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Antenna Mechanical and R. F. Systems Measurements and Alignment Using ALSEP

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ABSTRACT

A valuable spin-off asset of the lunar exploration program has been the use of the Apollo Lunar Surface Experiments Package (ALSEP) transmitter systems for angular alignment as well as RF systems checks and alignment of AFETR large aperture telemetry antennas.

Accurately known ALSEP antenna coordinates on the lunar surface, together with those of a telemetry antenna on the earth's surface, makes possible accurate computation of antenna look angles versus time. In order to refine the accuracy of these angles, it was necessary to include the effects of nutations of the earth and librations of the moon. The resulting accuracy of computed antenna look angles is one or two orders of magnitude greater than that of techniques commonly used such as that using the sun's radio frequency noise emission. The use of Cassiopeia A is restricted due to the low level of flux density emitted by this star. Only high gain antennas are suitable for tracking Cassiopeia A, therefore it is impossible to make alignment comparisons with lower gain antennas.

The ALSEP is a very practical tool which enables real-time problem analysis and possible correction of alignment of antenna systems readout devices in almost real time.

The availability of information on the performance of the ALSEP transmitter makes possible simple and accurate assessment of RF systems performance quality. In addition, the tracking availability of about 12 hours each day makes it an extremely valuable training aid for antenna system operators.

I - INTRODUCTION

Coincident with the introduction of large aperture UHF (S-band) tracking antenna systems, necessitated by high gain requirements in deep space operations, came the problem of reliable acquisition. As frequency, gain and aperture are increased, the beamwidth is decreased. Acquisition information can be provided from either the computed/predicted vehicle parameters or by means of angular data generated by tracking sensors. These sensors could be telemetry antennas locked onto the signal from the vehicle, skin (or beacon) tracking radar antennas or optical tracking instruments. The angular data is transmitted to the antenna via a printout of angles versus time (pre-launch), synchro analog signals from a computer, a cartesian to polar converter in the low density digital data system or direct synchro slaving to another antenna which has already acquired the signal and is autotrackig it.

In order to assure reliable acquisition it was found necessary to direct the antenna electrical axis to the true direction of the target signal with approximately 0.6 of the antenna beamwidth. Thus for the TAA-2 the beamwidth of 0.37 degrees dictates that the TAA-2 antenna electrical/mechanical axis be directed to within 0.25 degrees of the source to acquire reliable, main-lobe autotrack. First side-lobe autotrack is quite possible when a signal level is sufficient to exceed the tracking threshold at the side-lobe gain level. The solution to this problem is to direct the antenna close enough with the acquisition system such that when the antenna autotrack is enabled, main-lobe acquisition is assured. This requires operator confidence in the reliability of the acquisition aid and operator skill in knowing when to enable autotrack and acquire the signal.

In order to insure the pointing accuracy required, accurate synchros and alignment are required. Synchro transmitters and control transformers with accuracy of ±3 minutes of arc are necessary when only IX synchros are used for slaving. This changes the loss of accuracy from that afforded by normal ±6 min. of arc synchros (20.1 degree) to that for ±3 min. of arc (20.05 degree). It is also necessary to eliminate or minimize loading on the IX synchro transmitters to prevent deterioration of this accuracy in slaving. The IX synchro slave indicator, normally a torque receiver, can load a IX slave output synchro transmitter and
<table>
<thead>
<tr>
<th>Antenna Designation</th>
<th>Dish Diameter Feet</th>
<th>2.3 GHz S-band Gain dB</th>
<th>2.3 GHz Receiving System NF dB</th>
<th>2.3 GHz Beam Width Degrees</th>
<th>Location Station/Ship</th>
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<tr>
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<td>40</td>
<td>5.0</td>
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ADDITIONAL TAA-8 OR TAA-8A (UHF) DATA

Frequency Range 2.2 to 2.3 GHz
Type of Feed Cassegrainian/5-horn cluster
Polarization RHCP and LHCP
Gain at Preamp Input 51.8 dB
Impedance at Preamp Input 50 ohms
VSWR at Preamp Input 1.4:1 (max)
Antenna Noise Temperature at Preamp Input 100 degrees K
Receiving System Noise Figure 1.6 dB (130 degrees K)
Feed Illumination Angle ±11 degrees
Axial Ratio 1.5 dB (max) (circular polarization)
Side-lobe Level -15 dB (min)
cause as much as ±0.5 degrees of inaccuracy, depending on the loading of the indicator itself on the torque receiver. This has been successfully circumvented by using a device with a trademark name for Torqsyn and called a synchro repeater. This is essentially a control transformer, servo amplifier with power supply and DC motor packaged in a size 23 synchro housing. Figure 1-1 is a block diagram of this device which minimizes the loading of the slave indicator on the synchro slave torque transmitter.

