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Radar Reflections From the Moon at 425 Mc/s [1]

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The characteristics of the lunar surface deduced from radar-lunar measurements conducted at the U.S. Air Force Trinidad Test Site during 1960 are discussed.

Evidence is presented which tends to confirm that, at 425 megacycles per second, the front portion of the moon is a comparatively smooth reflector while the back portion behaves as a rough scatterer.

The pulse decay of the average envelope of lunar echoes is found to follow the slope of the Lommel-Seeliger scattering law.

From the cumulative probability distributions of the total cross section of the moon measured on two different days, it is indicated that 50 percent of the total cross section measurements were less than 5.0 to 8.5×10^{11} square meters or 117.0 to 119.3 decibels above one square meter.

Statistical data, such as the probability density functions of the total lunar echo amplitude and the autocorrelation function, are also presented.

The power density spectrum computed from the autocorrelation function is compared with the theoretical Doppler spread resulting from the moon's libration.

1. Introduction

The first radio reflections from the moon, using conventional radar techniques, were recorded at a frequency of 111.5 Mc/s at moonrise and moonset by the U.S. Army Signal Corps [Webb, 1946]. A more complete description of the Signal Corps results is described by DeWitt and Stodola [1949]. In order to obtain the required sensitivity, a receiver bandwidth of about 50 c/s, a transmitter pulse length of 0.25 sec, and a transmitter peak power of 3 kw were used. The experimental results showed that the returned echo amplitude was often less than the theoretically computed one, and, on occasions, could not be detected. In addition, the signal amplitude underwent unexpected fluctuations, having periods of several minutes, which were attributed to anomalous ionospheric refraction.

At approximately the same time as the Signal Corps observations, Bay [1946] also reported that radar contact had been made with the moon at a frequency of 120 Mc/s. These measurements indicated a power reflection coefficient for the moon's surface on the order of 0.1.

Kerr, Shain, and Higgins [1949] of Australia performed the moon reflection experiment at 21.5 Mc/s, during moonrise and moonset, mainly to study the characteristics of low angle propagation through the ionosphere. Their records [Kerr and Shain, 1951] indicated a rather slow amplitude fluctuation rate which also was attributed to ionospheric refraction phenomena. The rapid amplitude fluctuations, having periods of a few seconds, were explained by assuming that the moon's surface consisted of many random scatterers in relative motion, brought about by the moon's libration. This phenomenon, together with the evidence that the received pulse was stretched out several times the length of the (1-msec) transmitted pulse, showed that the moon was a "rough" reflector at the frequency used.

The first successful transmissions at UHF using the moon as a relay station were accomplished by Sulzer, Montgomery, and Gerks [1952]. Continuous waves (CW) radio signals at a frequency of 418 Mc/s were relayed from Cedar Rapids, Iowa, to Sterling, Va. It was found that the signal was subject to severe fading, its amplitude varying from the receiver noise level to occasional peaks as high as 10 db above the noise.

Measurements of radar-lunar echoes by Evans [1957] at 120 Mc/s, by Trexler [1958] at 198 Mc/s, and by Yaplee, Bruton, Craig, and Roman [1958] at 2860 Mc/s revealed that radar reflection takes place within a small area at the center of the moon's surface, the radius of which is approximately one-third the radius of the moon. These results confirmed that the moon appeared to be a quasi-smooth reflector at radio wave frequencies.

The characteristics of lunar echoes, such as libration fading of the order of 2 to 3 c/s and pulse lengthening to approximately one lunar radius, have recently been noted by investigators operating in the 400 to 440 Mc/s frequency range [Pettengill, 1960; Leadabrand, Dyce, Fredricksen, Presnell, and Schlobohm, 1960]. The latter phenomenon indicated the possibility that the rear portion of the moon behaved as a rough scatterer.

In this paper, the analyses of the reflectivity characteristics of the lunar surface, as determined from radar measurements made at 425 Mc/s, are discussed.

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2. Experimental Measurements

The experimental observations discussed in this paper were conducted at Trinidad, B.W.I., between January and July 1960, with a high-powered pulsed radar. Linear (horizontal) polarization was employed on transmission, while the reflected radar signals were simultaneously received on both the transmitted and the orthogonal (vertical) polarization. The transmitted pulse was 2.0 msec in duration, while the pulse repetition frequency was approximately 30 pulses/sec.

Automatic tracking of the moon was accomplished by means of an orbit programer which continuously positioned, in 3-min intervals, an 84-ft diam steerable antenna so as to follow the theoretical path of the moon.

The radar data pertaining to the lunar echo return were recorded in digital form on magnetic tape in order to facilitate data processing and analysis. In addition, photographic recordings were made of the various combinations of the amplitude, range, and time coordinates.

A tracing of a typical A-scope photograph of a radar-lunar echo recorded at Trinidad is shown in figure 1. The upper trace is the horizontally polarized signal while the lower is the vertical. It is noted that the pulse return is stretched out to ap-

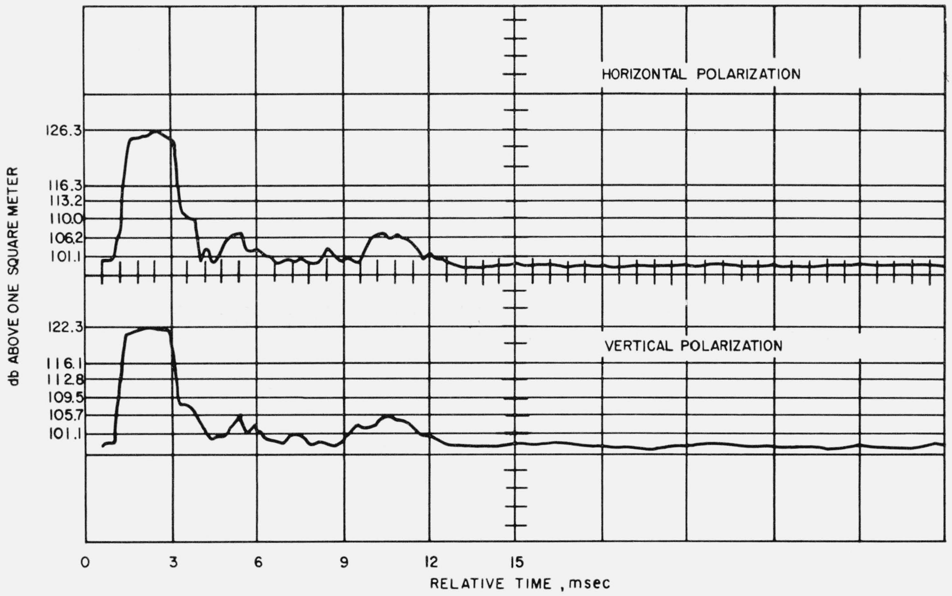

FIGURE 1. *A typical lunar echo recorded at Trinidad at 425 Mc/s, showing pulse lengthening.*

