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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APOLLO 14 MISSION
ANOMALY REPORT NO. 5

AND

APOLLO 15 MISSION
ANOMALY REPORT NO. 2

INTERMITTENT STEERABLE ANTENNA OPERATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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INTERMITTENT STEERABLE ANTENNA OPERATION

STATEMENT

There were six unexplained interruptions of antenna tracking during Apollo 14 and one during Apollo 15. Five of the Apollo 14 interruptions and the Apollo 15 interruption occurred prior to powered descent. The final Apollo 14 interruption occurred after ascent from the lunar surface, but prior to rendezvous. Random antenna oscillations occurred on all Apollo lunar landing missions where the antenna was used.

DESCRIPTION AND SYSTEM OPERATION

The lunar module S-band steerable antenna assembly (fig. 1) is mounted externally at the end of a tripod that is attached to the top of the lunar module ascent stage. The components of the steerable antenna assembly are the antenna radiation assembly and gimbaling system (fig. 2), a stripline package containing microwave circuitry, and an electronics package.

The antenna radiation assembly (fig. 2) consists of a 26-inch-diameter parabolic reflector with separate sum and difference inputs. The sum input is a pair of crossed dipoles located on a tapered pylon that is attached to the parabolic reflector. The difference inputs are two pairs of crossed slots that are cavity-backed in the ground-plane structure attached to the end of the pylon. One pair of crossed slots generates tracking-error information in the X-axis gimbal (X_g), and the other pair generates tracking-error information in the Y-axis gimbal (Y_g).

The crossed dipoles produce a sum antenna-beam pattern when radio-frequency energy is reflected from the parabolic reflector. The slots produce difference antenna beam patterns when individual slot outputs are added in phase opposition to one another. The antenna patterns are shown in figure 3.

Antenna tracking information is generated by shifting the received antenna beam pattern in the antenna X_g and Y_g directions. When the pattern is shifted, the S-band transceiver senses the signal-strength changes. Increases in signal strength cause the line-of-sight to the ground station to displace in the shifted direction; whereas, decreases in signal strength cause the line-of-sight to displace in the opposite direction. The antenna pattern is shifted by adding the sum pattern plus one of the difference patterns, thus, giving the composite shifted pattern shown in figure 3.

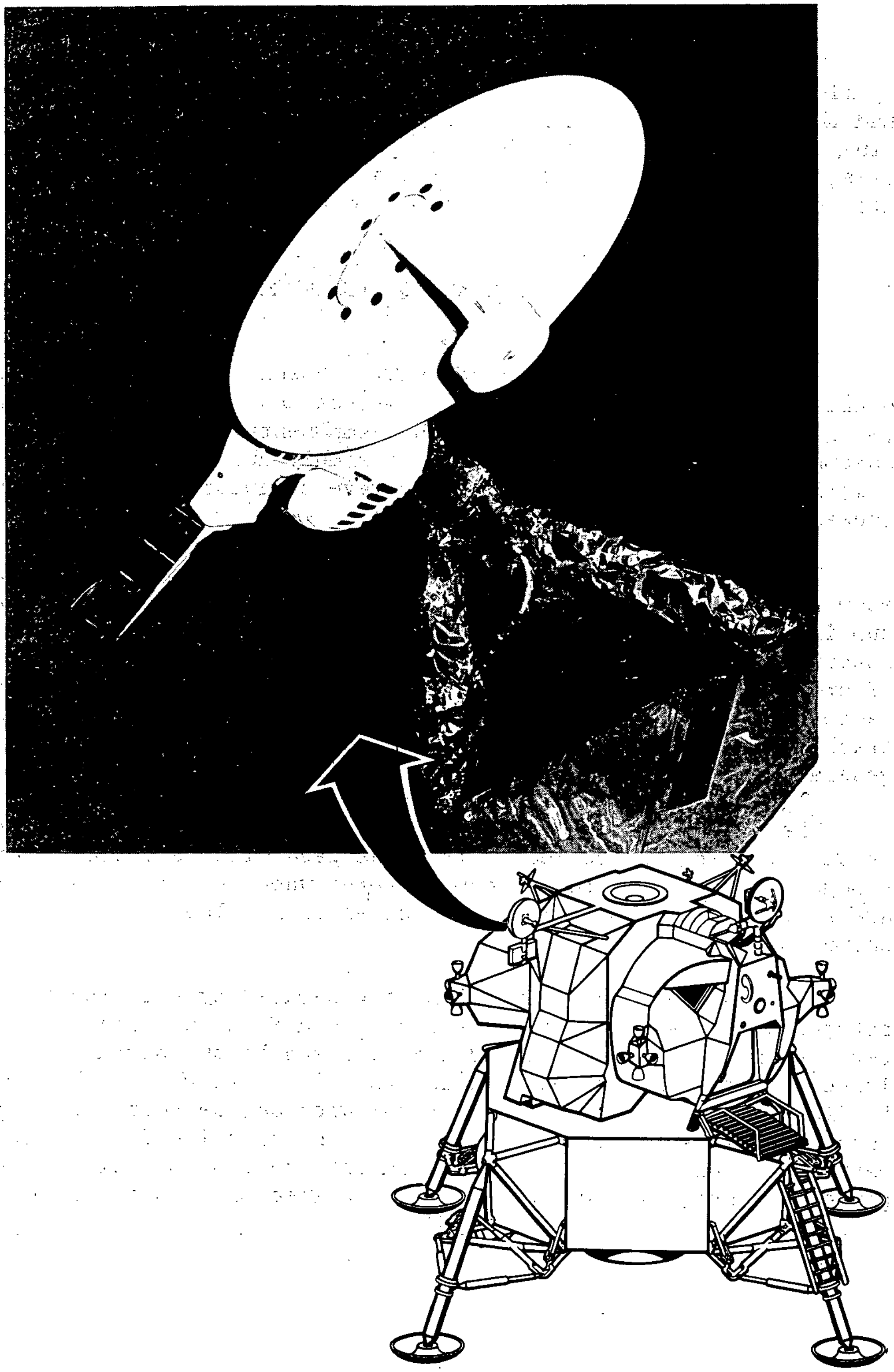
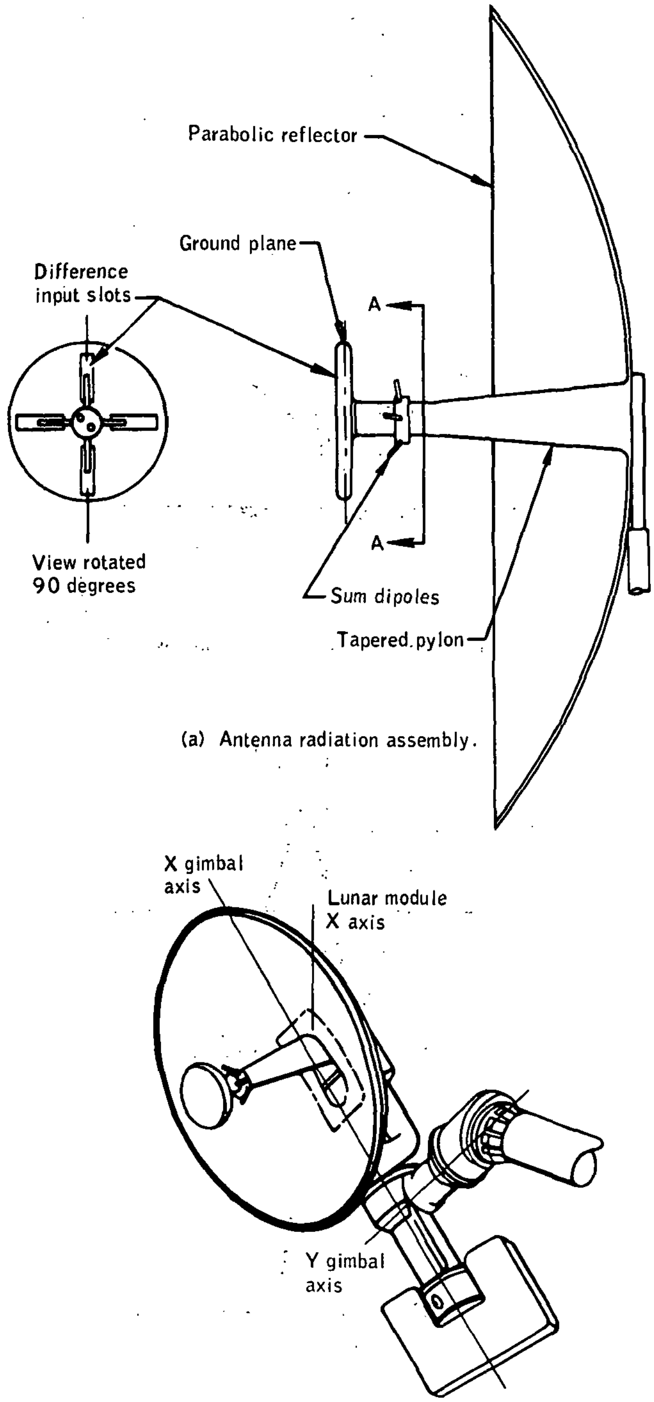


