TECHNICAL REPORT # 16

Date: January 1974
From: The Crawford Hill VHF Club, W2NFA

Subject: <u>Libration Fading on the EME Path</u>

One of the most troublesome aspects of receiving a moonbounce signal besides the enormous path loss and Faraday rotation fading, is <u>libration fading</u>. This report will deal only with libration fading its cause, effects and possible measures to minimize it.

Libration fading of an EME signal is characterized in general as a fluttery rapid irregular fading not unlike that observed in tropospheric scatter propagation. Fading can be very deep, 20 db or more, and the maximum fading rate will depend on the operating frequency. At 1296 mc/s the maximum fading rate is about 10 cycles per second and scales directly with frequency.

On a weak CW moonbounce signal, libration fading gives the impression of a randomly keyed signal. In fact on very slow CW telegraphy, the effect is as though the keying is being done at a much faster speed. On very weak signals only the peaks of libration fading are heard.in the form of occasional short bursts or 'pings'.

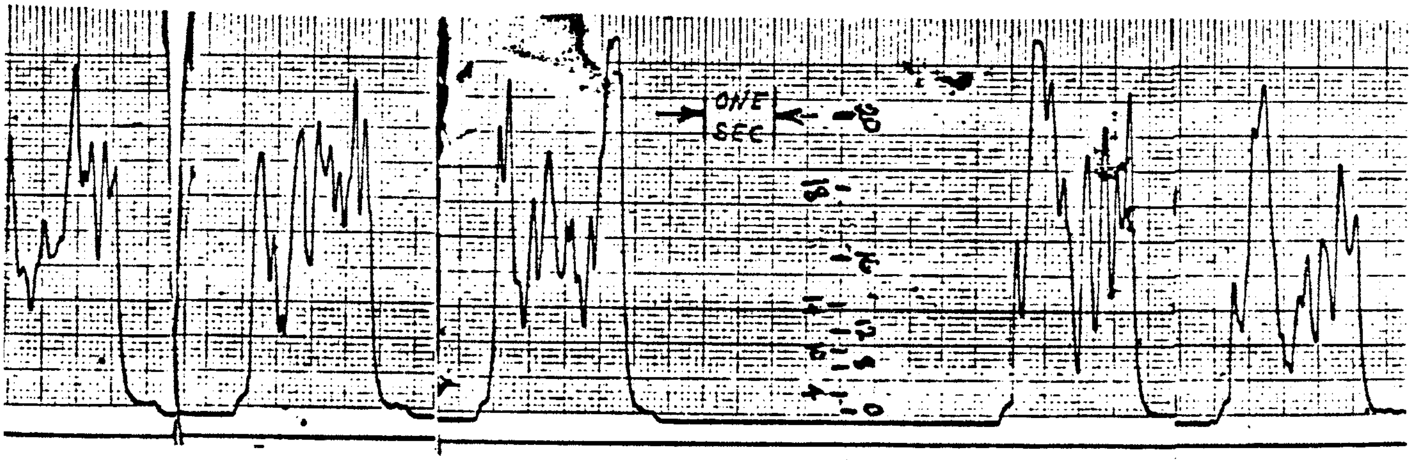


Figure 1. Moon echoes received at W2NFA July 26, 1973, 1630GMT. Antenna gain 44 db, transmitting power 400 watts and system temp. 400°K.

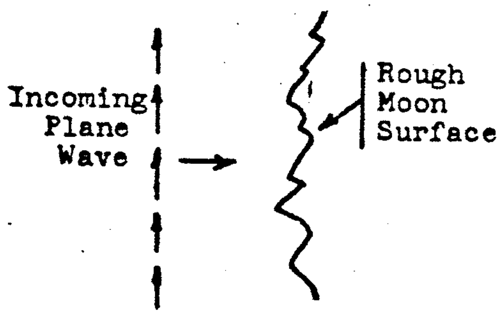
Figure 1 above shows samples of a typical EME echo signal at 1296 mc/s. These recordings made at W2NFA show the wild fading characteristics with sufficient S/N to record the deep fades. Circular polarization was used to eliminate Faraday fading, thus these recordings are of libration fading only. The recording bandwidth was limited to about 40 Hz to minimize the higher sideband frequency components of libration fading which persist but are much smaller in amplitude. For those who would like a better statistical description, libration fading is Raleigh distributed.