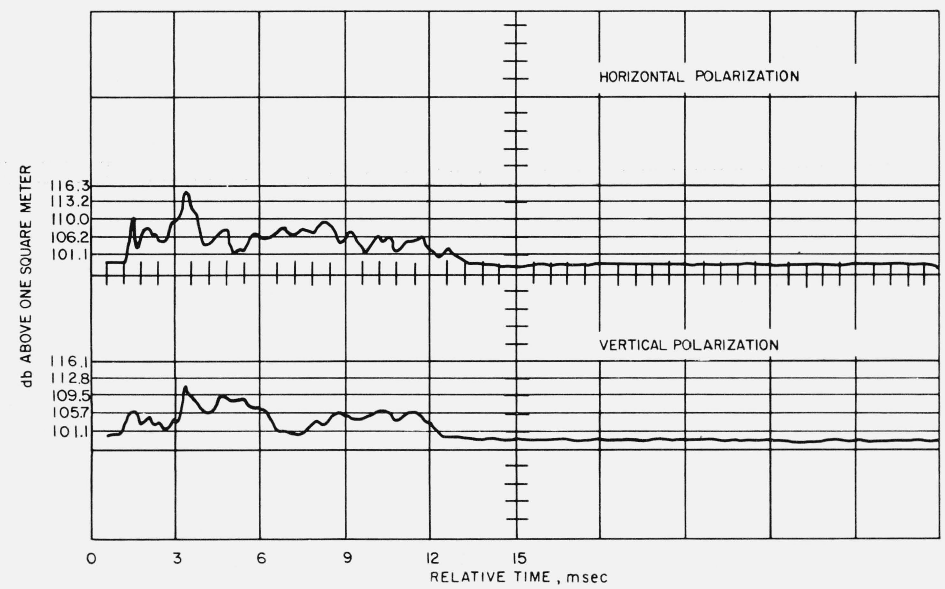

FIGURE 2. *A typical lunar echo recorded at Trinidad at 425 Mc/s, showing pulse distortion.*

proximately 12 msec in length and that the echo on both polarizations is similar in shape.

If the moon were a perfectly smooth body, an electromagnetic pulse incident on its surface would not be extended in range by reflection from the rear portions of its surface. This is basically due to the fact that, according to Fresnel diffraction theory, only a small region of the moon's surface would contribute to the received reflected energy, i.e., at 425 Mc/s, the radius of the first Fresnel zone is approximately 11.6 km.

With regard to the effect of scattering from a rough surface on the pulse shape, since all portions of a rough body contribute to the total reflected signal, the returned echo would be extended in length, i.e., the pulse lengthening would be equal to the time it takes the wave to travel from the nearest surface to the limb and then back again to the surface. Since the radio-depth of the moon is 11.6 msec, a pulse width of 2 msec, incident on a rough moon, would be elongated to a length of 13.6 msec after reflection. As indicated in figure 1, the lunar echo does undergo pulse stretching, the elongation being approximately equal to the theoretical predictions.

It is also seen in figure 1 that the maximum radar cross section of 126.3 db above 1 m^2 is obtained on horizontal polarization. This value compares reasonably well with the geometrically projected lunar disk area of 129.8 db above 1 m^2 (radius of moon=1740 km). Assuming a smooth moon with a power reflection coefficient of 0.15, the theoretical echoing area should be on the order of 121.6 db above 1 m^2.

At times, the lunar echo was found to undergo both pulse lengthening and distortion. A representative example illustrating these characteristics is contained in figure 2, the signal amplitude in this case being only 114 db above 1 m^2.

A selected sample of an amplitude versus time fading record, displaying the ionospheric effect of Faraday rotation and the presence of lunar libration, is shown in figure 3. The Faraday phenomenon is recognizable by the appearance of lunar signals of approximately equal amplitude in both the orthogonal receiver channels during the period when horizontal polarization was employed on transmission. The lunar libration is indicated by the rapid fading of the envelope of the amplitude-time function, the

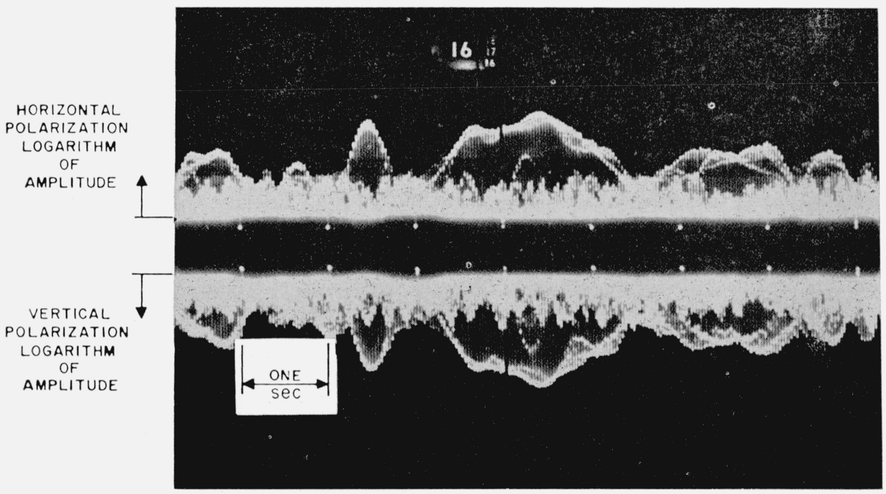

FIGURE 3. *Amplitude versus time film record of lunar echoes recorded at Trinidad at 425 Mc/s displaying Faraday rotation and lunar libration, 12 January 1960, 1617 EST.*