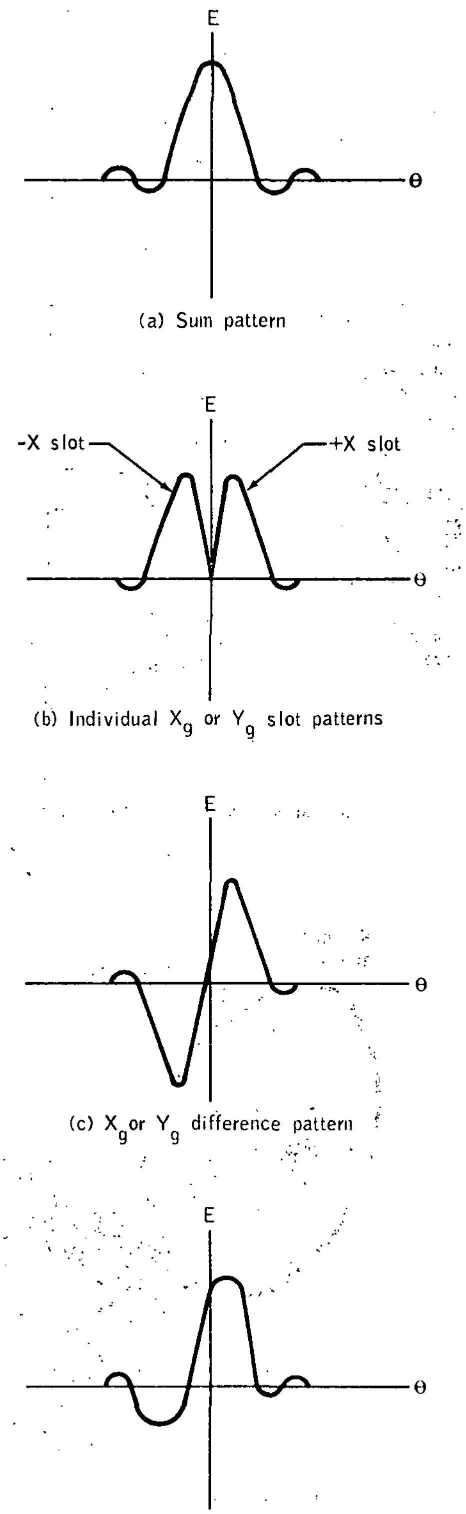
Figure 1.- S-band steerable antenna.



(a) Antenna radiation assembly.

(b) Antenna gimbaling system.

Figure 2.- S-band antenna radiation assembly and gimbaling system.



(a) Sum pattern

(b) Individual X_g or Y_g slot patterns

(c) X_g or Y_g difference pattern

(d) Shifted pattern (sum plus X_g or Y_g difference)

Figure 3.- Sum and difference patterns.

The stripline package contains a frequency-sensitive power divider and diode switches. Figure 4 shows the functional operation of the stripline package. Microwave energy from the sum and difference inputs is applied to the input port terminals of the power divider. The sum signal is fed to the power-divider input-port-terminal 2 while the difference signals are fed through the diode switches to the power-divider input-port-terminal 4.

The electronics package contains X_g and Y_g logic that drives the diode switches, a synchronous demodulator that separates the error tracking information into its proper tracking channels, and servo motors that position the antenna.

The electrical signals required by the diode switch elements are two synchronous square-wave signals, one having a frequency of 50 hertz and the other, 100 hertz. When both the 50-hertz signal and the 100-hertz signal are positive, the Y_g diode switch is turned on. When the 50-hertz signal is at zero volts and the 100-hertz signal is positive, the X_g axis diode switch is turned on. The resulting X_g and Y_g axis diode drive signals (fig. 5) are 5-millisecond rectangular pulses which repeat every 20 milliseconds. When the X_g or Y_g diode is turned on, the corresponding difference signal is switched to the power divider and added to the sum signal. This, in effect, shifts the antenna pattern off the boresight axis in the X_g or Y_g direction. The switching sequence is X difference plus sum, sum, Y difference plus sum, sum, etc., as shown in figure 6. The composite signal at the output of the power divider is an amplitude modulated radio frequency carrier (fig. 6) which is supplied to the receiver where the error signals are detected.