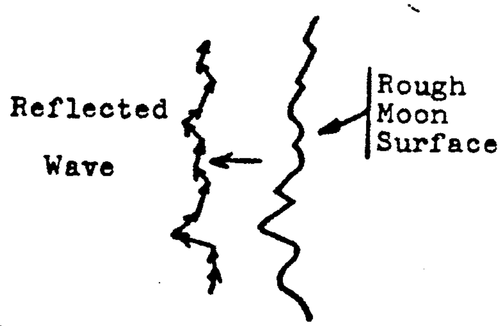
An interesting and useful aspect of libration fading is due to the mechanism which causes it. In the recordings shown by Figure 1, the average signal return level computed from pathloss and mean reflection coefficient of the Moon is at about the +15 db S/N level.

It is clear that enhancement of echoes far in excess of this average level are observed. This point should be kept clearly in mind when attempting to obtain echoes or receive EME signals with marginal equipment. The probability of hearing an occasional peak is quite good since occasional enhancement as much as 10 db is possible. Under these conditions however, the amount of useful information which can be copied will be near zero. The enthusiastic newcomer to EME communications will be stymied by this effect since he knows that he can hear the signal strong enough on peaks to copy but can't make any sense out of what he tries to copy.

What causes libration fading? Very simply it is due to multipath scattering of the radio waves from the very large (2000 mile diameter) and rough Moon surface combined with the relative motion between Earth and Moon called librations.

To understand these effects, consider first that the Earth and Moon are stationary (no libration) and that a plane wave front arrives at the Moon from your Earth bound station as shown below on the left.

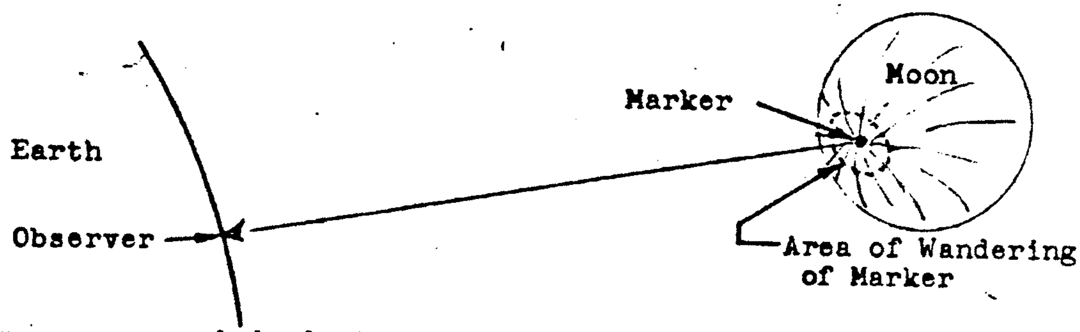




The reflected wave in the right hand drawing consists of many scattered contributions from the rough Moon surface. It is perhaps easier to visualize the process as if the scattering were from many small individual flat mirrors on the Moon which reflect small portions (amplitudes) of the incident wave energy in different directions (paths) and with different path lengths (phase). Those paths directed toward Earth arrive at your antenna and appear as a collection of small wave fronts (field vectors) of various amplitudes and phases. The vector summation of all these coherent (same frequency) returned waves (and there are a near infinite array of them) takes place at the feed of your antenna (i.e. the collecting point in an antenna system). The level of the final summation as measured by a receiver can of course have any value from zero to some maximum. Remember now that we assumed the Earth and Moon are stationary which means that the final summation of these multipath signal returns from the Moon will be one fixed value. The condition of relative motion between Earth and Moon being zero is a rare event about which we will discuss later in this report.

Consider now that the Earth and Moon are moving relative to each other (as they are in nature) so that the incident radio wave "sees" a slightly different surface of the Moon from moment to moment. Since the Moon surface is very irregular, ~~so~~ the reflected wave will be equally irregular changing in amplitude and phase from moment to moment. The resultant continuous summation of the varying multipath signals at your antenna feed point produce the effect called libration fading of the Moon reflected signal.

The term libration is used to describe small perturbations in the movement of astro bodies. Earth libration consists mainly of its diurnal rotation while Moon libration consists mainly of its 28 day rotation which appears as a very slight rocking motion with respect to an observer on Earth. This rocking motion can be visualized by considering placing a marker on the surface of the Moon at the center of the Moon disc which is the point closest to the observer, as shown below.



