PAPER 2

THE RAPID FADING OF MOON ECHOES AT 100 MC/S

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1. INTRODUCTION

In recent years the way in which the moon reflects radio waves has been the subject of much study. Observations by Yaplee [1] at 2860 Mc/s, Trexler [2] at 198 Mc/s, Evans [3] at 120 Mc/s, and others show that radio waves are reflected principally by a small region at the center of the moon's visible disk which has a radius of the order of one-third of the lunar radius.

The echoes obtained at meter wavelengths are subject to two forms of fading. One is a slow fading with a period of many minutes, which was shown by Murray and Hargreaves [4] to be due to the Faraday effect in the earth's ionosphere, which causes a rotation of the plane of polarization of the radio waves. Browne *et al.* [5], Evans [6, 7], and Bauer and Daniels [8] have measured the total electron content of the ionosphere by observing the total number of rotations of the plane polarized wave.

The other, a more rapid fading with a period of a few seconds, has been attributed by Kerr and Shain [9] to the moon's libration. This changes the distances of the scattering centers relative to the observer, thereby altering the phase of the signal returned from each center and consequently the amplitude of the combined signal. Browne *et al.* [5] have shown that the rate of this fading at transit varies from day to day depending on the rate of the moon's libration. Since the principal component of the moon's libration is the diurnal libration caused by the observer's motion due to the rotation of the earth, a variation of the rate of fading throughout the day would be expected. This paper presents the results of experiments that verify this.

2. THE OBSERVATIONS

The Jodrell Bank moon radio echo equipment has recently been rebuilt to operate at a frequency of 100 Mc/s. The transmitter is housed in one of the towers of the 250-foot steerable paraboloid; the receiver is in a laboratory away from the telescope and connected to it via a coaxial cable and preamplifier chain. The equipment parameters over the period of observation were: transmitter power, 8 ± 1 kilowatts; pulse length, 25 milliseconds; receiver noise factor, 3 db; receiver bandwidth, 7 kc/s; pulse recurrence frequency, 1.0 per second. The effective aerial collecting area was found to be 3300 square meters by observing the intensity of the radio source in Cassiopeia. To obtain circularly polarized radio waves and thereby eliminate the Faraday fading, a primary feed with coplanar mutually perpendicular dipoles and reflectors was used. The dipoles were fed in phase quadrature from a "hybrid ring." By carefully matching the dipoles when the feed was in position at the focus, truly circular polarization was obtained and the "hybrid ring" gave a rejection of the transmitter power at the receiver terminals of better than 30 db. Observations were made from moonrise to moonset on several days in June. The mean signal-to-noise ratio was 21.3 ± 2 db, and variations from the mean of not more than ±3 db over any five-minute interval could be observed. These small variations are thought to be due to drifts in the receiver gain and transmitter tuning, which alter the transmitter power. The over-all feeder losses are approximately 3 db; hence a signal-to-noise ratio of ±23 db