The receiver amplifies and demodulates the radio-frequency signal and generates a voltage proportional to the radio-frequency signal strength (used to automatically control the receiver gain). Since the tracking information is in the amplitude modulation of the radio-frequency signal, it appears superimposed on this generated voltage.

The automatic gain control voltage containing the antenna tracking information is routed to the X_g and Y_g error detectors that separate the tracking information into the respective two channels. Tracking information in the two channels then drives the servo motors to point the antenna in the direction of strongest uplink signal. Figure 7 is a block diagram of the complete tracking loops.

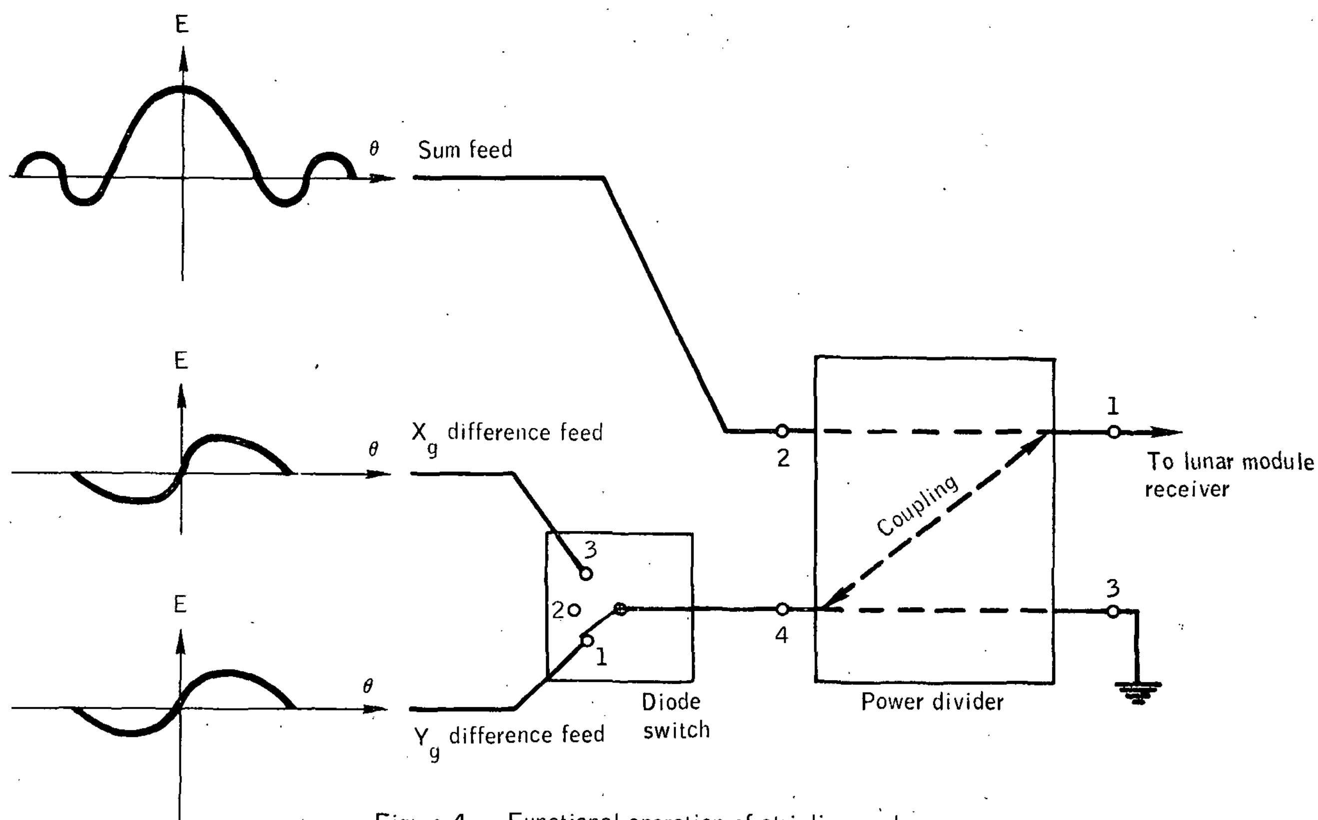


Figure 4.- Functional operation of stripline package

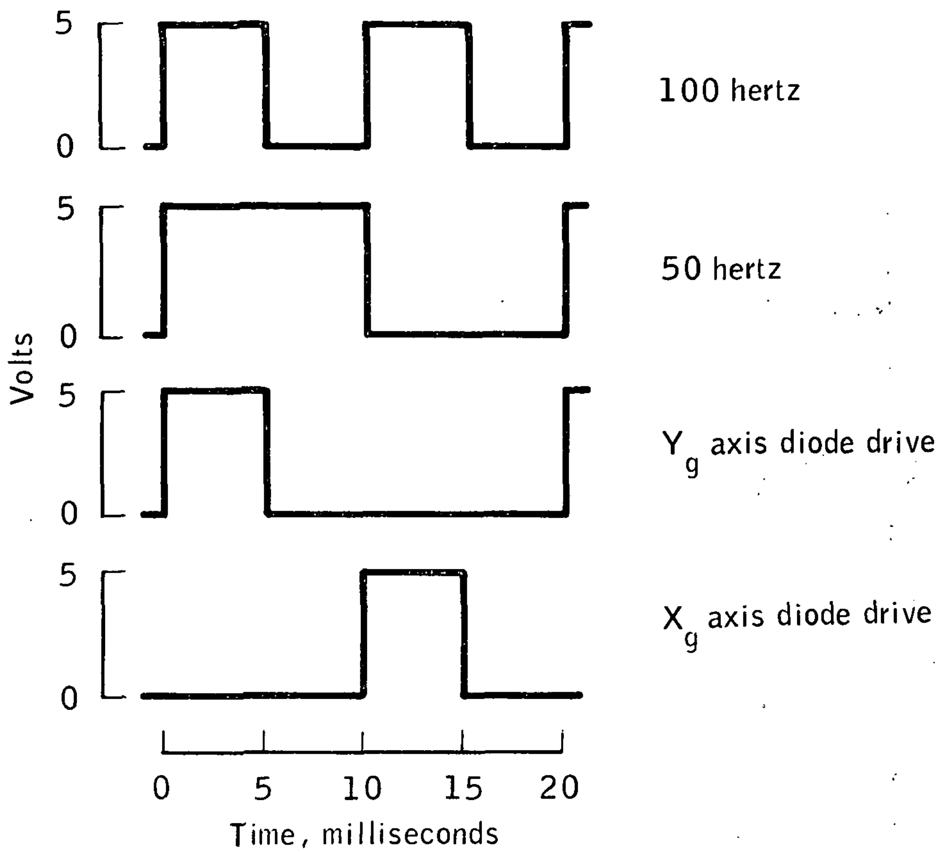


Figure 5.- X_g and Y_g axis diode drive signals.