After the errors of slaving are minimized within practical limits, precision alignment of the antenna mechanical/electrical axis with the synchro transmitters, indicators and digital encoders can then be accomplished. Alignment of these requires precisely known positions of radiating sources capable of being accurately tracked by the antenna. Solar boresighting which has been used in the past provide data with various emission component variations. These slowly and rapidly varying components affect the tracking error due to signal strength changes, changes in the RF center of the sun, sun spots and other phenomena. The tedious of checking conditions at a particular time limits the value of the sun as an accurate boresight source. Inaccuracies can be as high as 0.5 degrees when all varying components are not adequately considered. Although the sun has the advantage of high flux density, approximately 30 dB greater than the next star, it has serious limitations as a precision point source. Cassiopeia A, affords point source accuracy sufficient for accurate alignment checks; however, its emitted flux density is so low that only for the highest gain, most sensitive systems, with which we are concerned, can it be effectively employed. The need for simultaneous tracking of the same accurately known source for inter-alignment between high gain and lesser gain antennas limits the value of Cassiopeia A as an alignment tool.

Problems associated with ephemeris maintenance and the limited time they are in view of a particular station, together with the lack of orbiting vehicles radiating in S-band, limits the value of artificial earth satellites as calibration sources.

Another common method for alignment checks in both mechanical and electrical systems is the boresight tower. See Figure 1-2. This facility, if properly located, out of a noisy electrical environment at a high enough elevation angle to escape multipath problems and at a distance sufficient to be out of the near field of the antenna \( \left( \frac{20\lambda}{\text{min}} \right) \) is most versatile and valuable. In most cases, one of these factors mentioned is faulty and the boresight is of limited value. The boresight facility provides, with a proper signal generator, the capability of testing with signals at all frequencies in the band and various signal levels.

One technique that has proven to be very successful for the alignment of the large telemetry antennas at APETR is accomplished by tracking the ALSEP left on the moon by the Apollo astronauts. This procedure involves the computation of accurate look angles that are used as the reference for calibration. The next section discusses the procedure employed in the computation of accurate pointing information for ALSEP

**II - DEVELOPMENT AND EVALUATION OF THE COMPUTATION TECHNIQUES FOR ALSEP LOOK ANGLES**

In order to determine the feasibility of calibrating the telemetry antennas using the S-band ALSEP transmitter on the moon, it was necessary to generate pointing information that was sufficiently accurate to use as the standard for boresight calibration. Various procedures were examined and it was decided in June 1969 to construct an interia, unsophisticated computer program to generate this data, since this could be done in a relatively short period of time. This program was used to verify the techniques and transformation employed in a more accurate data reduction program that was developed later.

The HTEL computer program was developed as the initial routine and used for the first time in October 1969 to enable a telemetry angular bias analysis with the data obtained from the EASEP (Early Apollo Scientific Experiments Package) left on the moon by the Apollo 11 astronauts. It was very successfully used again in early December 1969 in combination with the Apollo 12 ALSEP as a boresight source for synchro alignment of the TAA-8A antenna at Station 91. More details of this effort are provided later in this report.

HTEL is a Fortran IV computer program developed for the IBM 360/65 system. The program accepts as input, selenographic position coordinates and computes azimuth and elevation angles versus time for any number of stations on earth. This program uses no external position information such as lunar ephemeris tapes. The spacial position of the moon is generated by the program. The sequence of the most significant computations made by the HTEL program are as follows:

(a) The fundamental orbit constants of the sun and the moon are advanced to mean elements of date by the standard time dependent secular expressions given in the American Ephemeris and Nautical Almanac.

(b) The position of the center of mass of the moon is computed in spherical ecliptic coordinates from harmonic series that use the positions of the sun and moon as arguments.

(c) The lunar ecliptic coordinates are rotated to mean equatorial coordinates and then updated to the true geocentric position of date by means of a nutation matrix.

(d) The input selenographic position of the beacon is rotated to selenocentric
coordinates by computations including the lunar librations.

