that at immersion the source must have been close to the centre of the beam, and, hence, that the observed fall in level corresponds to the flux density of the source.

4.2. *Diameter and position measurements.*—In an earlier paper (**2**) we estimated the position of the source on the assumption that its angular diameter is small in comparison with the scale of the diffraction pattern at the Moon's limb; it was estimated that the error arising from this assumption was less than 4″. We now present a more detailed analysis in which the diameter of the source is taken into account.

4.2 (*a*). *Estimate of angular diameter.*—It is clear from a comparison of the occultation curves shown in Figs. 3 and 4 with the calculated diffraction pattern for a point source, that the angular diameter is not small compared with the scale of the diffraction pattern at the Moon's limb. Thus neither the immersion nor the emersion curve shows the extensive lobe pattern to be expected from a point source. The immersion curve does show a single well-defined diffraction lobe, the intensity of this lobe being about 25 per cent of the intensity from the unobstructed source. The emersion curve does not show such an obvious diffraction lobe indicating that the source is asymmetrical with an apparent diameter which is smaller at immersion than emersion. It has been shown in Section 2 that the diameter of a source can be estimated from these observed increases in intensity associated with the Moon's diffraction pattern. However, as this is the first time this method has beeen used to measure diameters, we have carried out a more detailed investigation and compared the shapes of the observed diffraction curves with those calculated for sources of different diameters. The best fit at immersion was obtained for a diameter of 7″, and at emersion for a diameter of 15″. The calculated curves for these diameters are shown in Figs. 3 (*b*) and 4 (*b*); the time scale of these curves was estimated from the observed duration of the occultation as indicated in Section 2.

The estimated diameters are measured along the directions OA and OB respectively, as indicated in Fig. 6, which shows the path of the source behind the Moon. They therefore refer to two axes inclined at an angle of about 68°.

Now that the angular diameter has been estimated it is possible to define the duration of the occultation more accurately as in the following determination of the source position.

4.2 (*b*). *The position of the source.*—Reference to the curves given in Fig. 1 shows that for a source with effective diameters of 7″ and 15″ at immersion and emersion respectively the edges of the geometrical shadow are defined by the points at which the flux density is 0·28 and 0·38 respectively of the flux density from the unobstructed source. The corresponding times of disappearance and reappearance are given by:

$$\text{Time of disappearance } (T_1) = 08^{\text{h}}\,03^{\text{m}}\,50^{\text{s}} \quad \pm 5^{\text{s}}.$$
$$\text{Time of reappearance } (T_2) = 08^{\text{h}}\,40^{\text{m}}\,59^{\text{s}}\!\cdot\!5 \pm 5^{\text{s}}.$$

The two possible positions (p_1 and p_2) of the source corresponding to the above times of immersion and emersion are:

$$\left.\begin{array}{ll} p_1\text{: R.A. } 08^{\text{h}}\,56^{\text{m}}\,32^{\text{s}}\!\cdot\!3, & \text{Dec. } 14^\circ\,18'\,44''\!\cdot\!1 \\ p_2\text{: R.A. } 08^{\text{h}}\,56^{\text{m}}\,2^{\text{s}}\!\cdot\!2, & \text{Dec. } 13^\circ\,55'\,15''\!\cdot\!3 \end{array}\right\} \begin{array}{c}\text{Epoch}\\ \text{1960 December 8.}\end{array}$$

In calculating these coordinates it has been assumed that the difference between U.T. and Ephemeris Time (E.T.) is 34 sec, i.e.

$$\text{E.T.} - \text{U.T.} = +34 \text{ sec.}$$

The ambiguity in position can be resolved by reference to the observations of 1961 January 31. Thus at the time of the second occultation the declination of the Moon was approximately 14° 33′ and if the source had been at position p_2 it could not have been occulted. As the occultation was observed the apparent position of the source must be given by the coordinates of p_1. The apparent position of p_1 given above corresponds to a mean place for 1950.0 of

$$\text{R.A. } 08^{\text{h}}\,55^{\text{m}}\,55^{\text{s}}\!\cdot\!8, \qquad \text{Dec. } 14^\circ\,21'\,23''.$$

To check the above position the time of reappearance was estimated for 1961 January 31. It was found to be $19^{\text{h}}\,20^{\text{m}}\,05^{\text{s}}$ U.T. and is indicated by the full arrow in Fig. 5. The calculated and observed times of reappearance agree within the limits of error of the measurements and thus confirm the position of the source*

* It should be pointed out that in addition to the rise in level there was another approximately equal rise in received power at about $08^{\text{h}}30^{\text{m}}$ U.T. As it was not possible to decide with certainty from the records of 1960 December 8 which of these two rises was associated with the fall in level shown in Fig. 3, the full analysis was repeated using the alternative time of reappearance. This gave a source position of R.A. $08^{\text{h}}55^{\text{m}}48^{\text{s}}\!\cdot\!3$, Dec. 14°23′17″ (Epoch 1950), and a calculated time of reappearance on 1961 January 31 of $19^{\text{h}}19^{\text{m}}06^{\text{s}}$ U.T. This calculated time is indicated by the broken arrow in Fig. 5, and does not agree well with the observed time of emergence. As the calculated R.A. also lies outside the limits of error of the 3C position, it seems that the rise in level at $08^{\text{h}}30^{\text{m}}$ cannot be the rise associated with the emergence of 3C212. It is possible that it is associated with the emergence of a second source which disappeared behind the Moon at about $07^{\text{h}}30^{\text{m}}$ U.T., where the record is disturbed by interference, but it seems more probable that it is associated with the commencement of an interfering signal. If so, it is particularly unfortunate, as in a total observing period of about one month only two other possibly spurious increases in received power of about this level were noted.