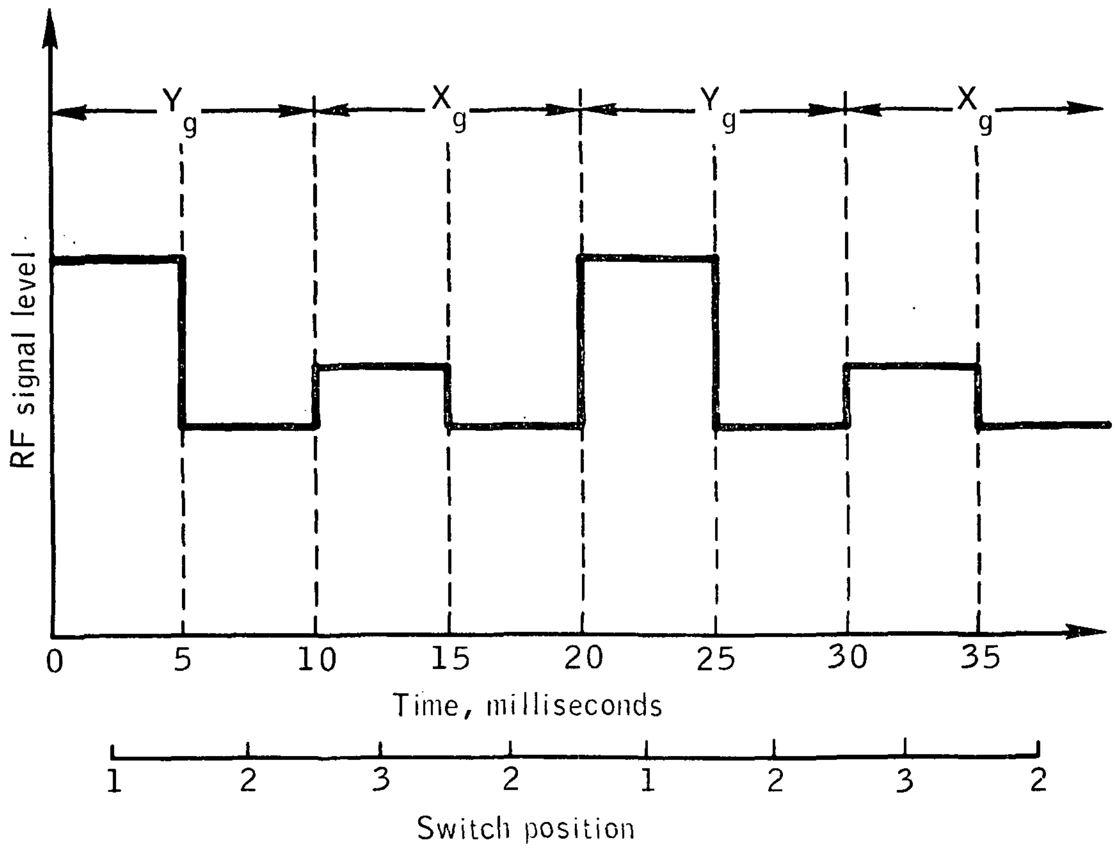


Figure 6.- Envelope of amplitude-modulated signal.