(e) The position of the beacon relative to the moon is combined with the position of the moon to provide a geocentric vector to the beacon, which is transformed to look angles for an earth fixed station.

This section presents a discussion of the approximation procedures used in HTEL. Comparisons of data generated by this interim program to Apollo data obtained from NASA and to angular data generated by the more sophisticated data reduction routine developed later at AFETR are also included here.

Computation of the Mean Position of the Moon

In 1905, E. W. Brown published his development of the theory of the motion of the moon. Brown's Lunar Theory consists of algebraic expressions for the geocentric spherical coordinates of the moon. These expressions are Fourier series whose parameters are explicit functions of time and were obtained by integration of series expansions of the equations of motion. The equations for the spherical coordinates consist of a linear function of time and small secular and periodic parts. Each coefficient is a constant with some period and secular changes. There are over 1650 terms in the equations for longitude, latitude and parallax. An example of these expressions is given by Equation (1) where only the first three terms for the longitude are shown.

\[ \lambda = \lambda_0 + K_1 \sin (\lambda_0 - \lambda_M) - K_2 \sin (2\lambda_0 - \lambda_M - \lambda_S) + \cdots \]  

where

- \( \lambda \) = ecliptic plane longitude
- \( K_1 \) and \( K_2 \) = constant coefficients
- \( \lambda_0 \) = mean longitude of the moon
- \( \lambda_M \) = mean longitude of lunar perigee
- \( \lambda_S \) = mean longitude of the sun

The mean longitude arguments are the orbital constants of the sun and moon that are given in any copy of the American Ephemeris and Nautical Almanac in the form:

\[ a + bt + ct^2 + dt^3 \]

where \( a, b, c \), and \( d \) are constant coefficients and \( t \) is time since an epoch corresponding to the position coefficient \( a \).

In the HTEL computer program, only the terms whose constant coefficients in latitude and longitude are greater than one arc second and greater than 0.1 arc second in parallax are included. Therefore, of the original 1650 terms in Brown's theory, only about 120 are used in HTEL.

Since Brown's original publication, better values for some of the constants and coefficients have been derived and were adopted at the International Astronomical Union in 1964. These changes are included in the HTEL computer program. Since 1964, data compiled by NASA's Jet Propulsion Laboratory have resulted in additional significant changes in the lunar position as derived from Brown's theory. These changes were not incorporated into HTEL since the program provided sufficient accuracy until the more advanced computer routine LULA was available.

Computations of Nutation and Librations

It is not the intent of this paper to provide the detailed description of the calculations of nutations of the earth centered reference axis or of the librations of the lunar reference coordinates. The standard techniques used for these purposes can be found in the references to this paper. The purpose here is to indicate some of the approximations used by HTEL in these computations.

Nutation represents the difference between the position of the true rotational axis of the earth and the mean celestial pole. It is composed of the short-period effects due to the action of the sun and moon on the figure of the earth. As a result of nutation, the true equator of date differs from the mean equator of date by two increments. These increments represent an angular dispersion in longitude along the ecliptic plane, \( \delta \phi \), and a dispersion in the angle between the equatorial and ecliptic planes, \( \delta \epsilon \).

The standard solution for \( \delta \phi \) and \( \delta \epsilon \) involve the evaluation of series solutions where again the arguments are the orbital position constants of the sun and moon. These equations contain about 70 terms for each of the angular nutations. The HTEL program employs a truncated version of these series where only 15 terms are computed for each quantity, \( \delta \phi \) and \( \delta \epsilon \). The values computed in this manner compared to within 0.01 seconds of arc with the values tabulated at specific times in the American Ephemeris and Nautical Almanac.

The empirical laws of Cassini are known to describe only approximately the rotation of the moon on its axis. The irregularities of this rotation, treated as deviations from the laws of Cassini, are called the physical libration of the moon. Expressions for the physical librations are the results of complex derivations involving the lunar motion and observationally determined constants. A comprehensive description of the theory of physical librations is given in Kopal.

The libration theory yields expressions which are sine series expansions for the librations in longitude and the ascending node angle. The theory results in a cosine series for the libration in the inclination of the mean lunar equator. With these corrections to the Euler angles, the
classical Euler rotation matrix is constructed for the transformation from selenographic to selenocentric position. The HTETL computer program again uses a truncated version of the series expansions for the libration angles, as suggested by Holdridge11.