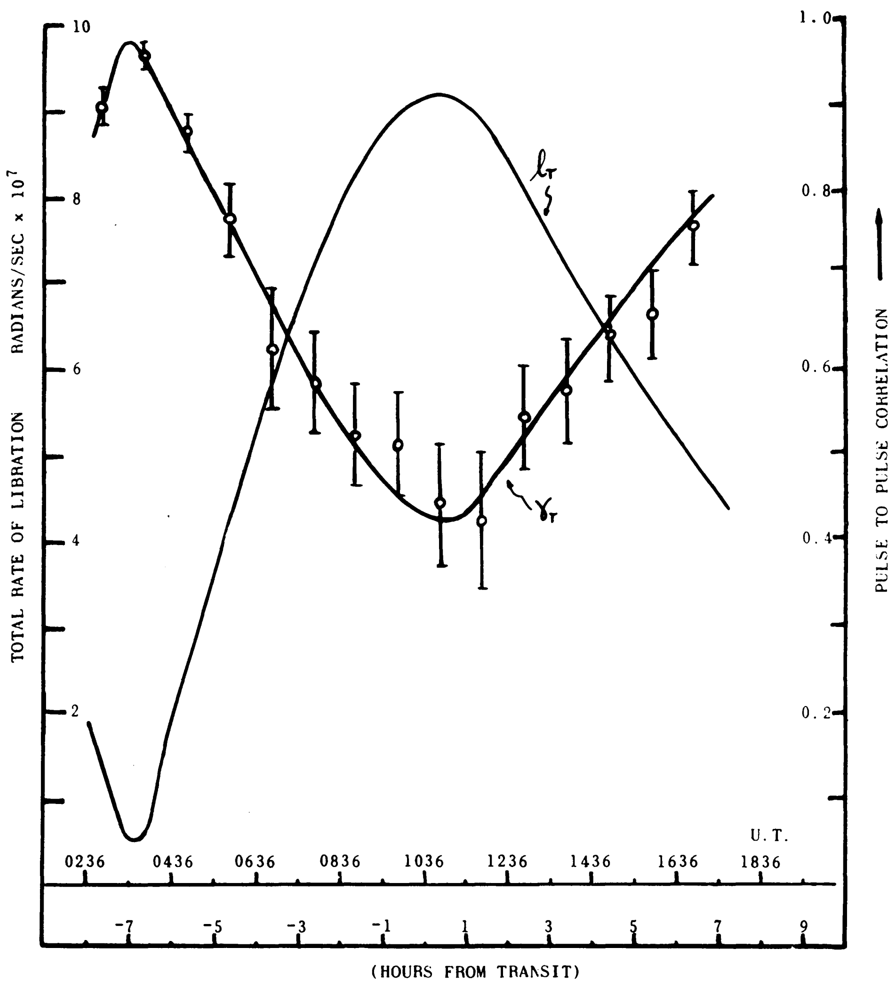

FIG. 1. The variation of the total libration l_T at 1958 June 15 calculated using the expression given in the text. Also shown is the pulse-to-pulse correlation for echoes one second apart observed on this day.

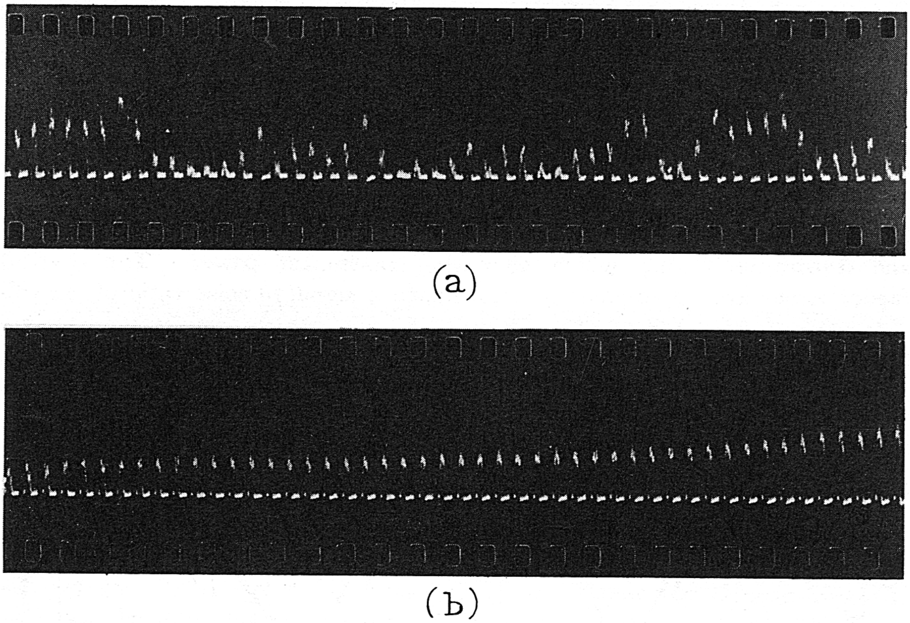

Fig. 2. (*a*) Echoes strobed from the timebase near transit showing rapid fading. (*b*) Echoes strobed from the timebase near moonrise where the fading is slow. In both samples the echoes are one second apart.