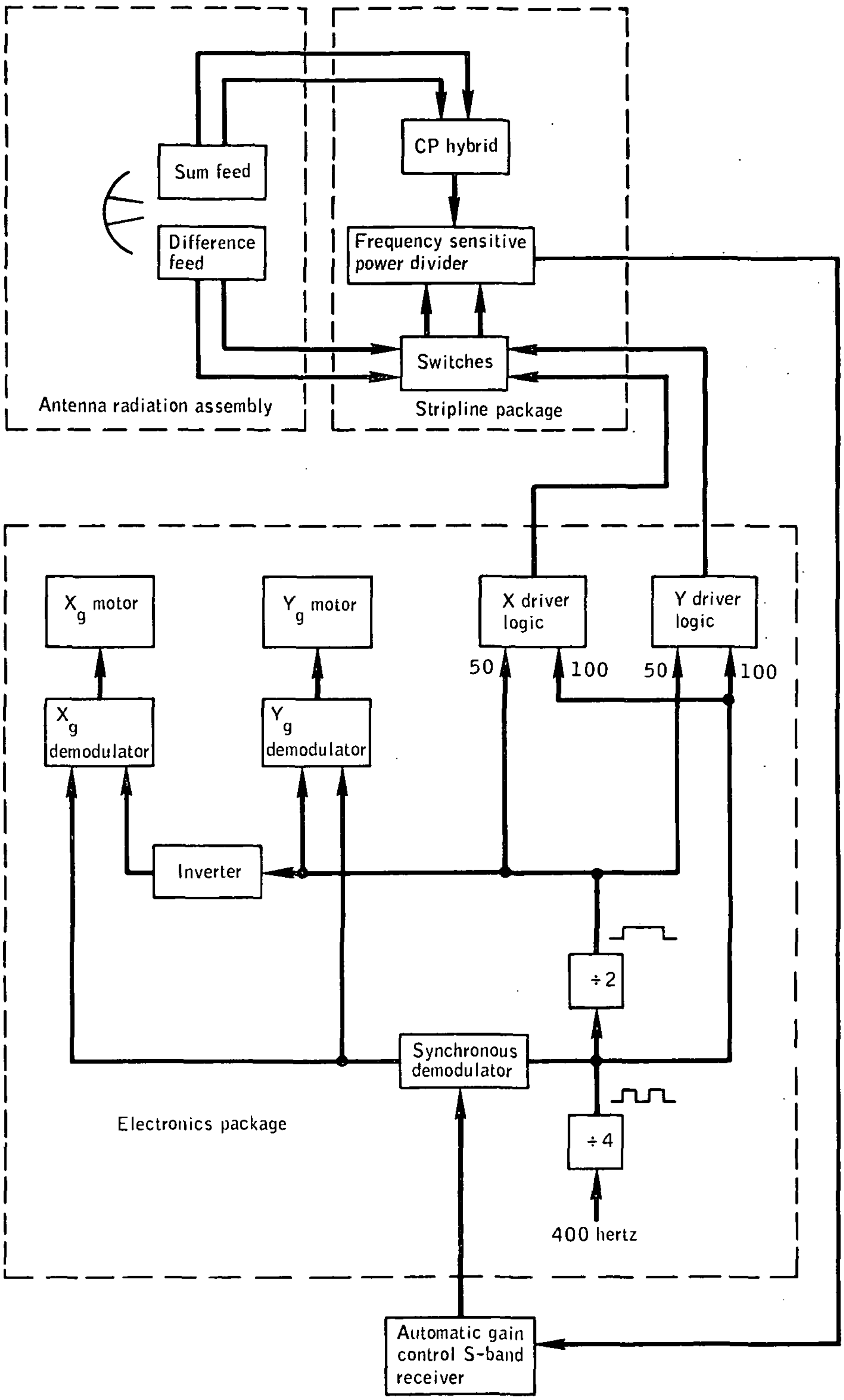


Figure 7.- Antenna tracking system.

DISCUSSION

Data Indications

All six unexplained Apollo 14 tracking interruptions (fig. 8) have similar characteristics. Five of the interruptions occurred during coverage by the Goldstone tracking station, and figure 9 shows the ground-station-received signal strengths at these times. During the coverage of revolution 32, another incident was noted with the same type of antenna response. The response indicates that the antenna began to experience approximately 2- to 3-hertz mechanical oscillations which became increasingly larger in amplitude with time. When the oscillations exceeded 10 degrees peak-to-peak, excessive drive-motor current caused the circuit breaker supplying 28 volts dc to the motors to open. The antenna was also reported to be noisy, indicating the continuous driving that occurred during the oscillations. The oscillations occurred randomly at other times during the problem period, but damped out without causing tracking interruptions. Similar oscillations occurred during the Apollo 11, 12, and 15 missions, but only Apollo 15 and 16 experienced tracking interruptions. Figure 10 shows typical signal strength variations associated with damped antenna oscillations for Apollo 15.

There are three conditions that could cause the antenna to oscillate:

a. Amplitude modulation on the uplink radio frequency carrier (fig. 11).

b. Noise capacitively or inductively coupled into the track error line (fig. 12).

c. Hardware problems resulting in tracking loop instabilities.

The S-band receiver automatic-gain-control voltage is telemetered at one sample per second. The lack of antenna gimbal angle data, which is not telemetered, and the low automatic-gain-control voltage sample rate prevents determination of whether the problem occurred in the antenna or the receiver. These data would also show whether the antenna is responding properly to the received signals.

Carrier Amplitude Modulation

Tests have shown that very small amounts of amplitude modulation on the S-band carrier (0.5 percent) near the 50-hertz antenna-lobing frequency will cause the antenna to oscillate and lose track. These same effects were also found at 16, 25, 33, 100, and 150 hertz, but to a lesser degree.

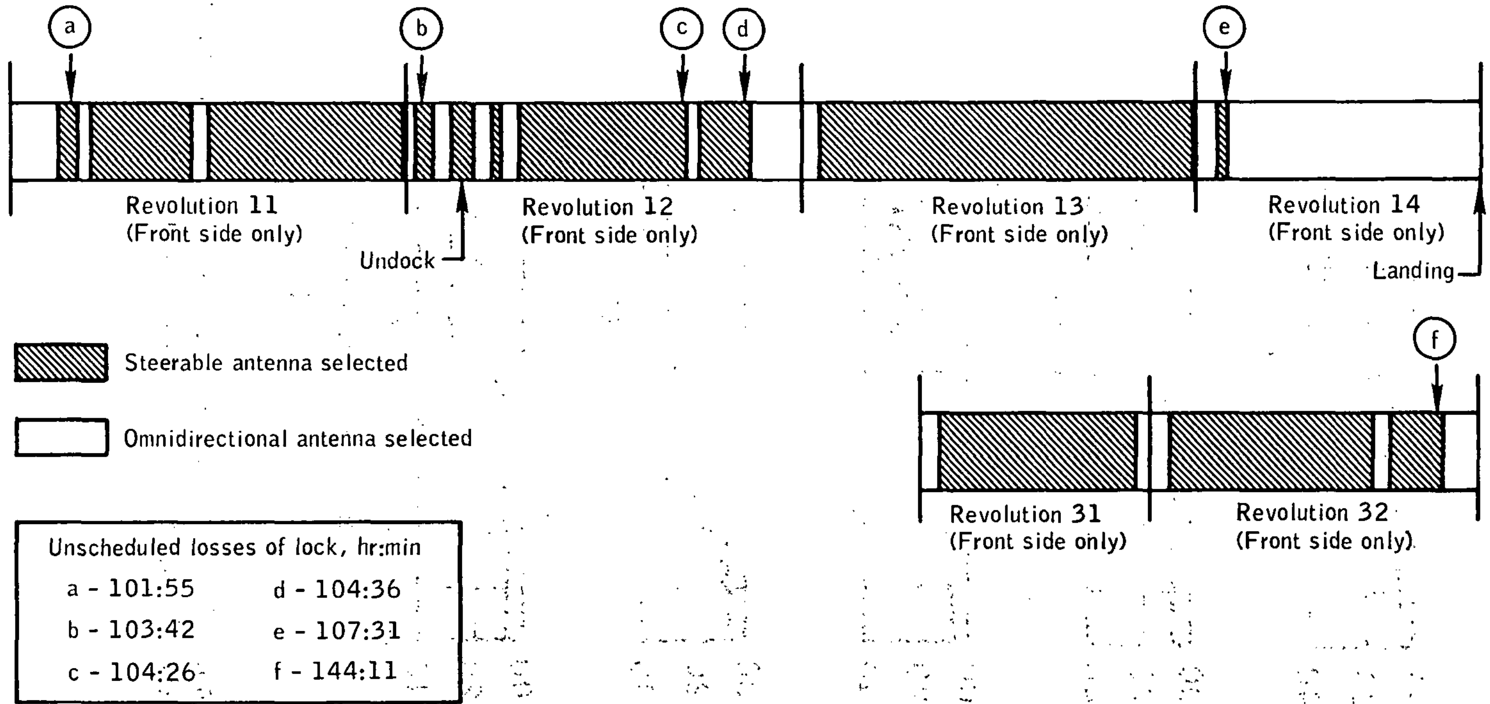


Figure 8.- Unexplained tracking interruptions during Apollo 14.