Evaluation Results

The evaluation of the accuracy of the HTETL program was possible through data supplied by NASA Goddard on Apollo 11 and 12. This data included the intermediate values of selenocentric position of the beacon and geocentric position of the moon as well as the final geocentric position of the beacon.

Using the selenographic position supplied by NASA, the selenocentric position as computed by HTETL was first compared to the Goddard data. These positions differed by about 0.1 km. At the lunar distance, this would result in an angular error of less than $2 \times 10^{-5}$ degrees; therefore, these results verified the fact that the libration computations and transformation provided sufficient accuracy.

As previously mentioned, the orbital constants of the sun and the moon and the nutation computations were compared with data in the American Ephemeris and Nautical Almanac and found to be satisfactory.

The final geocentric positions of the beacons differed from the HTETL values by about 23 km in the worst case. This corresponds to an angular error of about 0.003 degrees at the lunar distance and was satisfactory for telemetry antenna calibrations. Practically all of this difference was accounted for in the comparisons of the geocentric position of the moon. The lunar ephemeris computations contained in HTETL cause the moon to lead the current NASA ephemeris of the moon by approximately 0.003 degrees. This situation was observed with the Apollo 11 data and the two cases of Apollo 12 obtained for different times. The HTETL program was used as an interim computation tool until the more accurate LULA program became operational at AFETR.

The LULA program described in reference 7 uses the JPL Ephemeris Tape to provide the position of the moon. In addition, the complete series expansions tabulated for nutation and librations are included in this routine. A comparison of the final geocentric position of the beacon as computed by LULA with the value supplied by NASA resulted in a difference of about 0.25 km. This program, therefore, provides pointing information that is consistent with NASA to approximately $4 \times 10^{-5}$ degrees.

As a final comparison for HTETL, azimuth and elevation angles were generated for the Apollo 12 ALSEP beacon by LULA and HTETL for two days. During this period, a complete range of values in look angles was obtained. The average spatial difference computed for all of these values was 0.0029 degrees. The values produced by HTETL were again observed to lead the angles in time determined by LULA.

Currently, the HTETL program is used at AFETR only for planning lunar tracking missions. The LULA program is the data reduction routine used to generate angles for telemetry antenna calibration efforts at AFETR.

III - SYSTEM DESCRIPTIONS

A. Large Aperture Antenna System

Typical of the large aperture antenna systems (LAAS), with which we are concerned in precision alignment is the TAA-8, Figure 3-1. Others are the TAA-BA and the TAA-2. The TAA-8 will be described briefly here. It is comprised of the following subsystems:

- Reflector
- Feed, Cassegrainian, Pseudo Conical Scan, S-Band Horns
- RF Preamplifiers and Down Converters
- Pedestal, elevation over azimuth
- Servo drive and control
- Synchro readouts
- Encoder readouts
- Mode controls

The reflector, a parabola, together with the feed system, (designed to evenly illuminate the entire reflector surface), the RF preamplifiers and down converters are supported by a pedestal. The pedestal serves to support and provide means to move the reflector, feed and RF systems in both elevation and azimuth. Drive motors in the pedestal are energized by the servo system in response to error signals created in a manner dependent upon the mode of operation.

Azimuth and/or elevation errors during autotracking are created by video signals which are demodulated from the received RF signal. The video amplitude and phase are determined by position of the antenna with respect to the signal source. In the manual mode the error signals are generated by the control transformers in response to the positioning of synchro torque transmitters by the hand wheels.

In the slew mode the errors are taken from potentiometers positioned by the slave control "joy stick". In the slave mode the error signal is generated by the control transformers (CT) which are mechanically connected to the azimuth and elevation axes of the pedestal, in response to the inputs from the slave source synchro torque transmitters.

The servo system causes the drive motors to be energized in the direction to move the pedestal to reduce and null out the error signal. This is true for all modes of operation.

Angular indicator devices (Figure 3-2) in the antenna system are of two types, synchro indicators and digital (binary) displays from optical encoders which are mechanically connected to

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each axis of the pedestal.

Digital encoders of 15 bits are employed. A 15 bit encoder results in possible resolution of ±1 bit in 32768 bits of which is 0.011 degrees. A 13 bit encoder only results in possible resolution of ±1 bit in 8192 bits or –360^2 = 0.044 degrees.