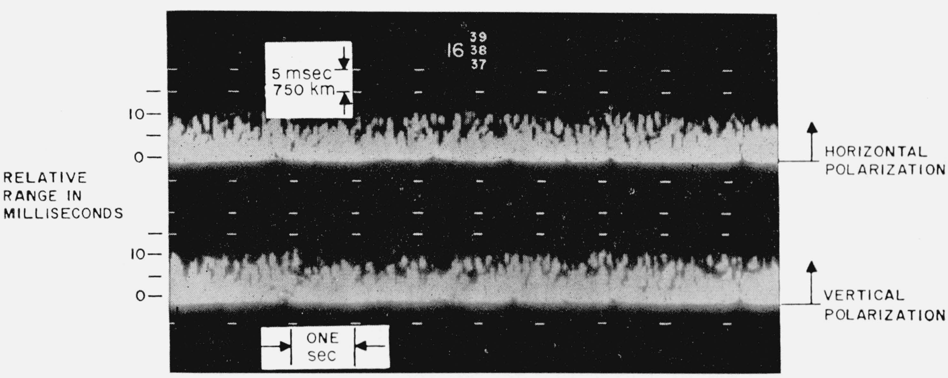

FIGURE 4. *A typical range versus time photograph of radar-lunar echoes recorded at Trinidad at 425 Mc/s, 12 January 1960, 1638 EST.*

back portion of the pulse returns exhibiting a much higher fading rate than the front portion.

It is interesting to note that the fading patterns of the main echo pulse (the large signal amplitude) observed on both polarizations are identical. The significance of this is that the polarization of the incident pulses on reflection from the front part of the moon is maintained, which implies that this region of the moon's surface appears reasonably smooth at a frequency of 425 Mc/s. Depolarization of a signal which should occur on reflection from a rough surface would result in the amplitude fading patterns observed on orthogonal polarizations to be somewhat different.

A typical range-versus-time photograph of lunar echoes, also revealing pulse lengthening, is shown in figure 4. The signal fading indicated by the reduction of the echo intensity in the back portion of the range scale is basically due to the moon's libration.

3. Data Analysis

3.1. Lunar Reflection Laws

The supposition that the moon is a rough body at radar frequencies has led to the speculation of various scattering laws and functions to describe the manner in which radio waves would scatter from the moon's surface. A method of investigating an applicable scattering law is to characterize the decay rate of the trailing edge of a lunar echo.

In order to reduce the effect of short-term fluctuations in the envelope of a lunar echo, 130 A-scope photographs, consisting of 65 different pulse returns received on the two orthogonal polarizations, were averaged to obtain a representative sample for analysis purposes. The resultant lunar echo, shown in figure 5, was obtained by dividing each pulse into 0.25-msec intervals. At each interval along the pulse, an average amplitude was calculated from the 130 different data points.

It is seen that the trailing edge of the pulse can be described in terms of the third degree polynominal, $\alpha+\beta\theta+\gamma\theta^2+\delta\theta^3$, where the constants $\alpha=39.06$, $\beta=74.33$, $\gamma=39.09$, and $\delta=-3.38$. The variable, θ, is the angle of incidence with respect to the normal to the surface of the moon. It is obvious, however, that the angular scattering law, as suggested by Leadabrand [1960], A_1 (sin $2\theta/2\theta)^{20}$, where $A_1=163$, does not seem to apply to this example.

The trigonometric functions, $A_2 \cos\theta$ and $A_3 \cos^2\theta$, where $A_2=11.2$ and $A_3=13.65$, also shown in figure 5, are representative of the Lommel-Seelinger and the Lambert scattering law, respectively.

The Lommel-Seelinger law refers to scattering taking place from a rough surface having irregularities that are large compared with wavelength. The energy scattered from all regions of the surface is the same. Thus, when considering radio wave reflection from such a surface, the received power is only proportional to the cosine of the angle between the incident ray and the normal to the surface.

The Lambert law, which applies to the scattering from a diffuse surface having irregularities on the order of a wavelength, states that the scattered energy in any direction is proportional to the cosine of the angle between the incident ray and the normal to the surface and to the cosine of the angle between the scattered ray and the normal.

When the relative echo power is plotted as a function of the cosine of the angle of incidence, as depicted in figure 6, it is found that the Lommel-Seelinger law and the Lambert law reduce to straight lines and that the pulse decay rate follows the slope of the Lommel-Sellinger scattering law displaced by a factor of approximately one-eighth.

It should be mentioned that Pettengill [1960] has reported that, following the decay of the initial specular component, the angular distribution of power in the moon echo obeyed the Lambert-type law except for a small amount of limb brightening at the extreme ranges. Since the Trinidad and Millstone Hill investigations were conducted at approximately the same frequency, i.e., the transmission frequency at Millstone Hill was 440 Mc/s compared to 425 Mc/s at Trinidad, the discrepancy in the results may be attributed to the fact that the lunar echo analyzed by Pettengill was a composite of 24,000 pulses, integrated at each 500-μsec range increment.

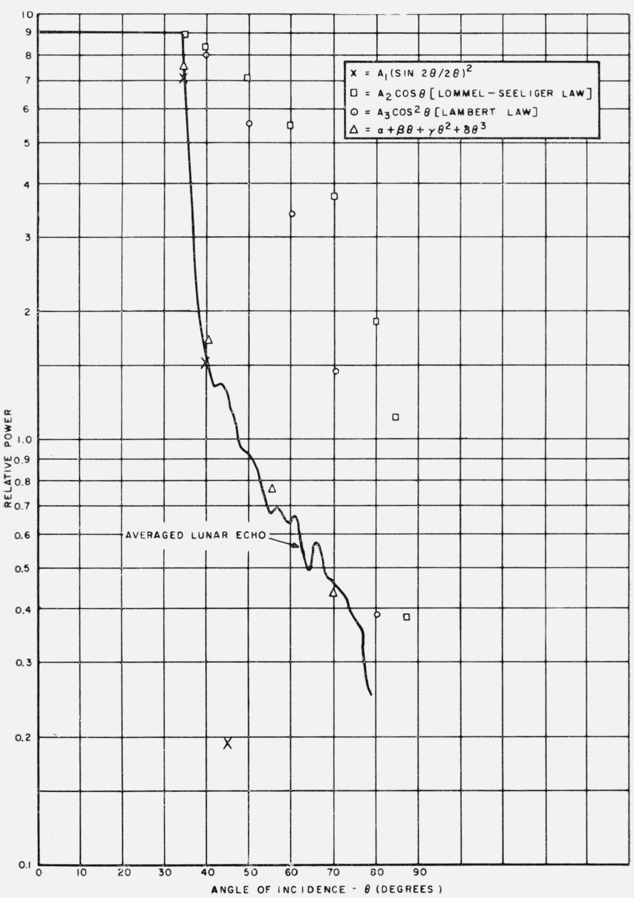

FIGURE 5. *Scattering laws applied to lunar echo as a function of the angle of incidence.*