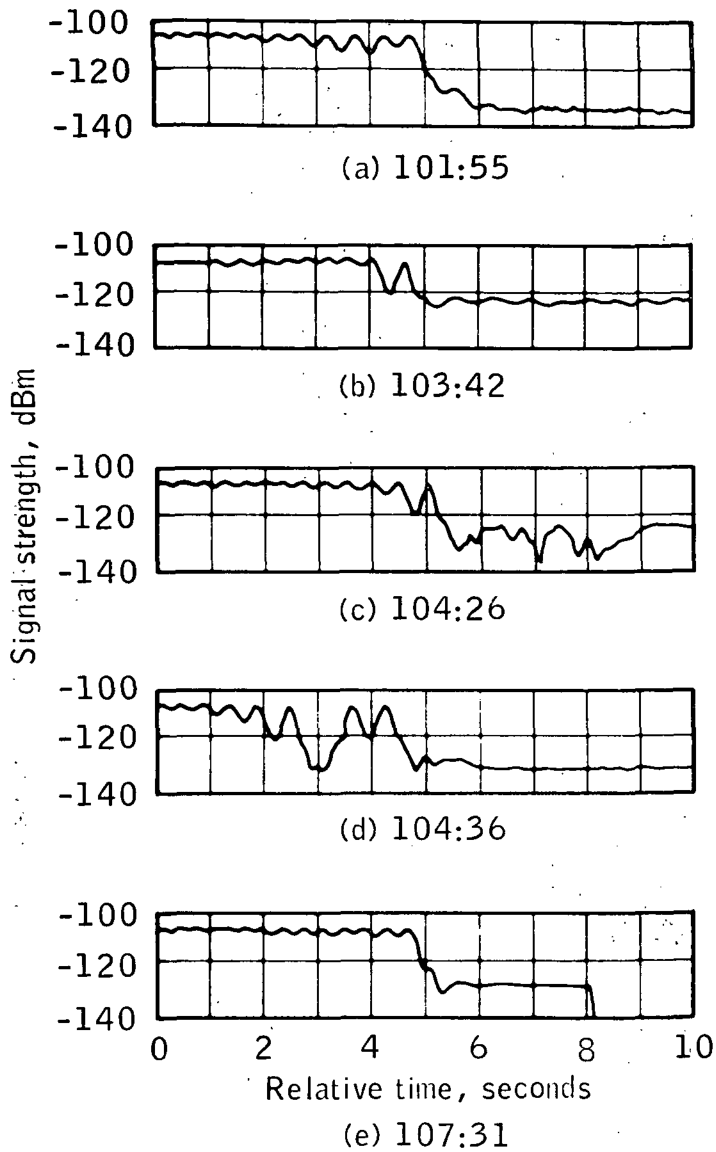
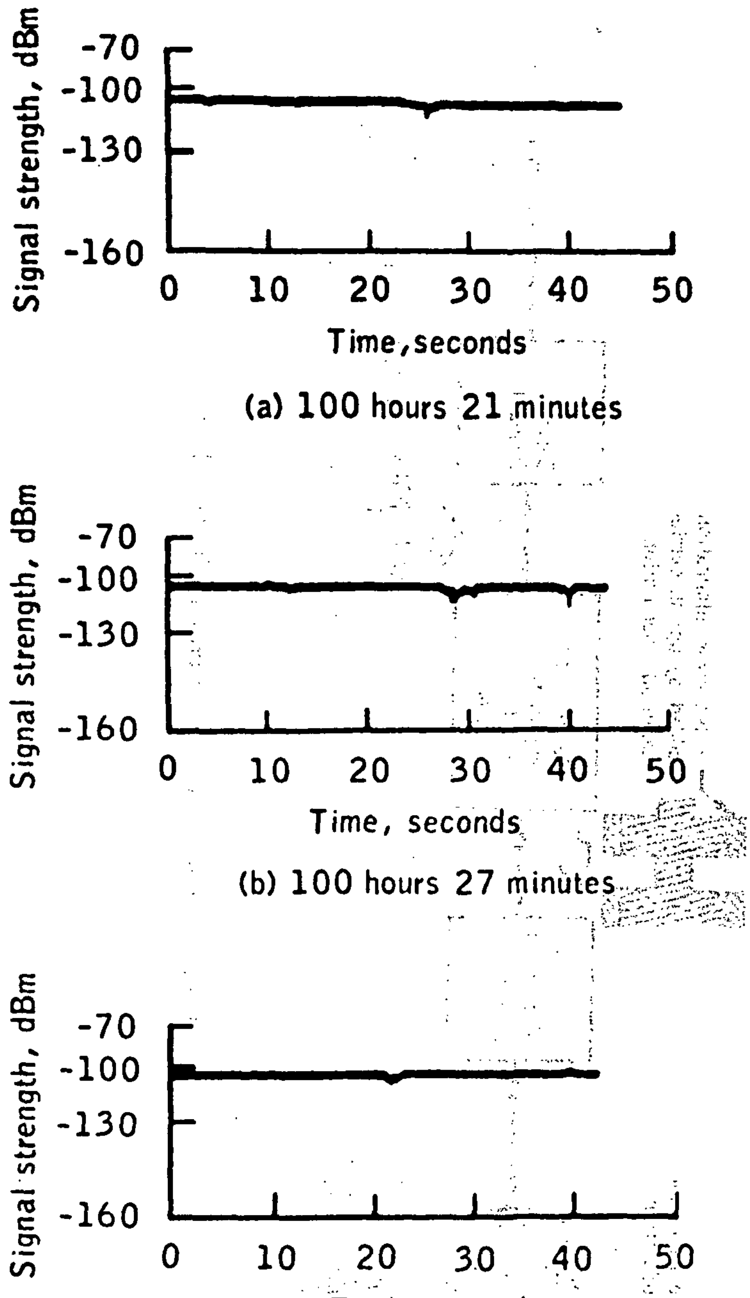


Figure 9.- Apollo 14 received signal strength oscillations associated with five of the six unexplained losses of lock.



(a) 100 hours 21 minutes

(b) 100 hours 27 minutes

(c) 103 hours 14 minutes

Figure 10.- Apollo 15 damped antenna oscillations at random times.