Synchro indicators rely upon synchro torque transmitters connected to the pedestal axes and torque receivers used to drive the indicating devices. A 1X synchro results in 1 degree movement in the indicator for each 1 degree movement in the antenna. The accuracy of such an indicator is dependent upon the loading the indicator places on the torque receiver. If not loaded, normal synchro accuracy may be as good as ±0.1 degree. To gain more indicator accuracy and resolution, a fine, or 36X, synchro is used. The synchro torque transmitter in this case in geared down by a 36:1 ratio from axis movement, resulting in a torque receiver driven indicator to move one degree for each 1/36 degree of antenna axis movement or 360 degrees of indicator movement for each 10 degrees of antenna movement. With no loading considered, theoretical accuracy for standard 26 synchos could be ±0.1/36 or ±0.0028 degrees. Loading of torque transmitter by more than one torque receiver or of the torque receiver by the indicator could result in errors in the indicators of ±0.5/36 or ±0.0140 degrees for the 36X indicator. Loading effect may be reduced and accuracy improved in the 1X and the 36X indicators by employing Torqsyns in all indicators and ±3 minute synchro torque transmitters installed in the data modules.

The 36X transmitters are also used to drive synchro torque receivers (or Torqsyns) which drive precision, linear, 360 degree potentiometers. A regulated 10 volts DC across the pots permits a 0 to +10 volts signal to be generated for 0 to 10 degrees, 10 to 20, and each 10 degrees to 350 to 360(0) degrees. This output is used to drive pens on a pen recorder for analog recording of angles. The angle record charts are annotated by the operator for each 10 degrees traversed by the antenna in both azimuth and elevation to maintain continuity of the data. Time code is recorded with the event pens on the same recorder, as angles are recorded.

B. ALSEP Description

The Apollo Lunar Surface Experiments Package (ALSEP) was placed in operation on the moon by Apollo 12 astronauts. Its purpose is to return lunar scientific data to the earth for as long as one year after the departure of the astronauts. The ALSEP System Functional Block Diagram is shown by Figure 3-3.

The Early Apollo Scientific Experiments Package (EASEP) placed in operation on the moon by Apollo 11 astronauts was a stripped down version of ALSEP. It operated for a brief period at 2276.5 MHz. Thermal control and antenna pointing designs were traded off to insure easy deployment.

The ALSEP is powered by a SNAP-27 Radioisotope Thermoelectric Generator (RTG). ALSEP 1 (2278.5 MHz) has been operating since November 1969 and exhibits no significant deterioration in performance. ALSEP 2 (2279.5 MHz) left by Apollo 14 astronauts has been operating since early February 1971 and exhibits similar characteristics to ALSEP 1. The power output of the transmitter is 1 watt (+30 dBm). The gain of the 33 degree beamwidth, right hand circularly polarized, helical antenna aimed at the earth is 11.5 dB. The loss in the RF line to the antenna from the transmitter is 1.1 dB.

The experiment scientific data and engineering (housekeeping) data, in digital (PCM Bi-Phase) form are included in a prescribed telemetry format and used to phase modulate (1.25 radians) the RF carrier. Details of the telemetry format follows:

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<th>Mode</th>
<th>Bit Rate (kbps)</th>
<th>Words/Frame</th>
<th>Format Bits/Word</th>
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<tr>
<td>Contingency</td>
<td>0.530</td>
<td>64</td>
<td>10</td>
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<tr>
<td>Normal</td>
<td>1.060</td>
<td>64</td>
<td>10</td>
</tr>
<tr>
<td>High</td>
<td>10.600</td>
<td>32</td>
<td>20</td>
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</tbody>
</table>

Sync Pattern is 22 bit Barker Code 11100010010 plus complement.

Simultaneous reception of commands and transmission of data are possible. Redundant transmitters and data processor components are available in the package and selectable upon command from an earth station. The ALSEP's transmitter operates continuously.

IV - RESULTS

Results of using the ALSEP for tests of the angular alignment are readily obtained by having the operators acquire and autotrack the ALSEP.

The 36X analog azimuth and elevation angles versus time are recorded. At 6 minute intervals the 1X and 36X control panel azimuth and elevation indicator dials and the binary readouts from the digital indicator bits, are read and logged. For simplicity and speedy readout the binary readings are made in octals (3 bit groups) from the most significant to the least significant grouping. For a 15 bit or 13 bit encoder the readout is made in 5 octals. Table 4-1 shows value of octals in terms of angle fractions. All angles are recorded or logged versus time.