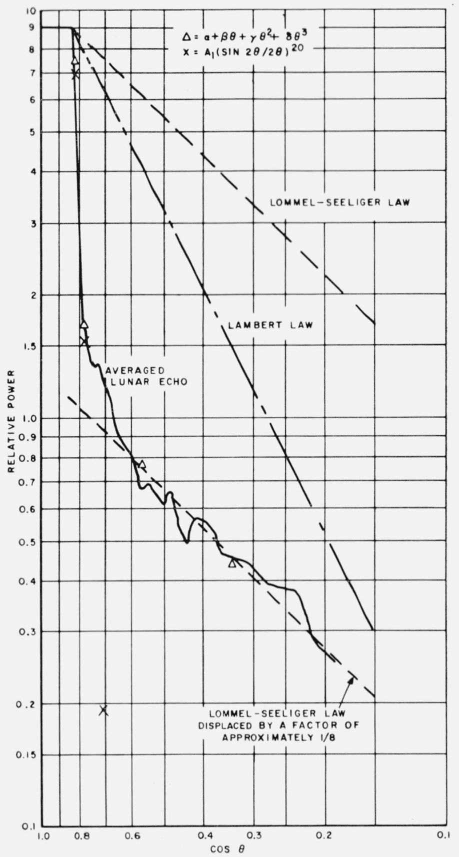

FIGURE 6. *Scattering laws applied to lunar echo as a function of the cosine of the angle of incidence.*

However, Browne, Evans, Hargreaves, and Murray [1956], have found that an analysis of lunar echo data, observed at a frequency of 120 Mc/s, gives best agreement with the Lommel-Seelinger scattering model.

3.2. Cross Section and Reflection Coefficient of the Moon

In analyzing the cross sectional area of the moon and the statistical distribution of the amplitudes of lunar signals, which is discussed in the next section, the magnitude of the amplitude of the received echoes was measured at a constant position within the pulse, i.e., at 1 msec after the beginning of the pulse which corresponds in range to a lunar depth of 150 km.

The cumulative probability distributions of the total cross section of the moon observed on 8 February 1960, during two 10-min periods, are shown in figure 7. The total lunar cross section is merely the addition of cross sections obtained on the orthogonal polarization receiver channels. Each cumulative distribution curve was calculated from approximately 18,000 individual data points. The interval between 1430 and 1440 EST corresponds to the time when the moon was oriented at an azimuth angle of about 72.6 deg and elevation angles of 6.0 to 8.0 deg, while between 2025 and 2035 EST it was at an azimuth angle varying from 5 to 344 deg and elevation angle of about 82 deg.

It is seen that, for the low angle measurements, 50 percent of the total cross sections were equal to or less than 5.0×10^{11} m^2, while, at transit, the value increased to 7.5×10^{11} m^2.

Lunar observations on 12 January 1960 disclosed that 50 percent of the total cross sections near the horizon were equal to or less than 8.5×10^{11} m^2, while at transit they reduced to 6.0×10^{11} m^2.

Assuming that the moon is a perfect conducting sphere, its radar cross section is then the projected geometric area of the whole disk or 9.5×10^{12} m^2. It follows that, for 50 percent of the observations, the power reflection coefficient of the moon's surface appeared to lie between 0.05 and 0.085. It is estimated that the experimental error incurred in this analysis should be less than 3 db.

Measurements made by Fricker, Ingalls, Mason, and Swift [1960], at a frequency of 412 Mc/s using a CW system, indicated a lunar power reflection coefficient of 0.074. According to Blevis and Chapman [1960], radar observations of the moon at 488 Mc/s also made with a CW system, revealed a power reflection coefficient of about 0.05. The uncertainty in both experimental results is reported to be less than 3 db.

Since the Trinidad results, obtained by pulsed radar techniques having a pulse length less than the radio depth of the moon, are in excellent agreement with other experimental data taken with CW systems in the same frequency range, it would appear that the moon must be sufficiently smooth for Fresnel-type reflection to take place.

3.3. Statistical Distribution of Lunar Fcho Amplitudes

The rapid fluctuations of radar pulses reflected from the moon's surface are usually attributed to the libration which is defined as the oscillatory motion of the moon about an axis which itself changes with time.

The effect of the moon's libration on the reflected signal can be explained by assuming that the mocn's surface consists of a random number of scatterers. The amplitude of the reflected pulse, as observed on the earth's surface, is the resultant of the signals reflected from each of the scattering elements. Since the moon undergoes an apparent rocking motion, or libration, the signals scattered from various parts of its surface are continuously undergoing random changes in phase and amplitude which, in turn, produce fluctuations in the resultant signal.

For surface irregularities which scatter incident radiation with random phases and amplitudes, the probability of occurrence of any resultant signal amplitude is therefore given by the Rayleigh probability distribution law. The concept of the Rayleigh distribution is maintained, provided that the number of scattering areas is large, i.e., at least on the order of 10 or greater.

The probability, $P(R)dR$, of finding an amplitude between R and $(R+dR)$ is therefore given by