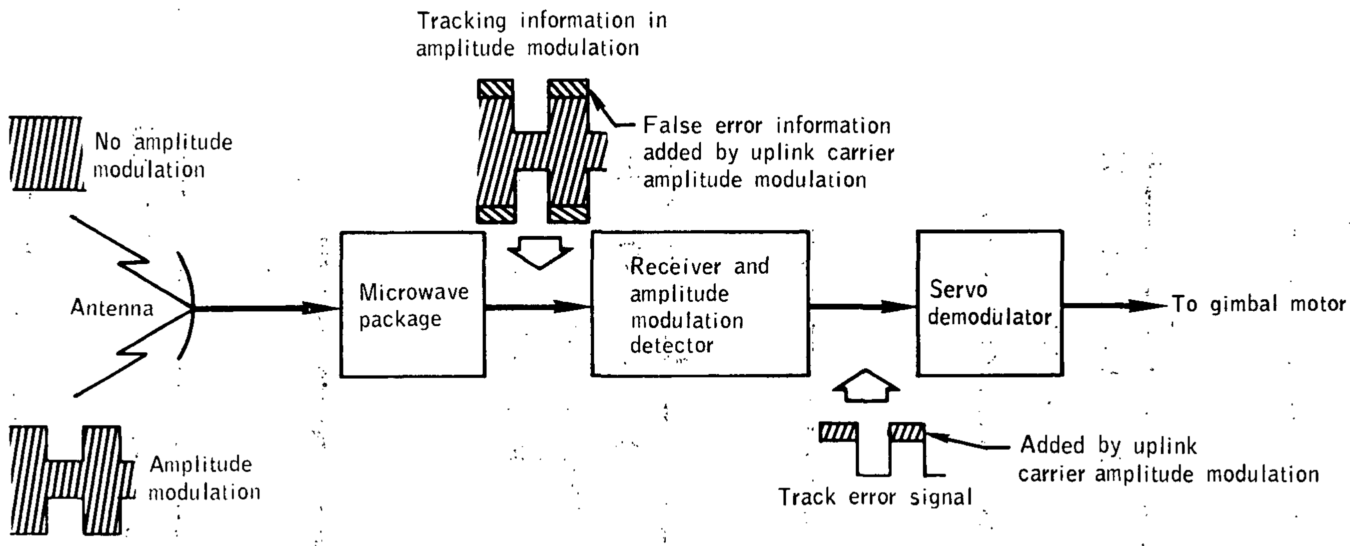


Figure 11.- Result of uplink carrier amplitude modulation.

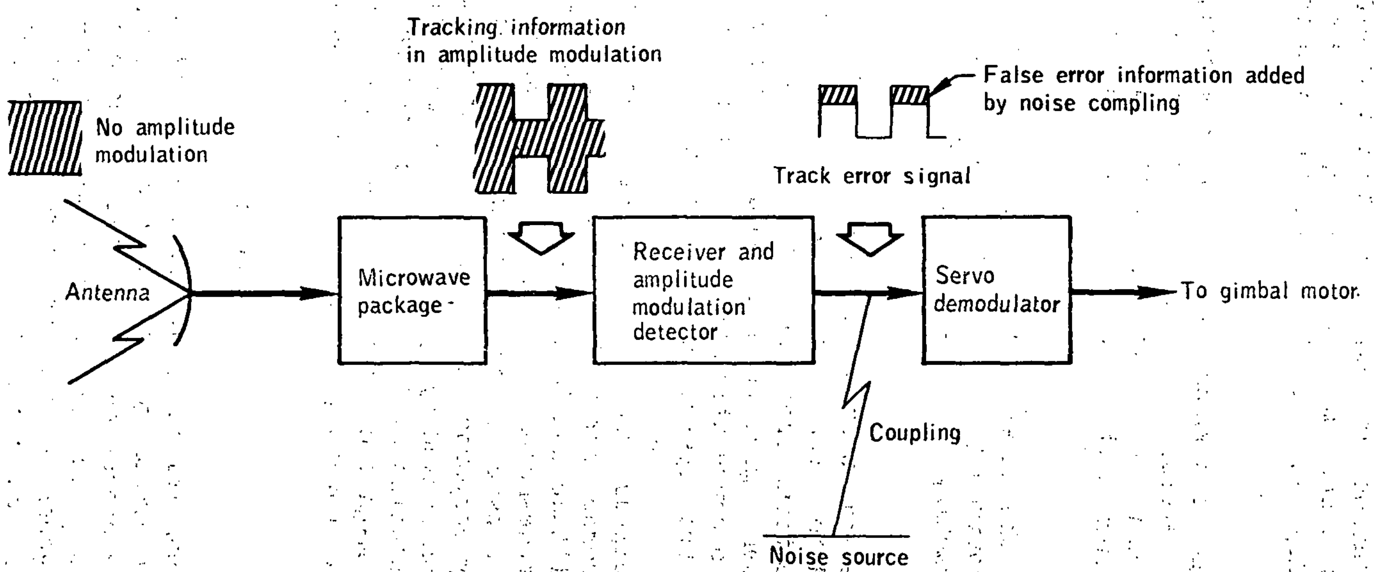


Figure 12.- Result of noise coupled into track error line.

Amplitude modulation of the uplink signal can be caused either by vehicle blockage or uplink signal multipath (reflections) from spacecraft structure, the lunar surface, or reaction control system engine plumes. Some amplitude modulation also exists on the uplink signal transmitted by the ground antenna, and varies with the uplink mode being used; however, this is normally less than that required to cause significant oscillations.

Vehicle blockage is a known cause of antenna oscillations and tracking interruptions. Several instances of tracking interruptions from vehicle blockage did occur on Apollo 15, but the unexplained instances on Apollo 14 and 15 occurred when the antenna was not pointed near the vehicle structure.

Multipath from the lunar surface normally occurs when the spacecraft is near the lunar horizon (fig. 13) and can cause oscillations; however, oscillations and tracking losses also occurred without multipath conditions.

Service module and lunar module reaction control system engine firing times were examined to determine if antenna oscillations were excited by uplink signal reflections from engine exhaust plumes. Service module reaction control system engine firings could have contributed some of the oscillations, but no correlation was noted after undocking nor with lunar module reaction control system engine firings.

Incidental amplitude modulation superimposed on the transmitted uplink signal was recorded during the Apollo 15 mission to determine if and to what extent amplitude modulation existed. In a test, the recordings were used to amplitude-modulate a transmitter signal which was then radiated into a flight S-band system. The results of this test indicate that the antenna usually responds with minor oscillations to the uplink-carrier amplitude modulation caused by uplink voice communications. (Uplink-carrier amplitude modulation of 1 percent or greater can result from voice modulations). The magnitude of the antenna oscillations induced during the test were small, however, and in no case did the antenna break track.

Noise Coupling

There is the possibility that noise could have been coupled into the antenna or receiver circuitry from other operating equipment. Of all the spacecraft hardware operating at the time of the oscillations, only three pieces of equipment could have produced noise at the required frequencies. However, none can generate noise anywhere close to 740 volts ac (capacitive coupling) or 18 amperes ac (inductive coupling) required to couple sufficient energy to create oscillations in the antenna circuits.