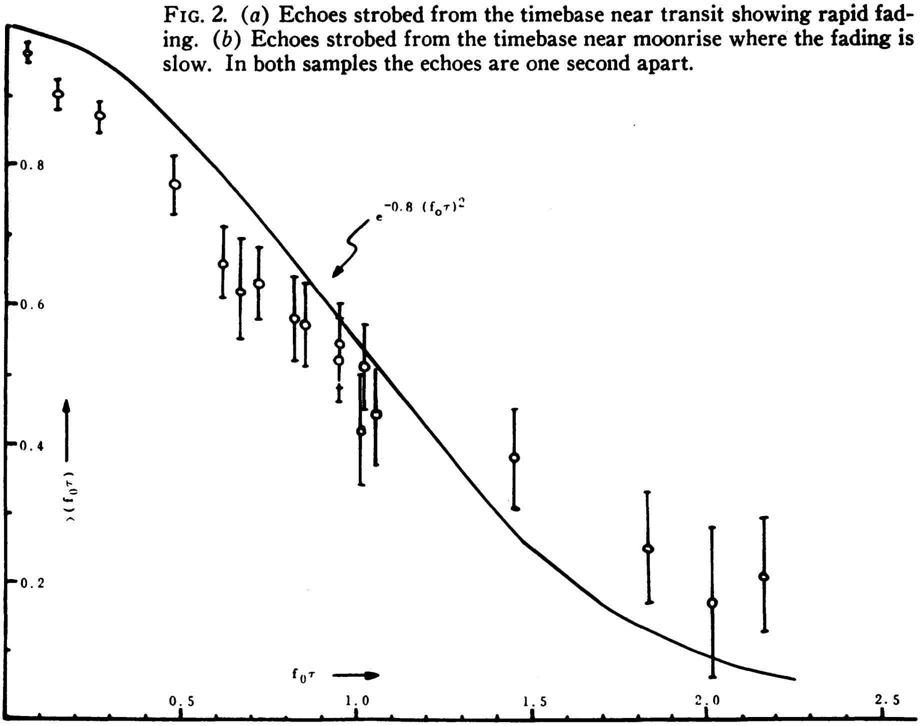

Fig. 3. The observed autocorrelation function $\gamma(f_0\tau)$ for echoes at 100 Mc/s. Also shown is a Gaussian function exp $[-0.8(f_0\tau)^2]$, which is the best fit to the observed points.