Then over a period of time we will observe that this marker wanders around within a small area. All this means is that the surface of the Moon as seen from the Earth is not quite fixed but changes slightly as different areas of the periphery are exposed due to this rocking motion. Moon libration is very slow (of the order of 10^{-7} radians per sec.) and can be determined with some difficulty from published Moon ephemeris tables.#

Although the libration motions are very small and slow, the large surface area of the Moon having so many scattering points (small areas) means that even these slight geometric movements can alter the total summation of the returned multipath echo by a significantly large amount. Since the librations of Earth and Moon are calculable, it is only logical to ask if there ever occurs a time when the total libration is zero or near zero? The answer is yes, and it has been observed and experimentally verified on radar echoes that minimum fading rate, not depth of fades, is coincident with minimum total libration. Calculation of minimum total libration is at best tedious and can only be done successfully by means of a digital computer. It is a problem in extrapolation of rates of change in coordinate motion and in small differences of large numbers.

At W2NFA, several libration fading minima on echoes have been observed, recorded samples of which are shown ~~below,~~ Figure 2. Comparison with Figure 1 shows the lack of rapid fading indicating that libration has slowed down considerably. Note that the fades are still quite the same in depth and enhancement. In general libration fading on echoes will be most severe at Moon zenith and will have minimas only in the regions near Moon rise or set, elevation angles of roughly 20 to 30 degrees but not with daily regularity. And most important of all, the minima are cusp like in occurance and are easily distinguishable for brief periods of approximately one half hour or less.

The American Ephemeris and Nautical Almanac, published annually by the U.S. Govt. Printing Office and obtainable from the Superintendent of Documents, Washington, D.C. 20402; or,
The Astronomical Ephemeris, published by Her Majesty's Stationery Office, 49 High Holburn, London W.C.1

These effects are for echo recordings and it is interesting to contemplate the effect for a given point-to-point path on the Earth which is of more immediate interest. This more useful case involves determining the simultaneous minima for both station locations on echoes. A problem which is more complicated and as yet has not been considered. It is conceivable that the point-to-point libration fade minima may rarely occur in general except for specific paths such as two stations located on the same meridian. Much computation for an extended period and variety of paths has to be undertaken before a clear picture of what to expect can be formulated.

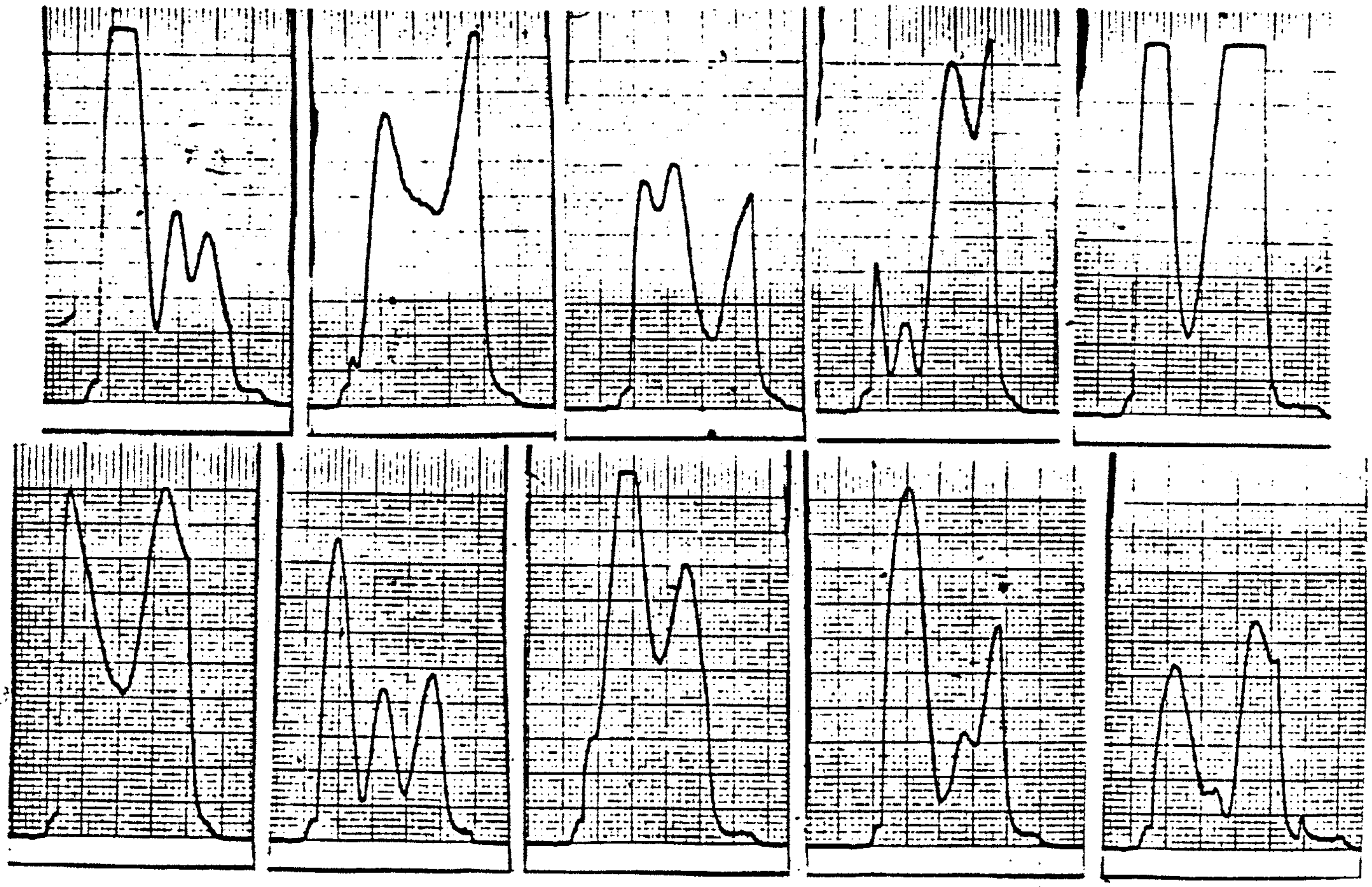
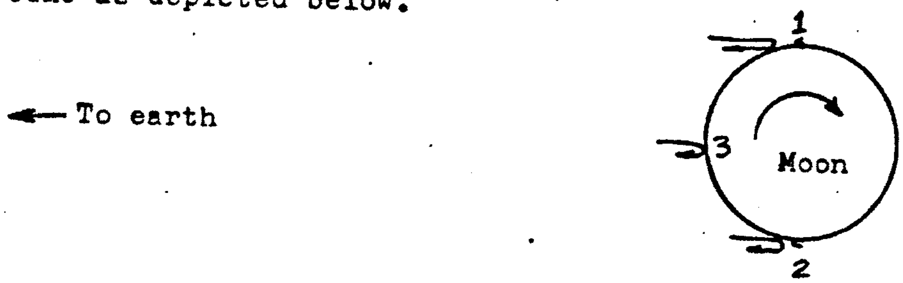