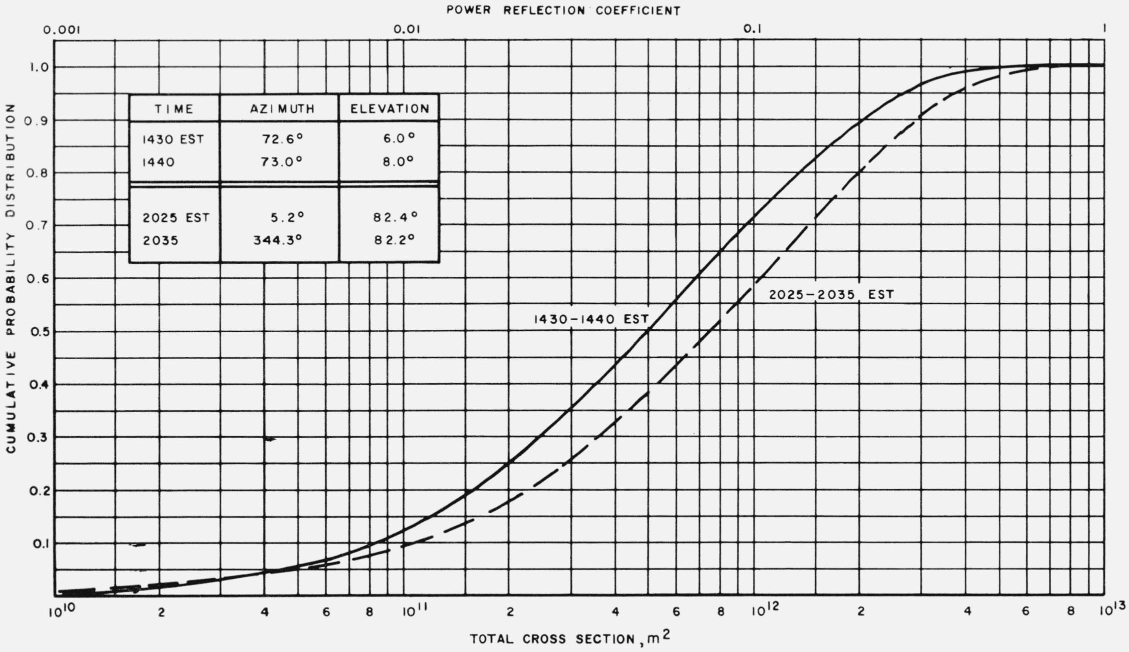

FIGURE 7. *Cumulative probability distribution of the total cross section of the moon, 8 February 1960.*

$$P(R)dR=\frac{R}{\psi}\, e^{-\frac{R^2}{2\psi}}\, dR, \tag{1}$$

where R is the amplitude of the resultant scattered signal at any instant of time, and ψ is a constant related to the mean value of R by

$$\psi=\frac{2}{\pi}\,(\overline{R})^2. \tag{2}$$

The condition in which a steady signal is superimposed on a signal which is the resultant of elementary contributions originating from random scattering areas is of considerable interest since it may approximate a possible situation prevailing in the lunar reflection of radio waves.

The steady signal corresponds to a specularly reflected wave coming from the first Fresnel zone or from a relatively small number of smooth surface areas in the region of the first Fresnel zone. The random signal is caused by the lunar libration or by random surface irregularities. If the number of smooth surface areas becomes very large, it is possible for the signals reflected by these areas to undergo cancellation and reinforcement. Thus, instead of specular reflection taking place, a random-type noise could result.

The probability density distribution function that describes the envelope of such a resultant signal can be written, according to Rice's theory of random noise [1945], as

$$P(V)=\frac{V}{\psi}\, e^{-\frac{V^2+B^2}{2\psi}}\, I_0\left(\frac{VB}{\psi}\right) \tag{3}$$

where B is the amplitude of the steady signal, V is the envelope of the resultant amplitude comprised of the steady signal (B) and the random signal (R), ψ is a constant defined by (2), and $I_0(VB/\psi)$ is the modified Bessel function of the first kind of zero order.

In determining the statistical distribution of the signal amplitudes, the lunar echoes recorded in two 10-min intervals between 1430 and 1440 EST, and 2025 and 2035 EST, on 8 February 1960 were selected. It should be noted that the amplitude data from these time periods are identical with the lunar cross section data discussed in figure 7. The statistical analysis was made on the total signal amplitude in order to reduce the effect of ionospheric Faraday rotation.

The probability density function of the total lunar amplitude, recorded during moonrise when the libration fading rate was normally low, is illustrated in figure 8. The theoretical curves were calculated utilizing (3) with $\psi=28.0$, this constant being evaluated from the experimental data.

The presence of a strong steady signal would be indicated by a probability density function which would be of the form of the $b=2$ curve where $b=B/\sqrt{\psi}$. It is seen that the experimental points coincide, to some degree, with the theoretical Rayleigh distribution $(b=0)$ for low amplitude values, but commence to diverge for a normalized amplitude of 12 or greater.

The experimental and theoretical probability density functions of the total amplitude of the lunar echoes observed for 10 min near transit are shown in figure 9. After normalization, the parameter ψ, for this time period, was found to be 40.0. It is interesting to note that the experimental data appear to tend

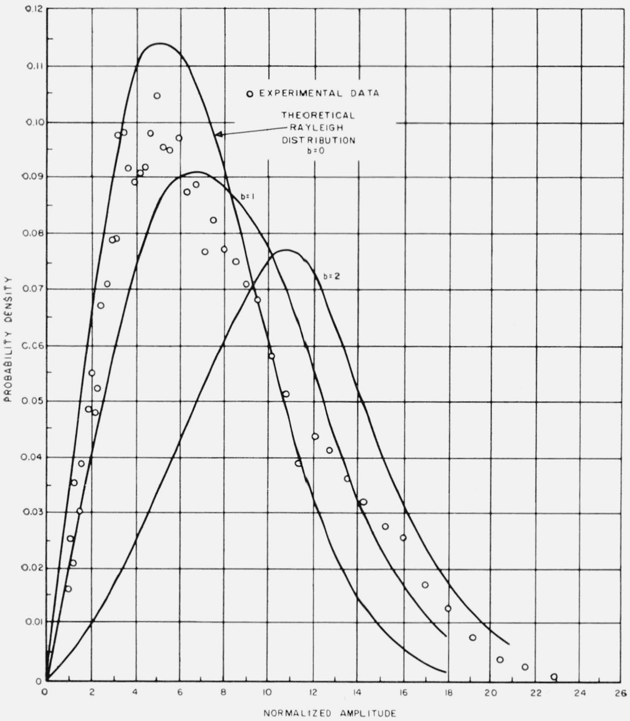

FIGURE 8. *The probability density function of the total amplitude of the lunar echo, 8 February 1960, 1430 to 1440 EST.*