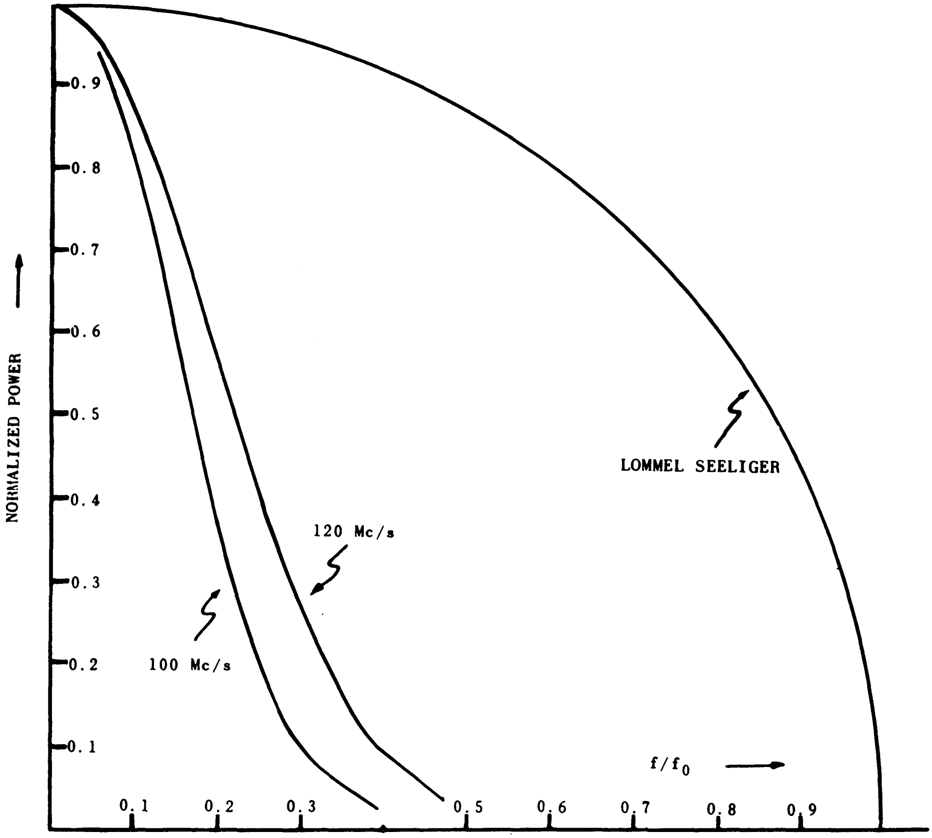

FIG. 4. The power spectra of moon echoes observed at 100 Mc/s and 120 Mc/s [3]. The power spectrum produced by a uniformly bright moon (Lommel Seeliger) scattering is also shown.

would be expected, assuming that the moon scatters with directivity $g = 1.8$ and reflection coefficient $\rho = 0.1$ (Evans [3]).

The three principal components of the moon's libration have been described by Browne [5], but since the expression given in that paper for the total rate of libration l_T is applicable only to transit observations, the equation

$$l_T^2 = (7 \times 10^{-7} \cos H.A. + l_L)^2 + (7 \times 10^{-7} \sin \delta \sin H.A. + l_\beta)^2 \text{ radians/second}$$

is used, where $H.A.$ is the hour angle and the other symbols have the same meaning as previously. Fig. 1 shows the variation of l_T during the hours of observation on 1958 June 15. Also plotted is the pulse-to-pulse correlation of echoes one second apart for groups of 300 echoes taken at hourly intervals. It is clear that libration introduces a marked variation in the rate of fading during the day. This is illustrated in Fig. 2(a) and (b), where two samples of echoes are shown. Those in (a) were observed near transit, when the rate of libration is high; those in (b) were at dawn, when l_T is at a minimum.

Evans [3] has shown how the autocorrelation function may be used to derive the power spectrum of the echoes and hence the distribution of the scattering centers. The autocorrelation function $\gamma(f_0\tau)$ (f_0 is the Doppler shift produced by reflection at the limb of the moon, τ the time separation of the echoes) for these observations is shown in Fig. 3 together with a fitted Gaussian function $\exp[-0.8(f_0\tau)^2]$. The resulting power spectrum is given by $P(f) = P(0)\exp[-(\pi^2/0.8)(f/f_0)^2]$ and is shown in Fig. 4 together with the power spectrum obtained in the earlier work at 120 Mc/s. The difference between the two curves is not thought to be significant; it probably arises as a result of errors in the Gaussian "fits" to the autocorrelation functions and errors in timing the pulse separation in the earlier work. It is clear that at both frequencies the scattering centers appear to be contained within a region whose radius is of the order of one-third of the lunar radius.

REFERENCES

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Discussion

F. G. Smith: May I ask two questions? I was surprised to see that, in the distribution of amplitudes in the rapid fading, echoes frequently fall to zero. The second question is concerned with the comparison of fading rates over the wide range of radio frequencies now available. Have any comparisons been made?

J. V. Evans: The Jodrell Bank results showed echo amplitudes (not power) and the distribution is similar to a Rayleigh distribution.

Yaplee: A Rayleigh distribution would be expected for a wide pulse, but not necessarily for one that illuminates one small annular region at a time.

Evans: In connection with Dr. Smith's second point, it is essential at each frequency to calculate the rate of libration at the instant in which we are interested, and this does not seem to have been done by some workers.