Figure 2. Echo samples of low libration taken at W2NFA at 1296 mc/s on July 28, 1973 1130 GMT, 30° elevation, 88° azimuth. Note much lower fading rate than in Figure 1 but equally deep fades.
The time scale and level calibration are the same as for Figure 1.

Further Considerations of Moon Libration

The simple concept of multipath scattering from the Moon must be extended for completeness to include libration spreading. The main component of libration motion is due to the earth's rotation and occurs when the moon is in its zenith position (directly over your station meridian). At this time the observer on earth is moving with considerable tangential velocity which may be translated to simple rotational motion of the moon.

Total libration motion of the moon and earth may therefore be considered as simple rotation of the moon over a small interval of time as depicted below.



Reflections occurring towards the limbs of the Moon designated above as points 1 and 2 have their radial distance to the earth changing in opposite directions due to the rotation of the Moon. Reflections from point 1 are increasing in distance to the earth while reflections from 2 are decreasing. From well known rules for Doppler frequency shift it is clear that the radio wave reflected from point 1 will be decreasing in carrier frequency while those from point 2 will be increasing in frequency. Reflections from the center of the Moon disc, point 3, will not be shifted in frequency because the radial distance to the earth is not changing.

Since reflections are occurring over essentially half the Moon surface (the half facing the earth), it is obvious that each reflection point (multipath scattering) will have a doppler shift of its own according to the change in distance to the earth with libration rotation. The grand total effect summed at your antenna terminals is a spreading or smearing of the incident CW signal into a carrier surrounded by symmetric sidebands which extend out to a maximum of

$$F = \pm \frac{2 L_t r_m}{\lambda} \quad \text{cycles per second.}$$

Here λ is the carrier wavelength, r_m is the moon radius in the same units as λ, (r_m = 2000 s. miles or about 10,000,000 feet) and L_t is the total maximum libration rate which is about 12×10^{-7} radians/sec. For a carrier frequency of 1296 mc/s, the maximum extent of the sidebands will be about ±20 cycles. At 144 mc/s it is about 2 cycles. The total energy in these Doppler spreading sidebands is small in the VHF-UHF range but increases at higher frequencies.