The LULA program is used to generate a printout of look angles versus time for a specified antenna. The computer printout of angles at 6 minute intervals (even 6 minutes) allows the operator to locate and acquire the ALSEP signal and also serves as a reference against which the readouts can be compared.

Figures 4-1 through 4-10 show plots versus time of data accumulated and the results of the
<table>
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<th>Octal Reading</th>
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<th>Bits</th>
<th>Angle Fraction in Degrees</th>
<th>Asterisk Example</th>
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<td>3</td>
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</tbody>
</table>
For use with 13-bit encoders, only bit 3 is active in octal 5 so octal reading 4 is either lit or not lit. This represents the least significant bit and resolution of the encoder system. An example of reading by this method follows: Bit lights marked by an * are on; Octal Readings would then be 56342. This is logged. Later, with the aid of this table, the value indicated for each digit is added to the others and the angle is 333.2329064°.

**Example**: 56342

<table>
<thead>
<tr>
<th>Binary Bits</th>
<th>Octal</th>
<th>Octal Bits</th>
<th>Angle Fraction in Degrees</th>
<th>Asterisk Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>15, 14, 13</td>
<td>1</td>
<td>4, 2, 1</td>
<td>0.0878756</td>
<td>Fourth Octal Reading is 4, value is 0.3515625°</td>
</tr>
<tr>
<td>12, 11, 10</td>
<td>2</td>
<td>4, 2, 1</td>
<td>0.1757512</td>
<td></td>
</tr>
<tr>
<td>9, 8, 7</td>
<td>3</td>
<td>4, 2, 1</td>
<td>0.2636268</td>
<td></td>
</tr>
<tr>
<td>6, 5, 4</td>
<td>4</td>
<td>4, 2, 1</td>
<td>0.3515625</td>
<td></td>
</tr>
<tr>
<td>3, 2, 1</td>
<td>5</td>
<td>3, 2, 1</td>
<td>0.4394371</td>
<td></td>
</tr>
<tr>
<td>2, 1</td>
<td>6</td>
<td>3, 2, 1</td>
<td>0.5273137</td>
<td></td>
</tr>
<tr>
<td>1, 0, 0</td>
<td>7</td>
<td>3, 2, 1</td>
<td>0.6151893</td>
<td></td>
</tr>
<tr>
<td>10-66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
While analog angle recordings are made, recordings also may be made of receiver AGC. This is compared with a pre- and post-calibration of AGC for a range of signal levels to determine the signal level of the ALSEP RHCP signal received. This affords a measure of the performance of the receiver system. Figures 4-11 and 4-12 show signal strength versus time for the TAA-8 and the TAA-3 at Grand Turk on 5 and 6 January 1971, while tracking ALSEP 1.

The beauty is that the ALSEP radiates a signal level sufficient to be received by smaller antennas, such as the 30 and 33 feet diameter dish antennas. This allows a check of interslaving alignment and performance of each system compared to the other in real time. Figure 4-13 is the results of such a test at Grand Turk between the TAA-3 and the TAA-8 while both were tracking ALSEP 1 on 5 and 6 January 1971.

The ALSEP transmitter power output (P_T) is specified to be 1.0 watts (+30 dBm) and the antenna, a RHCP helix with 33 degree beamwidth, has a gain (G_a) of 11.5 dB. The RF line between the transmitter and the antenna has a loss (L_L) from the lunar surface to the earth at 2278.5 MHz, a distance of 238,854 miles is 212 dB. The receiving antenna gain (G_R) is (see Table 1-1) 51.8 dB for the TAA-8 and TAA-8A and 49 dB for the TAA-2. The received power (P_R) is then, at the input of the preamplifier:

\[ P_R = P_T + L_L + G_a + L_p + G_A \text{ dBm for the TAA-8} \]
\[ = 30 + (-1.1) + 11.5 + (-212) + 51.8 = -119.8 \text{ dBm} \]
\[ = -119.8 \text{ dBm for the TAA-8 or -8A} \]
\[ = -122.6 \text{ dBm for the TAA-2} \]
\[ = -128.6 \text{ dBm for the TAA-3} \]
\[ = -131.6 \text{ dBm for the TAA-3A} \]