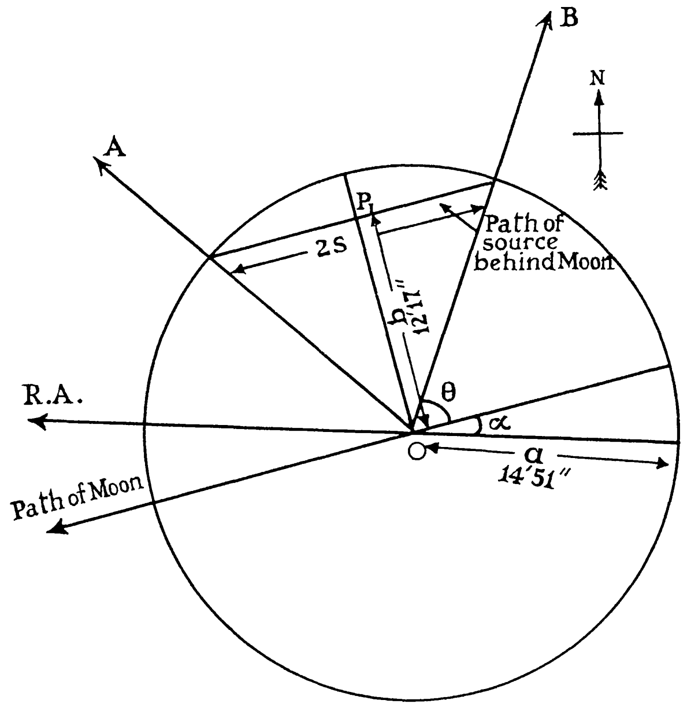

FIG. 6.—*Geometry of the occultation of 3C212. The positional accuracy of the method (Section 2.4 (b)) was estimated assuming the motion of the Moon to be confined to a change in R.A., i.e. α=0. 'b' is the closest distance of approach of the source to the Moon's centre. 2s is a measure of the duration of the occultation.*

5. *Discussion of results*

5.1. *The errors in the position and diameter measurements.*—The quoted errors in the computed position have been estimated only from the errors in measurement of the time of immersion and emersion and neglect any possible refraction in a lunar ionosphere and the effect of irregularities of the Moon's limb. The high degree of accuracy achieved is due to the circumstances of the occultation, the closest approach of the source to the centre of the Moon being about 12′. As pointed out in Section 2.4 (*b*), under these conditions an error of 1 min in the duration of the occultation introduces an error of only 12″ in the declination.

From observations of an occultation of the Crab Nebula, Elsmore (3) estimated the possible refraction in a lunar ionosphere as 13″ ± 8″ at a frequency of 85 Mc/s. This would correspond to about 2″ ± 1″ at 237 Mc/s and therefore is unlikely to be a serious source of error. It is unfortunate that a full investigation of the occultation of 1961 January 31 was not possible to enable the refraction to be investigated in detail. However, the agreement between the predicted and observed times of emergence suggests that any refraction is less than the errors of measurement and hence is less than 2″, in agreement with the measurements of Elsmore.

The irregularities in the Moon's limb can amount to a maximum of 2″ and are also unlikely to be a serious source of error. Taking into account all possible sources of error the position should be accurate to about ±3″. As this is less than the diameter of the source, further accuracy in positioning is not required.

The calculated emersion curve for a source of 15″ diameter agrees well with that observed. The immersion curve is not in such good agreement with the calculated curves, as the diffraction lobe appears to be rather more intense and wider than would be expected. However, there are severe fluctuations superimposed on this lobe which makes the observations somewhat uncertain. We consider it possible that these fluctuations are associated with the approach of the source to the limb of the Moon, but can propose no satisfactory explanation, although they may be associated with the irregularities in the Moon's limb. It must also be remembered that the actual shape of the diffraction pattern will depend on the shape and brightness distribution across the source and it is possible that a more detailed analysis would give better agreement between the theoretical and experimental curves. It is also possible that in the region of the diffraction lobe the record is influenced by the effects of refraction close to the Moon's limb. More observations of occultations will be required to investigate any such effect.

Although there is a slight discrepancy between the observed and calculated occultation curves, it is estimated that the error in the effective diameter will be less than 15 per cent.

5.2. *Comparison with other data.*—The available data on the source 3C212 are summarized in Table I. In order to facilitate a comparison of the flux densities at the different frequencies they have been expressed as a fraction of the flux density of the calibrating source I.A.U. 08N4A.