It should be made quite clear at this point that libration spreading caused by Doppler shift of the many reflections over the surface of the Moon is a small disturbance of the radio signal. The mean or average Doppler shift in carrier frequency caused by the rate of change in average range distance between earth and Moon is not considered in this report but can amount to as much as ± 4000 cycles/sec. at 1296

near Moonrise (+) and Moonset (-). This is the more familiar Doppler shift in frequency of a Moonbounce signal and sounds like a slowly drifting oscillator.

An overview of Moon reflection distribution with respect to frequency is useful to complete the libration fading and doppler spreading effects. When looking at a full Moon optically we see a bright uniformly illuminated disc. At much lower frequencies than light waves the picture is somewhat different. At 25,000 mc/s, the disc appears to be brighter at the center falling off in brightness by only 5 or 6 db at the edge. As we procede lower in frequency the central brightness area becomes smaller and the intensity falls off more rapidly towards the edge. At 1296 mc/s, the central area of most energy reflection (bright spot) comprises less than 1/3 the total disc area and the reflected energy falls off by 30 db or more towards the edge. At 144 mc/s the bright central area is even smaller and the edge of the Moon disc is all but invisible. Curiously, the average reflection coefficient of the Moon remains virtually constant over the entire VHF-UHF range at about 6.5%.

This distribution with frequency of the reflection characteristics of the Moon has been experimentally verified and is important to keep in mind as we consider further aspects of libration fading and doppler spreading.

Coherence Bandwidth

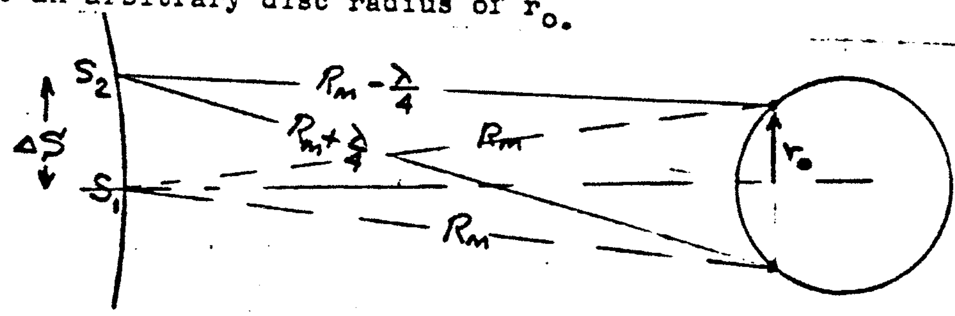
The total effect of libration fading and doppler spreading can be summed up in the following hypothetical experiment. Suppose that we transmit an AM signal to the Moon. ~~And~~ Suppose further that the carrier is modulated by a single tone whose frequency can be varied from about 100 Hz to 10,000 Hz. For low modulation frequencies the return signal can be demodulated and, except for the fading, will demodulate normally and be the same as the original signal. As the modulation frequency is increased, ~~we notice a curious result.~~ The demodulated signal ~~is~~ becomes distorted and appears to have 'selective fading'. The fact is that the two sidebands of the returned signal (an AM signal consists of a carrier with symmetric sidebands, two sidebands for a single tone modulation) have undergone different phase and amplitude changes, i.e. they are becoming incoherent.

The coherence bandwidth can then be defined as the frequency separation at which some degree of acceptable coherence still exists. At 1296 mc/s, the AM sidebands start becoming incoherent for a modulation frequency of a few kilohertz. This effect essentially scales inversely with frequency so that at 144 mc/s the sidebands will be coherent out to about 10 kHz. For these reasons AM and FM and other forms of modulation requiring coherent double sidebands are not recommended for voice or wideband moonbounce communications, especially at frequencies above about 1000 mc/s. And for the same reasons, SSBSC is recommended for all voice communication via the Moon.

Space Coherence

One possible method of reducing libration fading is by means of diversity reception where two spaced antennas are used and the receiver outputs are combined on a power basis. To implement such a system, the first consideration is how far apart ~~must~~ the antennas must be spaced so that the signals are totally uncorrelated. By power combining of these incoherent signals, a substantial reduction in deep fades will be achieved resulting in a more constant average signal level.

An estimate of the spacing of the two antennas can be made by a simple geometric analysis of the radio wave path lengths on a radar basis. The geometry is shown below for a single pair of reflection points at an arbitrary disc radius of r_o.