Receiving System Sensitivity

The threshold (T) of a receiving system is based on a theoretical sensitivity of a perfect receiver in dBm: \( T = K + T_e + B \). \( K \) is Boltzmann's constant in dBm (-198.6 dBm). The IF bandwidth (B) of the TAA-8 tracking receivers is selectable to as narrow as 50 kHz (47 dB). The noise temperature (T_e) of the TAA-8 receiving system is 230° K or 23.6 dB, so the threshold (0 dB S/N) for this system should be: \( -198.6 + 23.6 + 47 = -128 \text{ dBm} \). For the TAA-2 Antenna at GBI the system noise temperature is 629° K, but the tracking receiver IF bandwidth of 10 kHz is available. This results in a receiving system threshold of:

\[ -198.6 + 28 + 40 = -130.6 \text{ dBm} \]

The TAA-3 is: \( -198.6 + 24.1 + 40 = -134.5 \text{ dBm} \)

The TAA-3A is: \( -198.6 + 28.1 + 40 = -130.5 \text{ dBm} \)

From these calculations it is apparent that antennas with receiving system noise temperature as high as 645° K, but which have IF bandwidths as small as 10 kHz, are capable of receiving and readily tracking ALSEP if the antenna gain is as high as 41 dB. This indicates that antennas with 30 feet diameter dishes and fair efficiency can track ALSEP if they have narrow band IF strips available for their tracking receivers. Our experience indicates that the TAA-3A can track ALSEP 1 at 2278.5 MHz, indicating that:

(1) its gain is greater than the stated 40 dB;
(2) its receiving system noise temperature is less than 645° K (28.1 dB)
(3) the system will track successfully even with under 0 dB (S + N)/N in the full 10 kHz IF bandwidth. This may well be the case since the tracking bandwidth is in the order of a few cycles;
(4) the ALSEP is radiating greater power than that used in the calculations above (+40.4 dBm effective radiated power, ERP). This seems to be the case in view of the calibrated signal level indicated in Figures 4-11 and 4-12.

Inter-range-vector (IRV) messages may be generated at the Cape and routed to the downrange antennas via the Range Acquisition Low Density Data System (LDDS) to test their alignment and ability to acquire from the information thus supplied. This constitutes an overall acquisition system test, checking all components in the system.

V - CONCLUSIONS

A. Based on our experience in using ALSEP, it has proven to be a most practical, useful and accurate tool for use in Antenna Mechanical and RF Systems Measurements and Alignment. It also serves as a training aid for antenna systems operators in acquiring the signal, recognizing a side lobe and gaining a "feel" of the system. It also serves to test acquisition aids, be they other antenna systems, optical devices or those provided by the Range Acquisition System, in their capability to reliably and accurately direct the antenna into a position to acquire and autotrack the ALSEP signal. The level of the received signal serves both to allow identification of a side lobe (on the TAA-8 and TAA-8A at least) and to appraise the performance of the RF receiving system.

B. Summary:

1. Improvements of antenna tracking performance have been achieved as a result of
the use of ALSEP as follows:

<table>
<thead>
<tr>
<th></th>
<th>Azimuth</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TAA-2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From:</td>
<td>+0.175° Ave.</td>
<td>-0.41° Ave.</td>
</tr>
<tr>
<td>Improved to:</td>
<td>-0.01° Ave.</td>
<td>-0.02° Ave.</td>
</tr>
<tr>
<td><strong>TAA-8A</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From:</td>
<td>-0.67° Ave.</td>
<td>0.00° Ave.</td>
</tr>
<tr>
<td>Improved to:</td>
<td>-0.02° Ave.</td>
<td>0.00° Ave.</td>
</tr>
<tr>
<td><strong>TAA-8</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Verified Only)</td>
<td>(No change)</td>
<td></td>
</tr>
</tbody>
</table>

Encoders:
- +0.02° Ave.
- +0.02° Ave.

Dials:
- +0.04° Ave.
- +0.04° Ave.

Recorder:
- +0.025° Ave.
- 0.00° Ave.