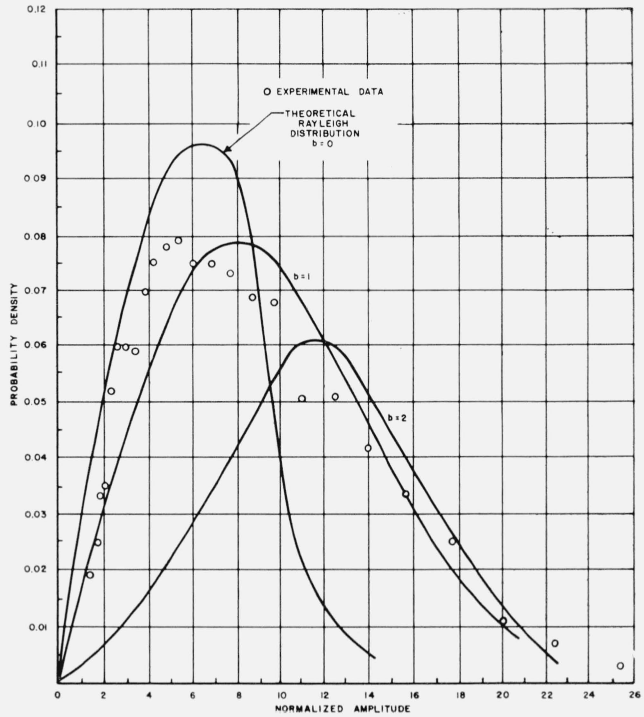

FIGURE 9. *The probability density function of the total amplitude of the lunar echo, 8 February 1960, 2025 to 2035 EST.*

toward the $b=1$ probability density curve except for the slight displacement at the maximum.

A comparison of the experimental points in figures 8 and 9 indicates that, at high elevation angles where libration fading is a maximum [Fricker, Ingalls, Mason, Swift, 1960], the amplitude signals were observed more often having greater magnitudes than those detected near moonrise.

An amplitude record of 1 min in duration (2026:20 to 2027:20 EST), taken from the same statistical population, was also analyzed to determine the effect of a shortened sample size on the experimental distribution. In general, it was found that the amplitudes of the 1-min sample were distributed in a somewhat similar fashion to those of the 10-min sample.

The results of this analysis reveal evidence of the presence of a slight specular component reflected from the lunar surface during the time when the moon was near transit. This was not the case, however, for observations conducted at moonrise.

It is possible that, instead of one large smooth region on the surface of the moon, there are many smooth areas which give rise to specular reflection. Thus, this would have the effect of imposing a random phase and random amplitude fluctuation of the resultant specular component. It would follow that the steady signal, which would be normally expected if the moon consisted of only one large smooth reflecting area, would, in essence, be washed out or smeared.

3.4. Doppler Frequency Shift

Because of the relative motion of the moon with respect to the earth, radio waves reflected from the moon are shifted in frequency.

The Doppler frequency shifts measured during the partial lunar orbits of 12 January 1960 and 8 February 1960 are shown in figure 10. It is quite evident that the experimental observations are in agreement with the theoretical predictions. The theoretical curves were computed according to the method proposed by Fricker et al. [1960]. The Doppler shift is a maximum of approximately +1130 c/s at moonrise and a minimum at the moon's transit.

The Doppler frequency shift at 120 Mc/s, as reported by Browne et al. [1956], was on the order of ± 50 c/s for observations taken when the hour angle of the moon was less than 30 min of time. Doppler shifts as large as ± 1000 c/s at 412 Mc/s have been recorded by Fricker, Ingalls, Mason, Stone, and Swift [1958].

3.5. Doppler Frequency Spread

Radio waves, when reflected from the moon, experience a Doppler spread in frequency in addition to undergoing a Doppler shift. The former phenomenon is predominantly the result of the moon's libration.

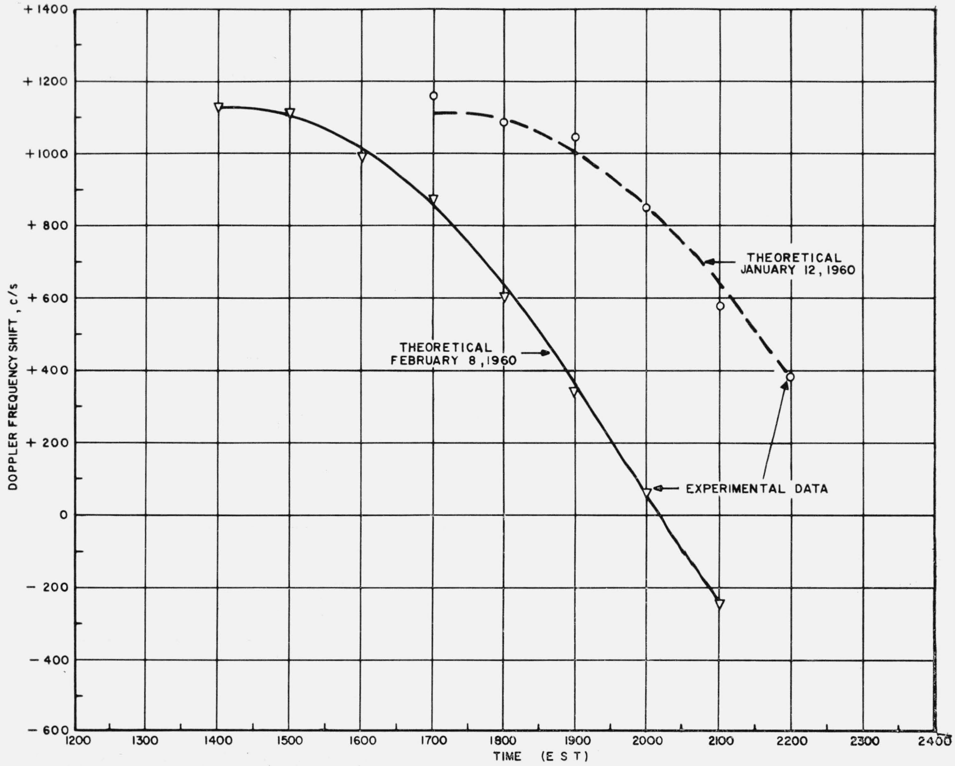

FIGURE 10. *Doppler frequency shift of lunar echoes recorded at Trinidad at 425 Mc/s.*

Fricker et al. [1960], have shown that the frequency spread at transit is always a maximum, while at moonrise it could have any value, depending upon the moon's effective total libration rate in latitude and longitude.

In an attempt to determine the existence of the Doppler frequency spread, the power spectrum for one lunar observation was calculated and compared with the theoretical prediction.

The power density spectrum is the Fourier transform of the autocorrelation function which is computed from an amplitude-versus-time function. In this analysis, the autocorrelation function was calculated from the total lunar cross section which is proportional to the square of the signal amplitude. The power density spectrum, as discussed in this section, defines, in essence, the frequency-power content of the time variation of the total echoing area of the moon.