This geometry permits a simple formula to be derived which gives the distance separation between S_1 and S_2 such that the radio signals are in phase at S_1 and out of phase by 180^o at S_2. The formula is

$$\Delta S = \frac{\lambda}{4} \frac{R_m}{r_o}$$

, where R_m, the distance to the Moon, is approximately 250,000 statute miles, λ is the operating wavelength, and r_o is the disc radius in the same units as R_m. r_o may be any value from zero to a maximum of 1000 miles. It is obvious then that the space coherence distance ΔS can have a value of infinity down to some minimum where r_o = 1000 miles. Recalling the discussion of energy distribution reflected from the Moon, it is possible to make a reasonable estimate for r_o such that a reflection point in a region of high energy reflection is chosen. At 1296 mc/s for example, a value for r_o would be 100 miles , for which ΔS computes to be about 470 feet!

What about the energy from within the 100 mile radius? It is large and indicates that a much greater spacing is demanded. The choice of r_o= 100 miles was made partly in consideration of the following analysis.

Inspection of Figure 1 indicates that fading rates of about 3 Hz are easily observed along with lower frequency components. At Moon zenith, the major contribution of libration is the rotation of the Earth. A short calculation will reveal that an observer standing at one point near the Earth's equator will actually be moving with a tangential velocity of about 1500 feet/second. Since the coherence distance, ΔS, computed above is only half a space cycle it becomes clear that for reflectors at r_o= 100 miles, the fading rate as observed on Earth will be of the order 3Hz!! This means that for a diversity antenna spacing of 470 feet all those fading components above 3Hz will be uncorrelated. Those below 3 Hz will be correlated and hence cannot be reduced at this spacing. Since these quantities are linearly related a spacing of about 1000 feet will be required to reduce fading rates in the region of 1 Hz by diversity reception.

It should be kept in mind that each antenna must be large enough to receive a signal with reasonable S/N since the addition of the second antenna will not substantially increase the average power level but will only minimize the deep fading. If one attempts to add the signals coherently from the antennas, the effective gain of the system will double (if both antennas have the same gain) but the fading ~~will~~ will be essentially the same as with a single antenna.

Another method of minimizing libration fading is to utilize the coherence bandwødth property in the form of a frequency diversity system. In its simplest form, one would transmit two signals spaced in frequency by greater than the coherence bandwidth and of nearly equal power through one antenna. To instrument this type of signal a double sideband suppressed carrier , DSBSC, type signal can be produced using a balanced modulator even at high power levels. The modulation frquency should be at least 5 to 10 kc/s at 1296 mc/s. Although the sidebands will be coherent in this type DSBSC signal ~~however~~, this property is not required.

An appropriate receiving system would be the usual front end converter down to some IF where selectivity can be achieved. At this point in the receiving system the signal is split and filtered. The two signals are separately detected and the outputs are combined on a simple rms basis through a resistive network. For CW operation the final beat note output of the detectors should be adjusted for the same pitch.

Frequency diversity is of course much easier to implement than antenna space diversity; however, ~~[illegible]~~ neither system has been employed in amateur moonbounce work to this authors knowledge.

Polarization Scattering

Another effect of scattering from the rough surface of the Moon is depolarization. This effect, which occurs for all polarizations including circular and linear, simply means that some of the incident radio wave energy in one polarization is scattered into an orthogonal or cross polarized wave energy. Specifically, if the EME transmitting antenna is linearly polarized and oriented say vertically, most of the reflected EME energy will be vertically polarized (neglecting Faraday rotation of course) but a small amount of reflected energy will be horizontally polarized (cross polarized).

At 1296 mc/s the average cross polarized energy will be about 15 db lower than the main or parallel polarized energy. At lower frequencies scattering is less and a smaller amount of energy will appear in the cross polarized component. The ratio of these levels (cross polarized to parallel polarized) varies considerably with time also. It has been observed on 432 mc/s EME (K2UYH) with linear polarization that the orientation (rotation) of the dipole feed in a parabolic reflector antenna system can be used to maximize signals while at other times the orientation makes little difference. Limited experience at W2NFA on 1296 mc/s EME with circular polarization indicates a difference of 10 to 15 db between right and left circular polarization on echoes and other signals which were known to be circularly polarized.

When depolarization is small, of the order -10 db or less, the loss in signal level for the desired polarization is small. However, when considerable depolarization occurs (such as observed on 432 mc/s EME) the loss in signal level can be as much as 3 db !