2. Signal Strength Measurements have yielded:

<table>
<thead>
<tr>
<th></th>
<th>Data Receiver</th>
<th>Tracking Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TAA-8</strong></td>
<td>-115.5 dBm Ave.</td>
<td>-117.5 dBm Ave.</td>
</tr>
<tr>
<td><strong>TAA-3</strong></td>
<td>-123.2 dBm Ave.</td>
<td>None</td>
</tr>
</tbody>
</table>

3. Advantages of ALSEP for use as an alignment tool include:
   a. Stability
   b. Signal Strength
   c. Accuracy
   d. Practicality
   e. Availability
   f. Many angles, Horizon to Horizon
   g. Two frequencies now, 3 and 4 later
   h. Valuable training aid
   i. Valuable for overall Range Acquisition System tests

4. Disadvantages include:
   a. Few frequencies, limited band segment
   b. RHCP only
   c. Slow moving
   d. Fixed signal level

C. A future consideration is that the precision of computed antenna angles together with the accuracy of a well aligned sufficiently sensitive S-band telemetry tracking antenna system should make possible at least a redundant system of navigation on a surface ship for about 12 hours each day. This has not been verified by actual tests. The development of the necessary software for the on-board digital computer, with which the antenna system is integrated, will be required for a concrete demonstration to be completed.

REFERENCES


(2) "Solar Boresighting of S-Band Antennas", William A. Sandberg, Sensing and Information System Subdivision, Electronics Division, Aerospace Corp., El Segundo, California.


BORESIGHT OPTICAL AND RF AXES

FIGURE 1-2
TAA-8 TRACKING SYSTEM

FIGURE 3-1
ANTENNA SYSTEM
ANGULAR READOUT
BLOCK DIAGRAM

TX — TORQUE TRANSMITTER
TR — TORQUE RECEIVER
TQ — TOROSYN SYNCHRO REPEATER

FIGURE 3-2
DIFFERENCE FROM COMPUTED ALSEP ANGLE IN DEGREES

LOCAL TIME, 9 NOVEMBER 1970

FIGURE 4-1
LOCAL TIME, 10 NOVEMBER 1970

TAAP-2
AFTER ALIGNMENT
ALSEP 1, 2278.5 MHz

FIGURE 4-2
DIFFERENCE FROM COMPUTED ALSEP ANGLES IN DEGREES

AZIM. 72.04°
ELEV. 1.87°

AZIM. 80.60°
ELEV. 27.91°

ZULU TIME, 5 JANUARY 1971

TAA-8 ALIGNMENT
DIGITAL READOUT
ALSEP 1, 2278.5 MHz

FIGURE 4-3
TAA-8 ALIGNMENT
1X AND 36X
DIALS READOUT
ALSEP 1, 2278.5 MHz

DIFFERENCE FROM COMPUTED ALSEP ANGLES IN DEGREES

AZIM 72.04°

ELEV 1.87°

AZIM 80.60°

ELEV 27.91

ZULU TIME, 5 JANUARY 1971

FIGURE 4-4
DIFFERENCE FROM COMPUTED ALSEP ANGLES IN DEGREES

6 JANUARY 1971

TAA-8
DIAL READOUT
ALSEP 1, 2278.5 MHz

FIGURE 4-5
TAAN-8 ALIGNMENT
ANALOG ANGLE RECORD
ALSEP I, 2278.5 MHz

FIGURE 4-6
DIFFERENCE FROM COMPUTED ALSEP ANGLES IN DEGREES

LOCAL TIME (ANTIGUA)
10 OCTOBER 1970

TAA-8A
BEFORE ALIGNMENT
ALSEP 1, 2278.5 MHz

LOCAL TIME (ANTIGUA)
11 OCTOBER 1970

FIGURE 4-7
LOCAL TIME (ANTIGUA)
11 OCTOBER 1970

TAAS-8A
BEFORE ALIGNMENT
ALSEP 1, 2278.5 MHz
DIFFERENCE FROM COMPUTED ALSEP$^0$ ANGLES IN DEGREES

LOCAL TIME (ANTIGUA)
13 OCTOBER 1970

TAA-8A
AFTER ALIGNMENT
ALSEP I, 2278.5 MHz

FIGURE 4-9
Figure 4-10

DIFFERENCE FROM COMPUTED ALSEP ANGLES IN DEGREES

LOCAL TIME (ANTIGUA)

14 OCTOBER 1970

15 OCTOBER 1970

TAA-8A
AFTER ALIGNMENT
ALSEP I, 2278.5 MHz
TAA-8, TAA-3
SIGNAL LEVEL
ALSEP 1, 2278.5 MHz

FIGURE 4-11
TAA-8, TAA-3
SIGNAL LEVEL
ALSEP I, 2278.5 MHz
TAA-3 VS TAA-8
ALIGNMENT
ALSEP 1- 2278.5 MHz

FIGURE 4-13