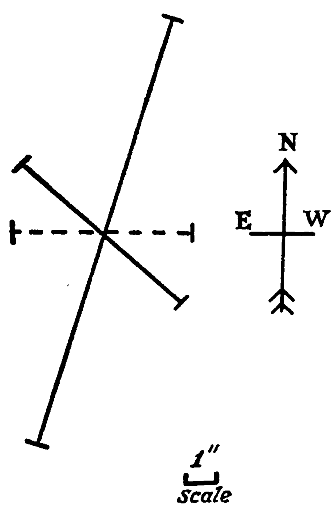

Fig. 7.—*Measured diameters of 3C212. The solid lines represent the occultation measurements. The broken line represents the interferometer measurements of Palmer, Allen and Rowson.*

The 3C position is correct to within the accuracy of the quoted errors. The present position exceeds the accuracy of the 3C position by a factor of about 4000, and is the most accurate measurement yet made of the position of a radio source.

The angular diameter measurements are in good agreement with those of Palmer, Allen and Rowson (4) whose value refers to a position angle of 90°. The three measurements of diameter are shown in Fig. 7; the interferometer measurement which is indicated by a broken line has been reduced to the value for the equivalent strip source of uniform brightness. The source is asymmetrical with a ratio of major to minor axes of about 2·5 : 1, the position angle of the major axis being about 160°.

TABLE I

Survey	Frequency (Mc/s)	R.A. (Epoch 1950)	Dec. (Epoch 1950)	Flux density ($\times 10^{-26}$ w.m^{-2} (c/s)$^{-1}$)	Ratio to 08N4A	Diameter	Position angle of major axis
3C(5)	160	$08^h 56^m 00^s \pm 5^s$	$14° 25' \pm 8'$	21	0·30	—	—
Jodrell Bank Diameter Survey (4)	158	—	—	—	—	6″	Referred to position angle 090°
Lunar occultation survey	237	$08^h 55^m 55^s{\cdot}8 \pm 0^s{\cdot}3$	$14° 21' 23'' \pm 2''$	16	0·32	7″ × 15″	160°

6. *Discussion*

The effective temperature of 3C212 as calculated from the data given in Table I is of the order of 10^7 °K at 160 Mc/s and hence comparable to that of Cygnus A and 3C295 which appear to have effective temperatures of about 10^8 °K. It therefore appears to be a highly excited radio galaxy and both its flux density and angular diameter indicate that it is at the same order of distance as 3C295. This conclusion is supported by a preliminary examination of the Sky Survey plates which show no prominent visual object in the radio position. Its identification is therefore of considerable interest, and provided the optical and radio positions coincide, it should present little difficulty in view of the accuracy of the present positional measurements and the fairly detailed diameter information. However, it should be noted that the optical and radio positions do not always coincide. In the case of 3C212 this should not be a serious difficulty as the source diameter is so small that even if the radio position is several times the optical diameter away from the optical position the area of sky involved is still sufficiently small to make a wrong identification unlikely. In view of the observed discrepancies between the optical and radio positions it might not appear worthwhile to measure the radio positions to an accuracy of 1″, but this is not considered to be the case, as an investigation of these discrepancies for the identified sources is likely to prove of great interest in itself.

Conclusions.—The results presented in this paper illustrate the potentialities of a survey of the radio sources made by the observation of lunar occultations, the data obtained on 3C212 being the most detailed obtained in any single set of measurements. The effective solid angle of reception of such a survey, which is determined by the size of the diffraction pattern at the Moon's limb, is only of the order of 1/500 sq. degree for wave-lengths of the order of a few metres. This is considerably better than has been achieved in the existing surveys and suggests that in addition to providing information on individual sources the method may prove a powerful tool in an investigation of the number/intensity relation and enable the observation to be extended to greater distances than have hitherto been possible. A detailed analysis of the method indicates that, with aerial systems of the order of size of the Jodrell Bank telescope and using modern parametric amplifiers, the rate of yield of information would be adequate to make such a survey well worthwhile. This problem will be discussed in more detail when the full analysis of the present survey is published.

In this preliminary survey we have confined our measurements to observations at a single frequency. It is suggested that in the more detailed surveys two frequencies should be used, as a comparison of the two sets of records would provide a valuable check on the results. They would also provide accurate spectral information due to the high resolution of the system. Finally, it may be noted that in addition to providing information on the radio sources a survey carried out at two frequencies would provide valuable information on a possible lunar ionosphere. The present limit to the density of the lunar ionosphere is set by the measurements of Elsmore (3) on an occultation of the Crab Nebula which gave a value for the angle of refraction in the lunar ionosphere at 85 Mc/s of $13''\!\cdot5 \pm 8''$, a barely significant result. However, a comparison of the occultation curves at two frequencies, one below 100 Mc/s and the other of a few hundred megacycles should permit this limit to be reduced by at least an order of magnitude. Thus a lunar ionosphere would produce a difference in apparent position on the two frequencies which it will be possible to measure with greater precision than the absolute position of the source. Indeed, a study of several occultations should make it possible to detect angles of refraction of a fraction of a second of arc. The possibility of detecting such small angles of refraction opens up the possibility of investigating other ionized regions in the interplanetary, and possibly interstellar, medium.

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