The autocorrelation function of the total cross section of the moon, calculated from radar data recorded during a 1-min interval on 8 February 1960, is presented in figure 11. The total signal power for each pulse, i.e., sum of the power received on the two orthogonal polarizations, was measured 1 msec after the rise of the pulse. This corresponds to the coverage of a spherical cap on the moon with a fractional radius of 0.404, the fractional radius being defined as the ratio of radius of the base of the spherical cap to the radius of the moon.

The power density spectrum derived from the autocorrelation function is given in figure 12. It is seen that the principal frequencies are all less than 1 c/s, i.e., 0.27, 0.53, 0.69, and 0.94, with the dominant frequency being 0.27 c/s.

The theoretical maximum Doppler spread for this particular time was found to be 2.21 c/s for the fractional radius of 0.404. This calculation was based on the lunar libration rate constants presented in table 1 and applied to the theoretical relationships of Fricker et al. [1960].

Since the Doppler frequency spread is directly proportional to the fractional radius of the moon [Fricker, Ingalls, Mason, and Swift 1960], and since the experimental dominant frequency of 0.27 c/s is 0.12 times smaller than the theoretical estimate of 2.21 c/s, it follows that the fractional radius within which the observed amplitude variation is contained is about 0.049.

At a frequency of 425 Mc/s, the first Fresnel zone on the moon has a fractional radius of approximately 0.007. It appears, therefore, that while the effective radius responsible for most of the amplitude variation is smaller than 713 km, the radius of the spherical cap corresponding to a fractional radius of 0.404, it is larger than the radius of the first Fresnel zone, 11.7 km, by approximately 7 times.

As shown in the photograph of the front portion of the moon's face, figure 13, there is a comparatively

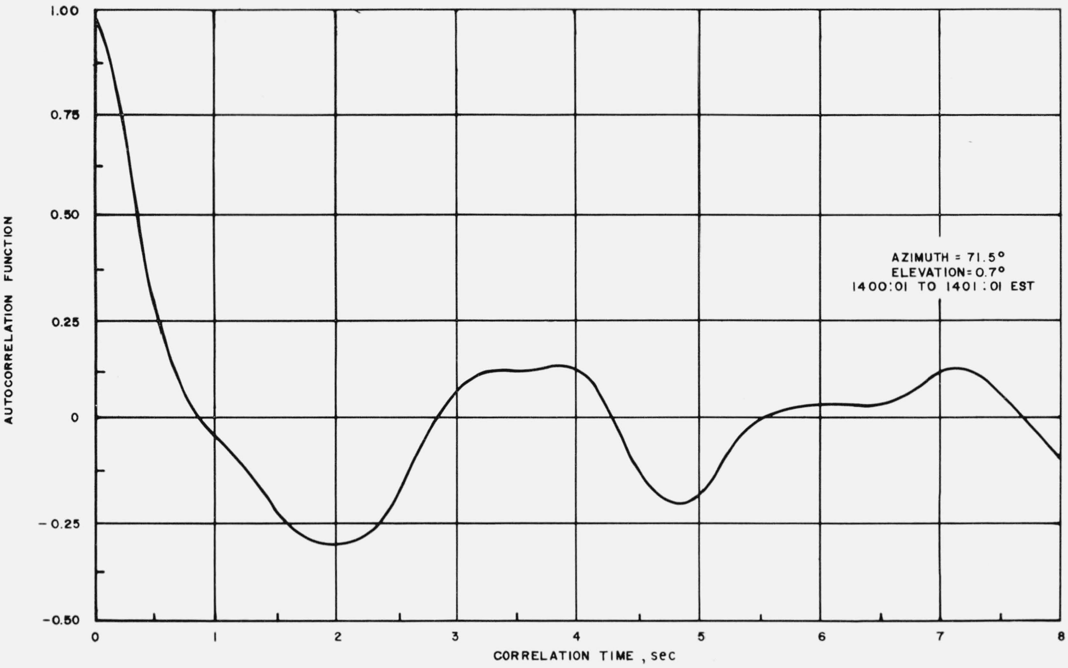

FIGURE 11. *Autocorrelation function of the total cross section of the moon, 8 February 1960.*

smooth area in the center of the moon, Sinus Medii, large enough to encompass at least 7 Fresnel zones. This region is surrounded by a number of mountain peaks that rise 5,000 to 8,000 feet [Neison, 1876]. It could be possible that the librational motion of these peaks account for the higher frequency terms obtained in the power density spectrum. For example, the mountain range, Rhaeticus with a fractional radius of approximately 0.08 to 0.09, could have imparted at its location a fading rate of about 0.84 to 0.95 c/s on 8 February 1960. It is interesting to note that the fading rate, possibly due to Rhaeticus, compares favorably with one of the frequencies, 0.94 c/s, present in the power density spectrum of that date.

The feasibility of mapping the surface of the moon by means of Doppler shift power spectrum measurements has been demonstrated by Pettengill [1960].

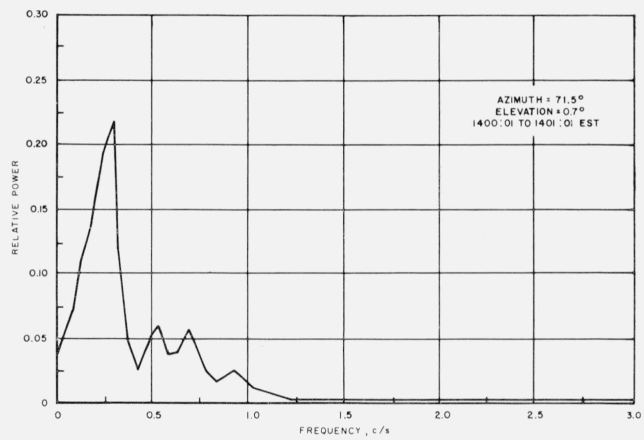

FIGURE 12. *Power density spectrum of the total cross section of the moon, 8 February 1960.*

TABLE 1. *Libration rate constants for the evaluation of Dopper frequency spread*

8 February 1960, 1401 EST

Azimuth angle	Elevation angle	Total libration rate in latitude l_{TB}	Total libration rate in longitude l_{TL}	$\nu_0=\tan^{-1}\left[\frac{l_{TB}}{l_{TL}}\right]$	Maximum Doppler spread
Degrees	*Degrees*	*Radians/sec*	*Radians/sec*	*Degrees*	*c/s*
71.5	0.7	-1.34796×10^{-6}	-5.14733×10^{-7}	69.1	5.450 K*

*K=Fractional radius of the moon.