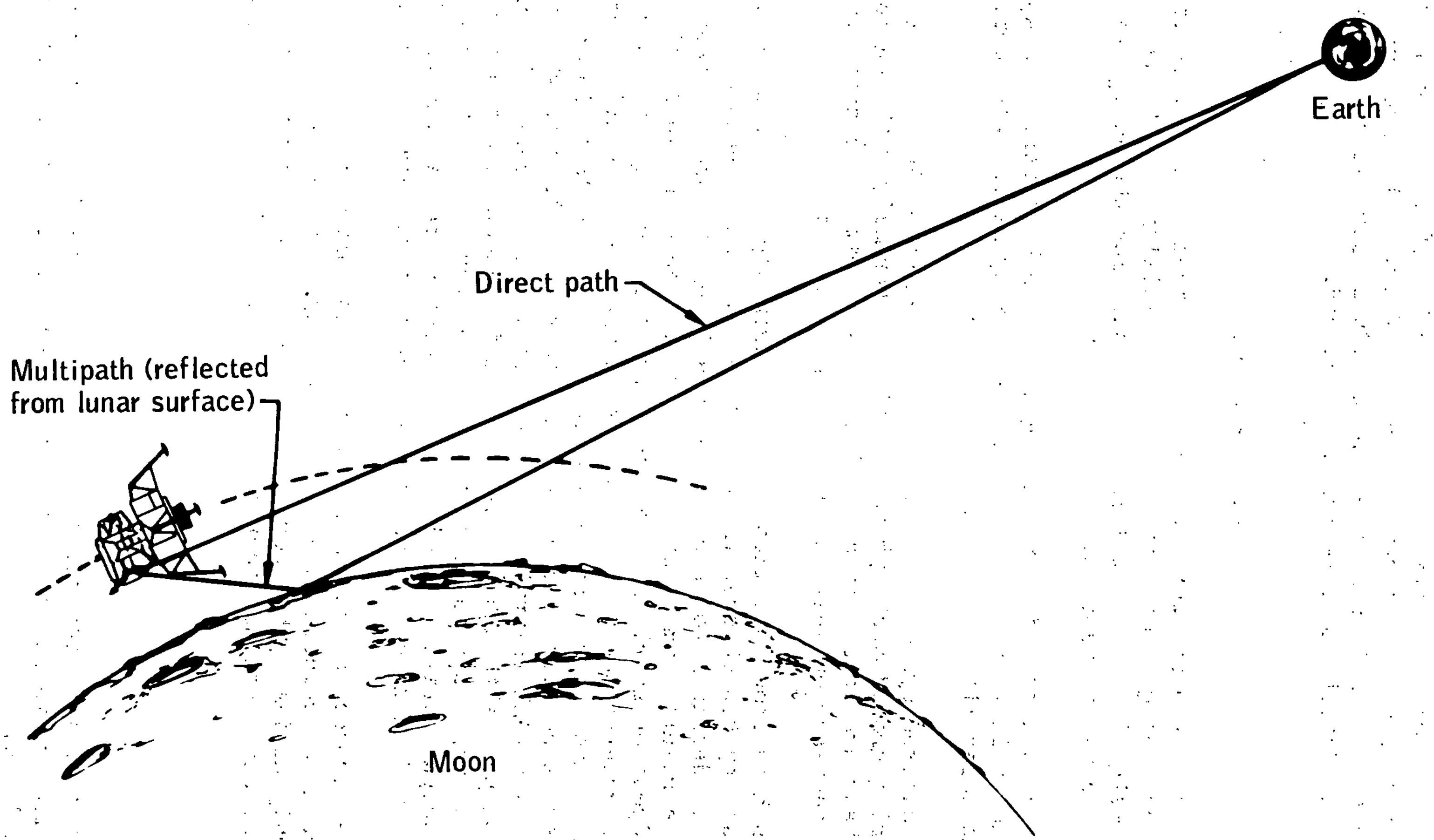


Figure 13.- Example of multipath signal reflection from lunar surface.

A special test was performed on the Apollo 16 lunar module to check noise coupling into the antenna circuits. The tracking loop error voltage was monitored while all other spacecraft electrical systems were operated and no detectable interference occurred.

Hardware Problems

Component problems which can affect received-signal strength, system friction, or loop gain may cause system instability. Tests have shown that the design is such that large deviations from the design values are required to cause instability.

Both the uplink and downlink signal strengths observed on Apollo 11, 12, 14, and 15 indicate that the radio-frequency levels were normal and within the capability of the antenna to track.

The measured system friction of the antennas on Apollo 14 and 15 was normal during ground tests prior to flight. Normally with degradation of brushes, bearings, etc., friction increases. Tests have shown that friction must decrease one-half to cause loop instability.

Tests have shown oscillations will begin when the tracking loop gain is increased by 6.0 dB over the design level. The antenna electronics circuitry is designed to be extremely stable by the use of feedback control. As a result, component variations can cause only negligible gain change. Opens or shorts in the circuitry would be required to cause gain variations greater than 3 dB. The S-band transceiver provides most of the tracking loop gain. An intermittent failure or drift in the S-band transceiver is not likely since oscillations were observed when the antenna was used with the primary or secondary transceivers. The antenna tracking output, although not measured during acceptance testing, was monitored during a special auto-track/temperature test. The antenna tracking output variation, using the temperature range expected in flight, was plus 0.5 dB and this is not sufficient to cause oscillations.

The environmental parameters to which the antenna is exposed in ground tests exceed the calculated and measured flight environment. Therefore, it is highly unlikely that components have failed in every flight, although, the oscillations occurred to some extent, in every flight.

CONCLUSIONS

1. Within the constraints of the available data and the results of system analyses, there is no evidence of the problem being caused by the flight hardware.

2. The magnitude of the amplitude modulation, as measured at the ground antenna input, was insufficient to cause significant flight antenna oscillations. Further, other conditions as presently understood such as multipath, blockage, reflections, etc., did not always exist when the antenna oscillated.

3. Further pursuit of this problem would require additional instrumentation on board the spacecraft. However, experience has shown that the frequency of loss of lock is merely a nuisance, consequently, spacecraft modifications are not justified at this stage of the program.

CORRECTIVE ACTION

The following actions were taken for the Apollo 15, 16, and 17 spacecraft to help minimize any contribution of incidental amplitude modulation of the uplink signal to antenna instability. Uplink modes having the lowest incidental amplitude modulation are being used whenever possible, and all tracking stations have been modified to incorporate subcarrier oscillators with very low amplitude modulation.

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