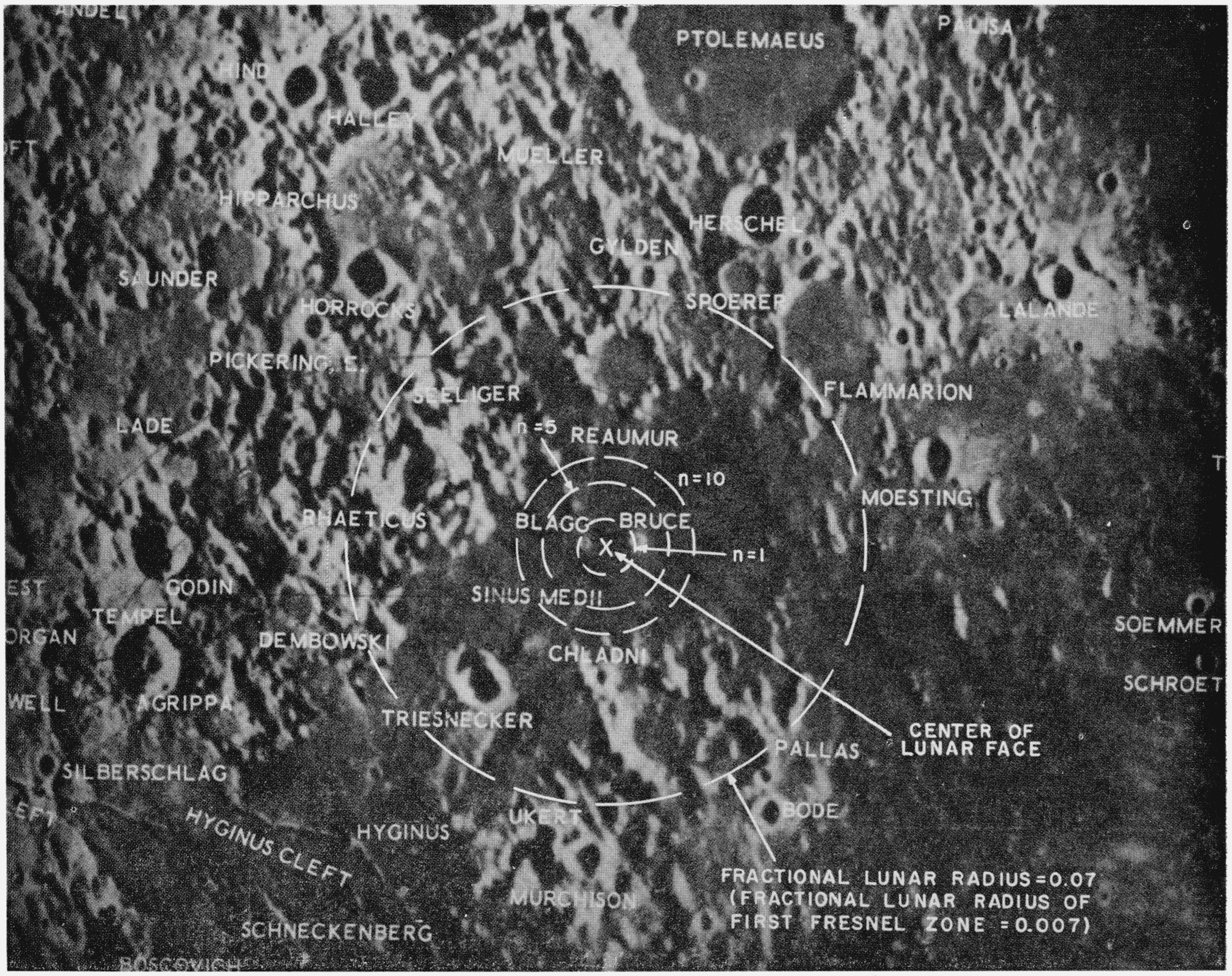

FIGURE 13. *Fresnel zones on the face of the moon.*

4. Conclusions

An analysis of radar pulses reflected from the moon has revealed pertinent data regarding the characteristics of its surface.

It appears that, at a frequency of 425 Mc/s, the front portion of the moon is comparatively smooth and is the region where specular reflection takes place. The following experimental evidence is the basis of this conclusion.

1. Radar-pulse measurements of the cross section and the power reflection coefficient of the moon are approximately the same as those determined by CW systems operating at a frequency of 412 Mc/s [Fricker, Ingalls, Mason, and Swift, 1960] and 488 Mc/s [Blevis and Chapman, 1960]. This indicates that a pulsed radar system covering a sufficient number of Fresnel zones measures the same echoing area as a CW system covering the entire surface of the moon.

2. The probability density function of the total amplitude of the lunar echoes, for one 10-min sample, reveals the possible presence of a steady signal which may be indicative of a specular reflected signal. The analysis is based on Rice's [1945] theory of random noise.

3. The envelope or fading pattern of the amplitude-versus-time photographs of the main lunar echo received on two linear orthogonal polarizations are always identical. This implies that the polarizations of the incident pulses are not altered on reflection from the front portion of the moon's surface.

4. The rotation of the plane of polarization of the radar-lunar echoes is found to be entirely due to the Faraday effect of the ionosphere. The polarization of the received signal often attains an acute angle of zero degrees and 90 deg, whereas, according to Senior and Siegel [1959; 1960], a rough body can be expected to yield a minimum signal, containing at least 30 percent of the total received energy. In other words, the polarization angle of signals reflected

from a rough body should vary between 18 and 73 deg and not between zero and 90 deg.

5. The pulse shape of the main reflected echo most often resembles the transmitted pulse.

The experimental evidence, indicating that the back portion of the moon behaves as rough scatter, is based on the following.

1. A-scope photographs of lunar echoes show that the pulses are stretched out in length to approximately the radio-depth of the moon, i.e., 11.6 msec.

2. It is found that the decay of the trailing edge of a composite lunar echo, which is the average of 130 echoes, obeys the Lommel-Seeliger scattering law displaced by a factor of approximately one-eighth.

The assistance of R. Wolfe in analyzing the radar amplitude data in the study of the scattering laws applicable to the lunar surface is greatly appreciated.

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